AC 2011-778: THE IMPORTANCE OF CONTEXT IN STUDENTS' UNDERSTANDING OF NORMAL AND SHEAR STRESS IN BEAMS

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Introduction

Processes of learning often include the modification of existing conceptions about the phenomenon being studied. For example, when students begin a course in transportation engineering they have likely had life experiences with driving that relate to concepts in the course (such as sight distance and stopping sight distance [1]) and these beliefs may conflict with experts' definitions. The process of modifying existing conceptions is called conceptual change. National attention to the importance of conceptual change in engineering and science fields is evident in a call for identifying pre- and misconceptions by field in *How People Learn* [2] and calls for research on fundamental learning processes in the Engineering Education Directorate at the National Science Foundation. Fundamental to investigating conceptual change and understanding is methodologies to determine and synthesize students' understandings. Although not often recognized in existing studies on conceptual understanding, the context provided to the interviewee has been shown to be influential to student responses. The purpose of this study is to examine the role of the context in students' understanding of normal and shear stresses in beams

Literature Review

Recent research trends in conceptual change research have highlighted the importance of context both in the development of conceptual understanding and in the investigation of it. Learners preconceptions seem to be organized into domains of knowledge [3, 4]. The boundaries of these domains are difficult to define, however, and many researchers argue that the specific context of a problem statement or interview question can affect which domain students' are thinking in [5, 6]. In order for findings about student understandings to be transferable, then, research methodologies need to explicitly account for the contexts created in the data collection processes. Until more is known about how learners use domain-specific reasoning and how they relate perceptions (such as interview questions) to particular domains, however, it will not be possible to characterize such research in terms of which domains were studied. The greatest progress has been made in using comparative methods to study reasoning, understanding and learning in different domains [7, 8]. The purpose of this study is to investigate student reasoning and understanding of normal and shear force in beams and the context dependence of their understandings.

Methods

Student understanding of beams in bending was investigated using interviews. A total of 31 students were selected from sophomore-level Mechanics of Materials courses to participate in interviews. Students were from three universities in the northwest; Washington State University, University of Idaho, and Gonzaga University. The students were interviewed after they had covered stresses and beams in class, including homework assignments and exam questions.

Interview Questions and Protocol

The interviews were guided by the use of an interview protocol containing 11 problems for discussion. Each question was based on ranking tasks[9, 10] in which students were asked to rank the magnitude of the shear force, shear stress, normal stress or bending moment. Students were asked to write or draw in the interview protocol to represent their answers. Examples of student answers consisted of writing down their rankings, drawing the stress distributions on a cut section of a beam, drawing shear and moment diagrams for a given beam, and the discourse associated with these answers. The questions asked students to consider the stresses and forces caused by bending in three distinct contexts: two-dimensional representations of multiple loading scenarios (shown in figure 1), three-dimensional representations of internal forces and loadings (figure 2), and a combined representation of a two-dimensional beam and its internal cross-section (figure 3). An outline of the interview questions is listed in Table 1.

Question: Context	**Description**
1: Beam Loading Scenario	A beam is shown with a point load in the middle and the student is asked to describe where the concepts (normal or shear stress) minimum and maximum locations are.
2: Beam Loading Scenario	A simply supported, uniformly loaded beam has ranking points located vertically across a single cut within the depth of the beam. (See Figure 1)
3: Beam Loading Scenario	A simply supported, uniformly loaded beam has points located across its neutral axis horizontally. (See Figure 1)
4: Beam Loading Scenario	A cantilever beam with a fixed connection has a point load located ¾'s the away from the support. The ranking points are located on the neutral axis spread horizontally along the beam.
5: 3D representation of cut on beam	A three dimensional representation of a beam is provided with a cut taken in the middle and a moment applied about the x-axis. (See Figure 2)
6: 3D representation of cut on beam	A three dimensional representation of a beam is provided with a cut taken in the middle and a moment applied about the y-axis. (Similar to Figure 2)
7: 3D representation of cut on beam	A three dimensional representation of a beam is provided with a cut taken in the middle and a shear force applied parallel to the cut. (Similar to Figure 2)
8: 3D representation of cut on beam	A three dimensional representation of a beam is provided with a cut taken in the middle and a moment applied about the x-axis and a shear force applied parallel to the cut. (Similar to Figure 2)
9: 3D representation of cut on beam	A three dimensional representation of a beam is provided with a cut taken in the middle and a moment applied about the cut, a shear force applied parallel to the cut, and a normal force applied perpendicular to the cut. The ranking points are located on spread vertically about the face of the cut. (Similar to Figure 2)
10: 3D representation of cut on beam	A three dimensional representation of a beam is provided with a cut taken in the middle and a moment applied about the cut, a shear force applied parallel to the cut, and a normal force applied perpendicular to the cut. The ranking points are located on spread vertically about the face of the cut. (Similar to Figure 2)

11: Full context	A simply supported uniformly loaded beam is shown with a cut taken near the middle. An image of what the cross-section of the beam looks like is also shown along with the delegated ranking points. (See Figure 3)

Table 1. Outline of interview questions

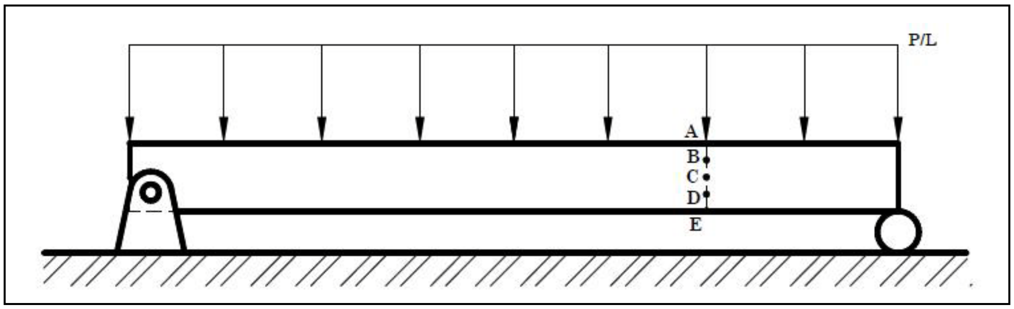

Figure 1. One-dimensional representation of a simply supported beam with uniform load

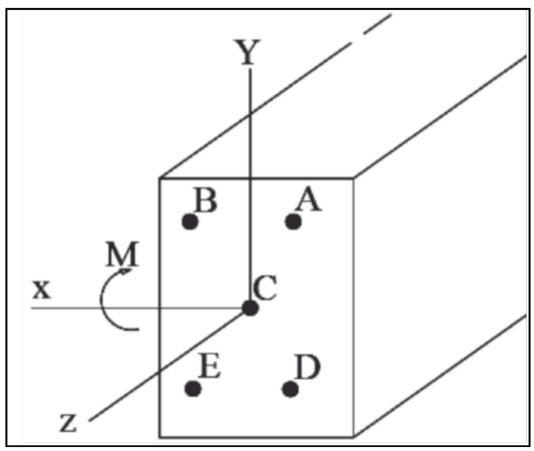

Figure 2. Three dimensional representation of a beam with a cut

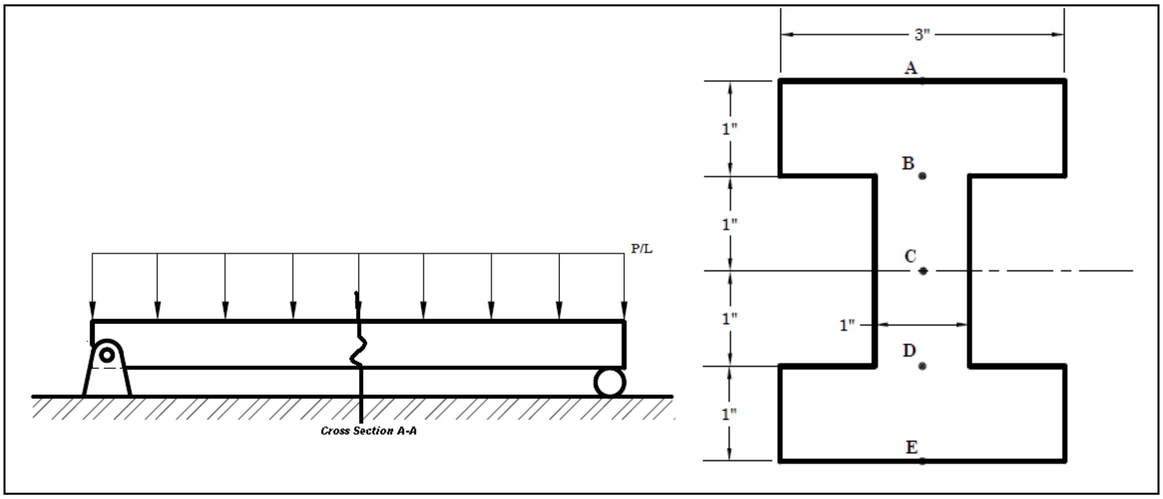

Figure 3. Simply supported uniformly loaded beam with a cut and cross-section representation provided

Interview Methodology
Each interview followed an overall outline of the questions shown in Table 1 that were asked of every student, but each interview was also conducted uniquely depending on the student's responses[11, 12]. This semi-structured approach utilizes probing questions to gain a deeper insight into a student's thoughts and follows clinical demonstration interview techniques [13-15]. The purpose of clinical interviews is to explore student reasoning and reveal cognitive structures around a set of concepts or ideas[13]. 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 [16, 17]. The goal of the clinical demonstration interviews is not to evaluate students on their answers themselves, but to understand their thought process or reasoning behind their answers. 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.

Coding and Analyzing
Data collected included students' written work from interviews and the audio recordings from the interviews. The visual representations from the interview protocol often were not labeled, but instead described verbally as they were drawn. Therefore both the interview protocol and the audio recordings had to be used together in order to accurately code the interviews.

The coding process followed the three steps outlined below:

1) List concepts, correctness of concepts, and reasoning commonly covered in each interview question
2) Create profiles for each student that document their understandings
3) Summarize student understandings of each concept across problems and contexts in the interviews

These three steps can also be viewed as different emphases when approaching the data, or the creation of different analytical matrices[18]. The first step emphasized the general content of each interview. Although the interview design was based on the underlying concepts that were intended to be discussed, this confirmatory step is required because students do not always apply the expected concepts when presented with interview questions. The second step focused on comparing the students' understanding of each concept identified in step 1 to the expert or correct understanding. This resulted in a listing for each student of which concepts they understood correctly and which they did not. The third step shifted the emphasis from evaluation to description, and resulted in a characterization of the details of each student's understanding, beyond whether it was simply right or wrong. This final step also served to add detail to where in the interview each student expressed particular conceptions. For example, while step 2 would show whether a student understood normal stress due to bending, step 3 would result in a comparison of how the student understood normal stress due to bending for each problem presented during the interview.

Results and Discussion

This presentation will focus on two sets of concepts as they developed through the course of individual interviews: the relationship between bending moment and normal stress, and the relationship between shear force and shear stress. These are two of the most fundamental concepts covered in these interviews, and represent a central part of the Mechanics of Materials curriculum.

Bending Moment & Normal Stress

Most students (16 of the 31) consistently expressed alternative conceptions of normal stress due to bending. In textbook representations of bending, a force pushing downward on a long, slim object (like a plank or a business card) causes it to sag or bow into an arced shape. At the beam becomes an arc, the top gets shorter (being the inside of a curve) and the bottom gets longer. This stretching and shrinking are caused by tensile and compressive normal stresses, respectively. It is these stresses, acting along the long dimension of the beam, which students frequently misrepresented. In the first context, for example, students were asked to rank the normal stress developed in various locations in a beam like the one shown in Figure 1. Many students were unable to perform this ranking and gave reasons similar to this example: "I don't think there will be normal stresses there because there is nothing there. There is no force coming out this way on the beam [indicating axially along the longitudinal dimension]." This is an example of how students commonly did not understand the relationship between bending moment and normal stress because they did not see the moment as the cause of normal stress. Students would instead reason that normal stress could not be present if no loads were acting in that direction. Correct understandings typically relied on an equation and symbolic calculations using the dimensions given in the figures to algebraically solve for the stress at each point.

There were, however, a total of seven students whose understandings were different in the different contexts during an interview. As described in the Methods section, each concept was presented in terms of three different contexts in each interview. These changes in understanding in different contexts are shown in Figure 4 below. As shown in the figure, most of these shifted from incorrect to correct understandings. For example, one of the students who believed that no normal stresses were present in the first and second contexts (including all of the two- and three-dimensional representations of beams in bending) shifted his reasoning when presented with Figure 3 in problem 11. When asked to rank various points in terms of normal stress in this context, the student reasoned,

> I want to say that it would be the greatest at A and E where your beam is the most in tension or compression due to the load. Then it would be lesser at B and D and then zero at C except I don't think that's right [pause] because it seems like I'm thinking about it like shear stress with the greatest on the outside. Well I guess they're the opposite of shear stress so maybe that does make sense

This reasoning highlights the fragility of this students' reasoning. First because the student does not refer to how this line of reasoning contradicts their earlier ranking, but second because of the drastic changes represented even within this short quote. The student does not seem to refer to any sources of information beyond their memory and the structure of the problem in front of them.

Two students changed their reasoning each time the context changed. For example, one student was slightly confused about moment and normal stress in the first context, reasoning,

> For the moment it's going to differ along this length [indicating horizontal length] but not along this length [indicating the vertical length or depth of beam]…then for normal stress [drawing a equal distribution about the cut of the beam] Yeah I'll just go with that for now…I don't really know though…that's kind of confusing to me right now.

It's important to note that this student attempted to draw the distribution of normal stresses (although the distribution as drawn was not correct), but did not seem to be able to relate normal stress to its cause, the bending moment. In the second context, when asked to rank the normal stress developed at various points on a three-dimensional representations of beam sections, this student reasoned,

> …I could see it being like this is in compression this in tension there's forces going normal…I don't know why I was drawing something different back here [referring to previous pages]…alright well I'll just go with E equals D which is larger than C which is zero because this is the neutral axis that's larger than the negative values of A and B.

The interviewer asked, "Okay, and what is causing those?" as a follow up, to which the student replied "The moment because its making the beam go like that [indicating bending]." This student did notice that the new reasoning contradicted past responses, but what is particularly interesting is how quickly the student adopts a completely different perspective of the problem. Despite previous confusions the student provided a rapid sequence of rankings, referred to the neutral axis and immediately recognized the relationship between bending moment and normal stress. Finally, when presented with problem 11 and the diagram shown in Figure 3, the student reverted to reasoning similar to their first response, saying "I'm gonna say they are all the same cause I'm gonna say that since every single point is being pushed down the same that there can't be any tension or compression going on. Or maybe there can. I don't know… except yeah I'd say there's no normal force in this actually or normal stress."

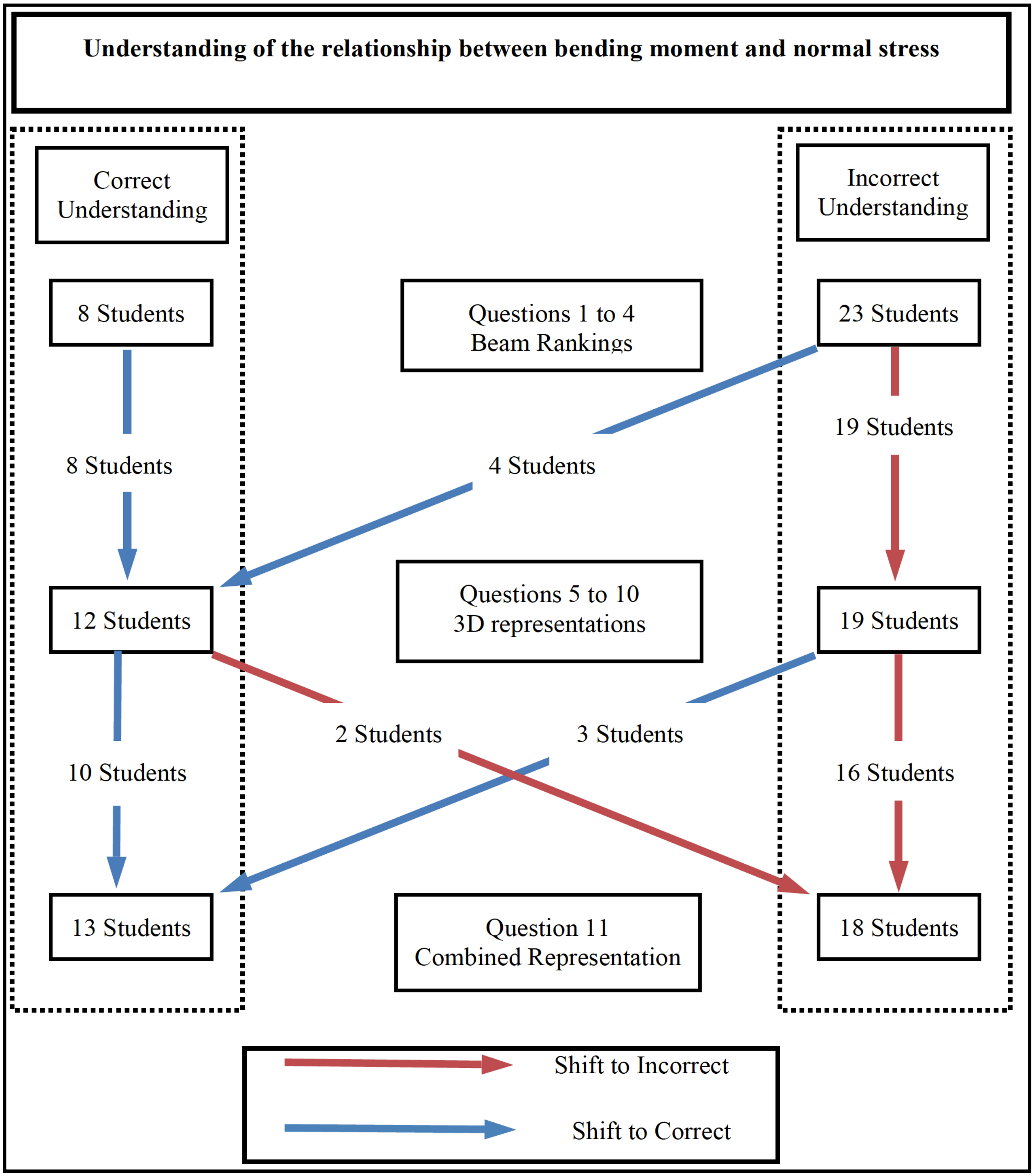

Figure 4. Student understanding of bending moment and normal stress

Shear force and shear stress

Students had similar difficulties determining the correct rankings for shear force and shear stress through the three contexts of the interview. Shear force is the cause of shear stress, but they have different vertical distributions along a beam's cross-section. Shear force is assumed to be constant at any point along the length of the beam, but shear stress is minimum at the top and bottom of a beam, and maximum at the center (more precisely, at the neutral axis). As with bending moment and normal stress, a similar chart can be used to show how students' understanding of the relationship between shear force and shear stress changed throughout the interview. Figure 5, below, summarizes the changes in student reasoning between the three contexts.

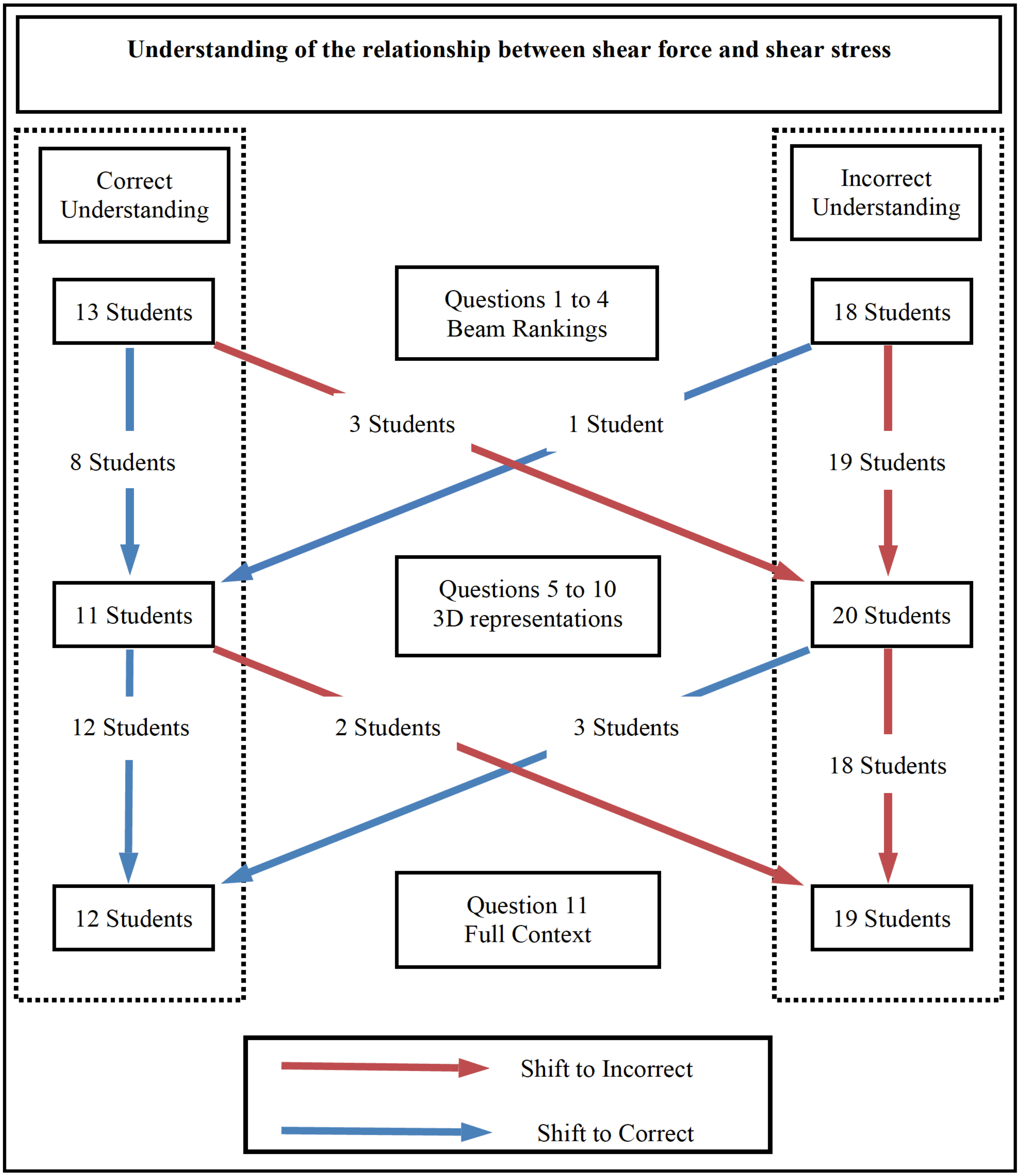

Figure 5. Student understanding of shear force and shear stress

There were six students who changed their reasoning throughout the interview. In the previous example, the three-dimensional representations seemed to help the student explain and understand the relationships between forces and stresses. As shown in Figure 5, however, this trend was reversed in terms of shear force and shear stress. One student, for example, was able to accurately describe the distribution of shear stress on the first five problems, and was even able to apply the shear stress equation to determine the correct rankings. When presented with the three-dimension problems, however, the student dropped this line of reasoning, instead saying, "shear stress is determined by the shear force and the cross sectional area, and I am assuming the area is constant so its gonna be…A equals B, equals C, equals D, equals E." Here the student is using a commonly cited misconception[19, 20] that stress is always equal to a force over an area. When approached with the final context of the interview in question 11 the student defaulted back to their original reasoning, and correctly ranked the points in terms of the magnitude of shear stress. The student revealed some residual confusion, though, when defending the ranking, saying:

> …this depends on the thickness at the points [referring to how the equation related to the ranking task]…but I'm not sure if the force is constant or if it just builds pressure throughout the beam…I think that the forces might all be constant throughout the beam. I don't see why they would need to be greater at certain places.

The student was again able to relate shear force and shear stress through the use of the appropriate equation, but was confused about what actually caused the shear force itself. This final context, like the second context, included a representation of the beam's cross-section, suggesting that this confusion about shear force and shear stress is more important for the student when thinking about the beam's cross-sections.

Some students also exhibited correct reasoning until the third context. One student, for example, was able to correctly explain and rank the shear forces and shear stresses in all the problems until question 11, where he reasoned, "since they are all taken at the same cross section then they should be distributed along that cross section… The shear stress should have the same ranking." Similar to previously quoted students, this student incorrectly assumes a direct relationship between shear force and shear stress.

Conclusions

Although only a few students in this study changed their reasoning based on the context of the problem statement, their reasoning was otherwise quite similar to the majority of students'. For example, the majority of students who generated incorrect rankings did so because of an assumption that stress is equal to force over area. This assumption was central in the cases of those students whose reasoning shifted based on the shifts in context. The visualization of area is also a key part of how the context changed during the interviews: the first context presentation included no presentation of area or cross-section, while the second two contexts represented areas in different ways. The centrality of these difficulties in the cases of students who switched their reasoning may suggest some elements that are important in helping students correctly understand what have been shown to be difficult concepts (like normal stress due to bending[19, 20] or shear stress[21]).

A large portion of students answered questions on normal and shear stress incorrectly. It is possible that if more students had answered correctly context may have become more important. For example, several students commonly believed that stress is force divided by area, and this incorrect approach was not influenced by context. However, as their understandings progressed they may have increasing reliance on the presentation of the problem and less on their incorrect and simplified rule. It should also be noted that the different contexts explored in this research represent only a small sub-set of contexts that could potentially affect students' reasoning. Although these problems involved different representations, they were all still textbook-style diagrams with associated ranking tasks being presented and probed by a collegial, nonjudgmental researcher. Consider, for example, how different student reasoning might be when verbally explaining pertinent real-world phenomena to younger students, or in a high-stakes written exam.

Results from this study may inform mechanics of materials educators. Misconceptions may be a context dependent phenomena. For example, students may be able to correctly answer mechanics problems given combined two and three-dimensional representations better than just two-dimensional representations. Future research, as stated below, is necessary to more fully explore this context dependence. There are also implications for assessment. For example, faculty sometimes place questions and problems on course exams that are in contexts different from those encountered previously, with the goal that students who "really know" the material will be able to solve these problems. These findings indicate that encountering new contexts may result in students initiating new or revised mental models of problems that have not been utilized previously, and certainly that students can show a relatively strong understanding in one context and not the other. These student shifts in understanding based on context also beg the question of what contexts are important for preparation for the engineering workplace. There is not time or resources to cover all contexts, so work must be done to align learning and engineering design contexts.

Future research is needed to determine the importance of these and other contexts and their relation to students' understandings. This work could initially be quite complicated considering the range of possible contexts discussed above, and the potential for differential context dependence across courses and disciplines. This research is vital, however to be able to use interview methods to investigate individuals' understandings of engineering phenomenon.

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