120th ASEE Annual Conference & Exposition
FRANKLY, WE DO GIVE A D*MN
June 23-26, 2013

Paper ID #7901

Conceptual Change in Mechanics of Materials

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Abstract

Conceptual change theories rely on data from disciplines outside of engineering, such as physics and astronomy, making the application of these theories to engineering a testable transition. There are diverse approaches to conceptual change theories, largely focused on the structure and size of knowledge. In this work we analyzed a large interview data set from a diverse set of topics in mechanics of materials and considered our data in light of Stella Vosniadou's 'Framework Theory' of conceptual change. Concepts investigated in interview data include shear and normal stress in axial loads and beams. We examine the following misconception from our data: stresses only occur in the direction of an applied load. A theoretical explanation is attempted for this misconception in terms of epistemological and ontological presuppositions from Vosniadou's theory. We suggest that students have extensive experience with objects moving and stretching in the direction they are pushed or pulled and these cultural experiences lead to an ontological/epistemological presupposition that objects behave as students have seen them behave.

Introduction

Conceptual change is a diverse and growing field. In engineering education most efforts in this area are related to the development of concept inventories [1, pg. 62, 2], with some work on testing and developing theory [3, 4]. There are diverse theoretical approaches to conceptual change ranging from cognitive [5, 6] to sociocultural approaches, with some efforts arguing that conceptual change can bridge these gaps [7]. The most recognized cognitive approaches are being developed by diSessa [8], Chi [5], and Vosniadou [9], and an argument is feasible that analysis of each of these approaches would be useful in the context of mechanics of materials. For example, all three have utilized student understanding of physical phenomena in the development of their theories. However, a description of each of these theories and how they might align with our data set is beyond the scope of this paper. The effort described in this paper utilized Vosniadou's 'framework theory' approach to conceptual change to attempt to understand a misconception in mechanics of materials.

Vosniadou's Theory of Conceptual Change

Vosniadou suggests a 'framework theory' of conceptual change, where the 'framework theory' forms a 'coherent explanatory system'[10] that students use to explain and understand phenomenon. Framework theories consist of ontological and epistemological presuppositions, or rules that are applied to what is considered to be 'true' in the world. These rules act as "constraints on the way individuals interpret their observations and the information they receive from the culture to construct specific theories about the physical world." [10, pg. 65] Further, changing these beliefs is the hardest kind of conceptual change, because it requires revision of knowledge, as opposed to addition, and the revision must happen at a deeply held level. [11, pg. 1] Within a 'framework theory' students may have one or more 'specific theories' that relate to a specific phenomena. A 'specific theory' is based on their observations of phenomena in a cultural context and includes their beliefs about what happens in events related to a specific phenomena. Collectively, Vosniadou refers to the 'framework theory' and 'specific theory' as an individual's mental model and that it forms a "complex construction which is supported by a whole system of observations, beliefs and presuppositions constituting a relative coherent and systematic explanatory structure." [9, 10]

An example of the 'specific' and 'framework' theories related to the concept of heat is provided to clarify these ideas. Example observations are "some objects feel hot, others feel warm, etc…" and " bigger objects are hotter/colder than smaller objects." [11, pg. 62]. An example student belief based on these observations is "hotness and coldness are two distinct properties of objects." [11, pg. 62] Finally an example ontological presupposition is "Hotness and coldness are properties of objects" and an example epistemological presupposition is "Something "exists" only if detectable through the senses, etc." [11, pg. 62]

The goal of this research is to examine an existing data set in mechanics of materials using Vosniadou's theory of conceptual change and to answer the following research questions and goals.

Research Questions/Goals

To identify student misconceptions in mechanics of materials related to axially loaded members and beams.

To develop hypothesized students' observations, beliefs, and presuppositions about axially loaded members and beams that may interfere with developing conceptual change.

Methods

A total of 51 students were interviewed. The first set of interviews was conducted in the Fall of 2009 with 23 students. Another set of interviews was conducted in the Spring of 2010 with 28 students. The students were all sophomore level engineering students who were taking mechanics of materials. Students were interviewed after they had covered the concepts in the interviews in class.

The interview protocol focused on stresses and strains in axially loaded members and beams. The protocol was designed to provide students multiple scenarios and contexts to share their understanding of stress and strain, including typical textbook or homework-like representations, ranking tasks, physical models, and pictures of failed members. Students were asked to think aloud as they solved the problem presented.

Ranking tasks have been used in the past with similar research to probe student understanding [12-14]. For ranking tasks, the students were asked to rank magnitudes of a given quantity for a concept given an axially loaded member or a beam. As an example, shown in Figure 1, the student was given an axially loaded member with stress elements placed throughout the member and asked to rank the elements based on a concepts such as normal and shear stress and strain.

Each interview followed a set of the questions that were asked of every student, but each interview was unique depending on the student's responses. This semi-structured approach utilizes probing questions to gain a deeper insight into a student's thoughts and follows clinical demonstration interview techniques [15-17]. The purpose of clinical interviews is to explore student reasoning and reveal cognitive structures around a set of concepts or ideas [15]. A student's reasoning is not only important because it allows the researcher to accurately judge if their answer is right or wrong but because it allows the researcher to see what beliefs or conceptions the student is utilizing. The demonstration portion of the interview refers to a technique used by physics education researchers where a demonstration of a particular phenomena is done for the interviewee and then they are asked to predict what will happen given the initial conditions [18, 19].

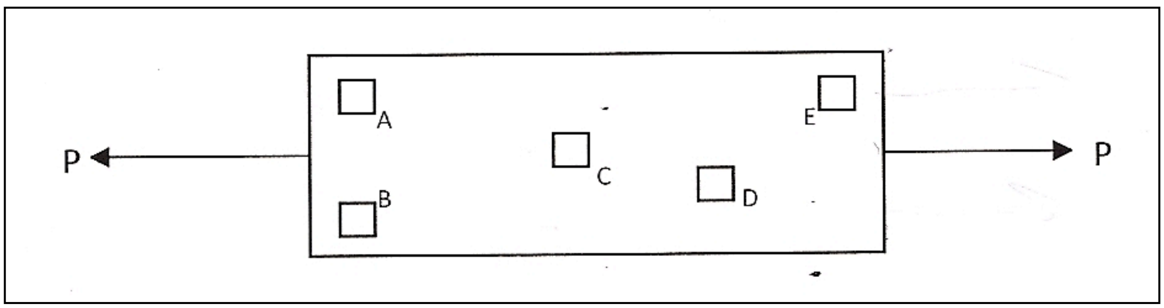

Figure 1: Example ranking task used in interviews

The overall goal of the interview analysis was to code for student's logic both in their talk and their writing during the interviews. This approach can be considered to be thematic analysis [20, 21], with themes being consistent patterns of logic in student reasoning. For example, in Figure 1 above, a large portion of students believed that the largest normal stress was at locations A, B, and E, and within that group of students a common rationale was either that those locations were close to the applied load or that they moved the most under the applied load (assuming the center location is fixed). These two themes were coded as 'big normal stresses near point loads in axially loaded members' and 'large movement of location equals large normal stress in axially loaded members." The propensity of these codes across these interviews and as they related to different interview questions was then loosely counted. Counting in this interview data is difficult because there is inconsistency in the language used and the commitment of students to these ideas. Common themes were evaluated in terms of Vosniadou's theory as observations in cultural context. Themes were combined to develop hypothesized student epistemological and ontological convictions.

Results

Students provided evidence across a multitude of contexts and questions that they believed that stresses act in the direction of the applied load. At this point in the paper this is considered a misconception, in that it is incorrect in the examples shown below and was reasonably pervasive across contexts and interviews. The example shown in Figure 2 below comes from an interview question where students were asked to draw the stresses acting on the stress element at the center of the axially loaded member. Although the case shown below is somewhat extreme in terms of the incorrectness of student responses, others students similarly believed that for an axially loaded member stresses only existed in the direction of the applied load.

Similar evidence results from interview questions where students were asked if shear stress acts in an axially loaded member. About half of the students interviewed replied that it did not, shown by the example below.

> ***Interviewer**: For this top member, are there shear forces acting in that member?*
>
> ***Student**: No.*
>
> ***Interviewer**: Are there shear stresses within this member?*
>
> ***Student**: I don't remember shear (informal talk) I don't believe so.*
>
> ***Interviewer**: Why do you say that?*
>
> ***Student**: Because again, the loads are in the horizontal….*

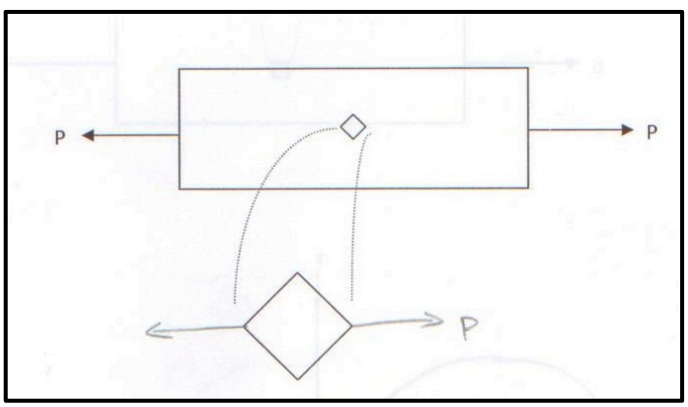

Figure 2. A student's representation of normal stresses on an angled stress element.

Students also believed that in an axially loaded member like that shown in Figure 3 the vertical deformation would have to be caused by a load in that direction. As shown in Figure 2, the orientation of the stress element did not seem to impact student reasoning about the direction of the stresses. The quote below also indicates that stresses and loads occur in the same direction.

> ***Interviewer**: Looking at that stress element which is oriented at an angle, go ahead and draw the stresses acting on it… Okay, describe the stresses that you have drawn.*

> ***Student**: There is normal in the X direction because the forces are going that way and there are going to be stresses in the vertical because it's shrinking in the middle.*

When asked to rank the stresses from top to bottom in a simply supported beam subjected to a point load students responded that the stresses would all be the same, using similar logic that stresses only act if there is a load in the direction of the stresses. For example, one student reasoned the following:

> ***Student**: Given a stress distribution of the bending moment, the top of the beam's going to be in compression and the bottom's going to be in tension. […]*
>
> ***Interviewer**: All right. And then go ahead and rank the points based on their magnitude of normal stress.*
>
> ***Student**: Believe they will all be equal…I'm pretty sure that they're all zero because there's no normal force along the beam.*

Although few students contradicted themselves as immediately as the quoted student, this type of reasoning was very common in the data.

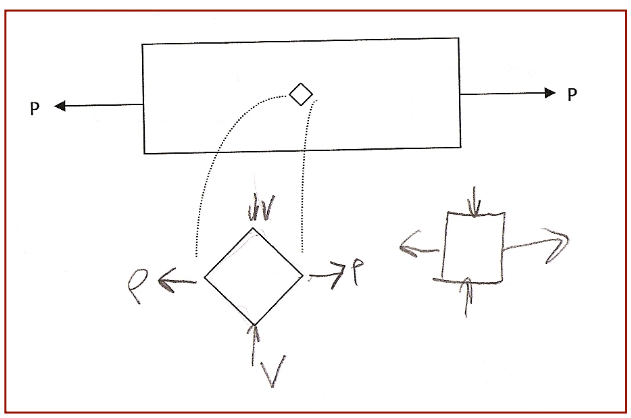

Figure 3. Figure from student interview indicating stresses act in direction of either applied load or a deformation

Discussion

Observations, beliefs and presuppositions are proposed based the finding that students believe stresses act in the direction of applied loads or deflections, as shown in Figure 4.

Observations are somewhat speculative descriptions of how students might typically interact with objects in the world, and are focused on directionality. They make sense in terms of day to day experiences. For example, when you push on a car you expect it to move in the direction you push. Or when you pull on a rubber band it get's larger in the direction that you pull and smaller in the direction perpendicular to the direction you pull; it certainly does not obviously change shape in a direction other than parallel or perpendicular to the applied load. A beam can fit this description in simple terms. If a simply supported beam is pushed down in the middle it will move downward in that direction. The ‘smiley face’ shape that results from this push makes the top shorter and the bottom longer, but this is far less obvious than the downward movement that can either be directly observed or imagined.

From these observations of the world and our data students often believe that stresses only result from applied loads in that direction, and that a change in shape in an object must result from a load in that direction.

Finally, we suggest that students have deeply held ontological and epistemological presuppositions that constrain what they believe is possible for axially loaded members and beams, simply stated as objects exist and objects deform as I have seen them deform. This can be summarized by saying that ‘stresses are a direct and directional causal result of applied forces’. By direct we mean that they would not happen without an applied load and by directional we mean that stresses and loads are in the same direction.

Presuppositions

- Stresses are a direct and directional causal result of applied forces
- Objects exist
- Objects deform as I see them deform

Beliefs

- Stresses happen in the direction of applied forces
- Objects only change shape due to a load in that direction

Observations in Cultural Context

- When you push on something it shrinks and when you pull on it it gets bigger
- When you push on something it gets bigger in the direction perpendicular to the load
- When you push on something it either deforms or moves in the direction it is pushed on

Figure 4: Observations, beliefs and presuppositions in mechanics of materials

Conclusions

Our data could similarly be analyzed in light of Chi’s Conceptual Change Theory of Ontological Shifts [5]. The idea is similar in that Chi suggests that students often analyze problems or concepts using incorrect ontological categories. For example, they may think of heat as a substance and not a process, and therefore have fundamental misconceptions related to heat and transfer. We found, at least for this preliminary analysis, that Vosniadou's theory was more suitable because a framework theory is tied to distinct physical phenomena, like deflecting objects, and not more generalized categories, like substances and processes.

Our findings could be tested by looking at other common concepts in mechanics of materials, like torsion or combined loadings. Torsion could be revealing because the development of shear strain, or a square becoming a parallelogram, as it relates to a twisting load, can be made relatively obvious (famous last words!) by twisting a pool noodle with squares drawn on it. This is different from the cases we examined because in axially loaded members and beams there are deflections (e.g. the axially loaded member gets longer or the beam moves down when you push on it), whereas in a torsional member there are no apparent changes in shape, just movement of points on the member. Combined loadings may also be revealing because they would force the student to confront potentially different day-to-day rules of how things deflect when you push, pull and twist them in a single object. Experience suggests that students have substantial difficulty with combined loadings, but it is unclear why this is true.

Understanding how theories of conceptual change may fit student misconceptions in engineering disciplines is ultimately useful because it could inform teaching practices. For example, if what is proposed in this paper has validity then spending time with students on how objects move and change shape under a variety of loads may help dispel the myth that stresses only act in the direction of applied loads.

Acknowledgements

This material is based upon work supported by the National Science Foundation Course Curriculum and Laboratory Improvement Program under Grant 0837749 and Engineering Education Program under Grant 1129460. Any opinions, findings and conclusions or recommendations expressed in this material are those of the author and do not necessarily reflect the views of the National Science Foundation.

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