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Curricular Materials and Methods for Student Conceptual Understanding in Mechanics of Materials

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Project Introduction

Completion of an engineering degree or passing the Fundamentals of Engineering (FE) exam does not in itself provide evidence that students have conceptual understanding of fundamental concepts in engineering. This is highlighted by past research in physics education and more recent research in engineering education. Research conducted over the past 20 years in physics education has illustrated students' lack of conceptual understanding of physics fundamentals[1] using the frequently cited Force Concept Inventory (FCI). The Foundation Coalition, a group of engineering education researchers, has developed similar instruments in topics such as circuits, dynamics, fluid mechanics, thermodynamics, and heat transfer. The implementation of these instruments has revealed similar very poor results in terms of students' understanding of fundamental engineering concepts[2, 3]. The generally high graduation rates, grades, and passing rates on the FE exam, compared to the generally low success rates on concept inventories, suggest that students are frequently using equations they do not understand. Efforts to reform engineering education to improve conceptual understanding must begin with research to identify students' pre- and misconceptions.

The particular course of interest to this project is Mechanics of Materials (MOM) (alternately called Strength of Materials).

Project Goal and Objectives

The goal of this project is to characterize student knowledge of select concepts in mechanics of materials and will be achieved through the following objectives:

Identify Key Concepts: Identify three key concepts in MOM that will be the focus of the efforts proposed herein.

Characterize Student Conceptual Understanding and Identify Common Misconceptions: Characterize student conceptual understanding and identify specific misconceptions related to selected MOM concepts.

Project Activities

Concepts of focus for this research were chosen based on input from mechanics of material faculty, a review of mechanics of materials concept inventory questions and research on student learning. Normal and shear stress and strain in axially loaded members and beams were chosen for investigation. These concepts are fundamental to the course and constitute a large portion of the curriculum.

More than 80 interviews were conducted for axially loaded members and beams separately with students from Washington State University, the University of Idaho, Gonzaga, and Spokane Falls Community College. The interview protocol and methodology was designed to capture students' understandings of these concepts using many different approaches, question, and figures. This approach allowed us to investigate if they had consistent tendencies across interview questions. Interviews were analyzed resulting in the identification of pre and misconceptions.

About 200 ranking tasks were developed using research results. Ranking tasks are comparative exercises where students are asked to rank a problem based on specified criteria. For example, a student could be required to rank locations in a beam based on the magnitude of normal stress at those locations. A book with conceptual exercises in mechanics, "Ranking Tasks in Mechanics of Materials" was published with Prentice Hall in 2010. A workshop was held in March of 2010 at the Pacific Northwest Regional Conference of ASEE on ranking tasks. The goal of the workshop was to expose participants to ranking tasks and to initiate development and use of these tasks. Also the PI of this project was invited to speak with faculty at Seattle University about project findings and ranking tasks.

A one-day workshop was held in the summer of 2011 with 16 university and community college faculty to share our research findings and develop approaches with experienced practitioners to overcome misconceptions that were determined in this research. When planning this workshop we were not sure how interested the faculty would be in our research findings, but found that they wanted to spend much more time than we had planned talking about the misconceptions we identified, including the data collection and analysis methods used in the research project. The faculty expressed a strong interest in continuing this collaboration through an annual meeting to discuss findings and develop curricular and classroom approaches to improving learning in mechanics of materials.

Project Findings

Two substantial consistent misconceptions regarding axially loaded members were found. The first is that in order for an axially loaded member to shrink in a direction then there must be a stress in that direction. When asked to draw a stress element parallel to the applied load and associated stresses, students drew vertical (perpendicular to the load) compressive normal stresses, even on stress elements oriented at 45 degrees from the applied load (see Figure 1 below). When reasoning about the phenomenon, students almost always indicated that the member would shrink in the vertical direction and, in order to shrink, there must be a stress acting in that direction. In alignment with the above misconception, students also believed that in order for there to be a stress or strain in a direction there must be a load in that direction. For example, when reasoning about the member below students oscillated between the two incorrect arguments that there is no applied load in the vertical direction and therefore there can be no stress and that in order for there to be a stress based on the deformation discussed above, then there must be an applied load. When these students were provided with a rubber band and asked about the vertical applied load they would be internally conflicted between their needing to be a load to cause the reduced vertical dimension and not seeing how there could be an applied load in the member they were using for their explanations.

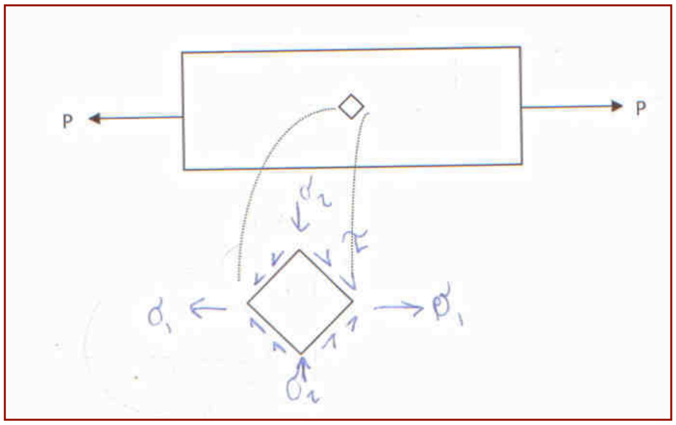

Figure 1- Stress element with normal stresses acting perpendicular to applied load

Students had comparable conceptual difficulties with normal and shear stress in beams. Similar to the findings in the axially loaded members, students commonly believed that normal stresses could only occur if there was a load in that direction, and had difficulty associating bending moments and normal stresses. For example: *Student #1: I don't think there will be normal stresses there because there is nothing there. There is no force coming out this way [indicates axially] on the beam.* Students also had difficulty identifying the correct normal stress and shear stress distributions. Students would either have an incorrect distribution of stress or would treat the force as a stress and distribute it equally over the cut section of the beam.

Another main finding is that students would change their approach and answers to a question depending on the context of the interview question. The context is the material and language used when asking the question and included the photograph of the member that was provided, the physical model, the wording of the question, or the drawing of the problem. For example, some students did not believe that shear stress is present in axially loaded members until they were shown a picture of a failed concrete cylinder, at which point they indicated the cylinder failed due to shear. Although this is not the reason for failure, the picture of the cylinder incited a previously unheard response in many participants. When asked about stresses and strains in beams, student answers depended on whether the picture was 2- or 3-dimensional or a combination of both. There were no distinct patterns in this context dependence.

Many students in both sets of interviews (axial loaded members and beams) incorrectly interchanged force and stress and often divided by seemingly random areas to determine stress. For example one student said: *Shear stress is determined by the shear force and the cross sectional area, and I am assuming the area is constant so its going to be the same (indicating same shear stress in cross section in beam).*

Students would often base their answers on observations of deformed shapes and strains. For example, students were provided a 6-inch wide exercise band in the axial load interviews and asked about the location and size of normal and shear stresses. Although they were instructed to ignore localized stresses due to the applied load by their hand, many students believed that the biggest stresses were near where their fingers and thumbs were stretching the band as they held onto it and stretched it. Similarly, when shown a picture of a deformed beam, students would describe the beam stretching on one side and compressing on the other side and relate this deformed shape to stress distributions.

These findings have implications for teaching MoM. In most textbooks and courses, relationships between external and internal loads and stresses are examined, and then strain and deformation are investigated. For example, the equations (sigma is normal stress) sigma = p/a, sigma = m*c/I, etc…, focus on the relationship between normal stress and internal load. However, our research suggests that students have a strong interest in and are able to observe and understand deformation much more than stress. Observed deformations may be able to be quickly interpreted to strains by students. If this was the case then this course could potentially be improved substantially by focusing on the relationship between external/internal loads and deformations/strains, followed by the relationship between strains and stresses.

Project Outputs and Publications

A ranking task book with more than 200 ranking tasks was published with Prentice Hall [4].

1. Brown, S., D. Lewis, D. Montfort, and R.L. Borden. The Importance of Context in Students' Understanding of Normal and Shear Stress in Beams. American Society for Engineering Education Annual Conference, Vancouver, BC. 2011.
2. Montfort, D. and S. Brown. Building Fundamental Engineering Knowledge: Identification and Classification of Engineering Students' Preconceptions in Mechanics of Materials. Annual Meeting of the American Educational Research Association, New Orleans, LA. 2011.

A publication is in process looking at theories of conceptual change and how results from this project might be interpreted based on these theories.

Project Significance and Future Work

We are interested in which concepts in mechanics are hard, why are they hard, and what can be done to improve learning related to these concepts. This project contributes to what is known about mechanics learning by identifying consistently hard concepts, beginning to formulate why these concepts are hard, and suggesting a new approach to mechanics teaching and learning based on our findings. Knowing that students believe 'big and important' stresses occur near point loads and that stresses normally occur in the direction of applied loads is contrary to expert knowledge in mechanics. Comparing these findings to other research in conceptual change allows for more broadly generalizable results. A revised focus on the relation between loads and deformations/strains may help students navigate mechanics in a way that specifically addresses and repairs these misconceptions. The ranking task book that was published from this work can provide opportunities for students to explore the variation and distribution of stresses in axial, bending, and torsional members.

This project will also contribute to cognitive science. Theories of conceptual change rely primarily on the works of Vosniadou, Chi, and DiSessa. Vosniadou's work focuses on ontological and epistemological commitments that are misconceptions. Our work suggests that student misconceptions may be at this deep and hard to change level of ontological commitments and further the theories of Vosniadou to engineering education. We are currently preparing a paper describing this link. We have secured a grant in the NSF REE program to analyze our results using various conceptual change frameworks, simultaneously with the analysis of research data from other topics and disciplines, including transportation engineering and computer science. We have also secured a TUES Type II grant to collaboratively develop curricular materials with 20 college and university faculty based on our previous and future research on student conceptual understanding in mechanics of materials.

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4. S. Brown and C. Poor, Ranking Tasks for Mechanics of Materials. New Jersey: Prentice Hall. (2010).