

## **AC 2007-61: ADDING CONTEXT TO A MECHANICS OF MATERIALS COURSE**

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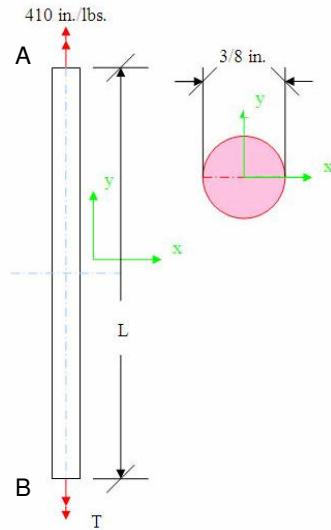
# Adding Context to a Mechanics of Materials Course

## Introduction

One of the greatest challenges in teaching fundamental engineering courses is getting students engaged in the material by making them feel it is relevant and has context in the “real world”. This is clearly important considering that providing context for abstract engineering concepts as well as “learn-by-doing” experiences can increase student comprehension<sup>1</sup>. In addition, a lack of context has been cited as a contributing factor to early attrition rates in engineering students<sup>2</sup>. Unfortunately, addressing real world applications in engineering courses is typically left until upper division, discipline specific classes. Contextual learning is often left out of engineering core course such as Statics and Mechanics of Materials, despite both the significance of the material taught in these courses to upper division classes and the pedagogical advantages to using such an approach in engaging multiple types of student learning styles<sup>3</sup>. Labs and case studies can help in developing context; this paper presents a project that can easily be adapted into any mechanics class, regardless of discipline or lab component, that helps students to personalize the material.

In order to illustrate the difference between contextual problems and those lacking context, consider a potential mechanics of materials problem:

A shaft is subjected to the torque shown. Find the shear stress developed in the shaft and the angle of twist at point A relative to point B.



**Figure 1** A basic torsional shear stress problem in mechanics of materials

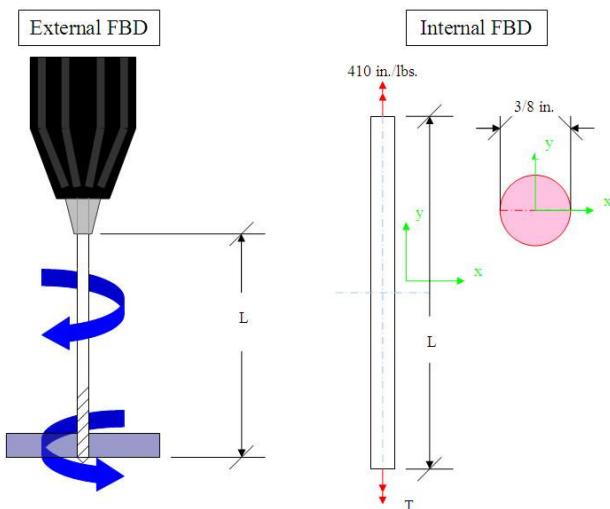
The problem does not tell the students anything about the source of the torque, the likely use of the shaft, or anything else that might allow them to place some context on why it might be valuable to know the shear stress or angle of twist. Even if the shaft were studied in a lab setting, the usefulness of the problem in life might not be evident. However, consider the same problem as developed by students in a Mechanics of Materials course, shown in Figures 2 and 3:



### Assumptions

- The torsion is being evaluated at the instant that the drill punches completely through the steel plate and becomes stuck.
- The torque on drill bit is 410in-lbs (per manufacturer specs).
- The steel plate and the drill remain stationary while the torque is applied.

**Figure 2.** Student developed torsion example problem



**Figure 3.** Student drawn external and internal FBD of drill in figure 2.

The calculations required for the problem are the same; however, the students are able to place the concept of torsion in context by selecting the source of the problem. This is an example of a student developed example for the “Photo Shoot” project developed for EM 321, the introductory Mechanics of Materials course offered at the South Dakota School of Mines and Technology (SDSM&T). The students chose the source of the problem, made assumptions on the behavior of the drill based on observations and some online research, modeled the behavior, solved for the internal stress and angle of twist, and evaluated the design based on their observations and calculations. While textbook problems have improved in how they try to model realistic situations, they still present examples in which all of the variables have been predetermined and for which there is a unique solution. Typical homework problems do not develop student skills in unstructured problem solving, emphasized in ABET 2000<sup>4</sup> criteria. Student developed problems help the students understand how simple models are developed, how to determine potential loads on a system, the rationale and necessity for the assumptions and

simplifications that go into mechanics problems, all components of unstructured problem solving.

### Team Project Description

EM 321 is the required mechanics course taken by civil, mechanical, geological and metallurgical engineers at SDSM&T. Because of the broad base of students, *finding a project that is contextually relevant for all of the engineering disciplines in the course is difficult* to impossible. For example, context relevant to Civil Engineers (“the triangular loading is commonly used in modeling soil pressure on retaining walls”) is unlikely to help students in other disciplines. Therefore, the team based project involves students personalizing the course material by having them identify, photograph, model, idealize and analyze items or structures found locally (on campus or in town) that exhibit the mechanical behaviors described in class. Students are also required to make assessments of the design of their chosen objects or structures based on their analysis.

An example of one student group’s introductory slides for the beam condition are shown in Figure 4. The example is based on the four steps of the project; these steps are described in Figure 5.

**Beam**

- Albert, a Panama Amazon, loves to sit on his Ca-cement perch (and nibble it)
- The perch is fixed and acts as a cantilevered beam.
- Beam stability is important to his safety.

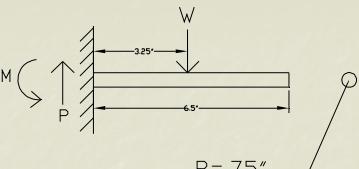


Assumptions were made to facilitate the modeling of the scenario. They are as follows: The bird is standing upright along the centroid of the beam; the weight of the perch has been neglected; and the perch is fixed (unmovable).  
Based on our calculations, the perch will sustain Albert's weight. It was observed that the stress of 9.8 psi was high for a perch made from calcium cement. In actuality, there is a metal bolt that runs the entire length of the perch, further strengthening the perch.

**Beam Example**

Albert is a Panama Amazon parrot that weighs approximately 1 lb. He loves to sit on his favorite calcium cement perch, especially at bedtime. Albert resides at the home of one of the team members on Freud Lane, Box Elder, SD. The behavior of the perch under flexural stress and transverse shear is important to the safety of the bird. Failure of the beam could cause the bird to fall. A fall is not only terrifying to a bird, but could cause injury as well. The perch used for the example is approximately 6.5 inches in length and has a diameter of 1.5 inches. It is fixed to the cage by a long bolt with 2 washers and a wing nut.

**External FBD**



**Internal FBD**

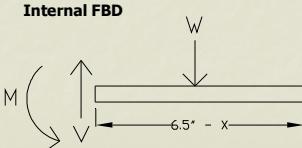


Figure 4 – Example of Beam Case from Student Project with Strong Personal Context

### **Step 1 – Take some pictures**

For each of the following, take at least one photo of a member (object or structure) in Rapid City that

- a. is in tension;
- b. is in compression;
- c. is in direct shear;
- d. behaves as a beam (i.e. has both transverse shear and flexural stress); and
- e. is subjected to a state of combined normal stresses (flexural + axial)

#### **Photo Rules**

- There must be one unique photo for each of the cases listed above. No double dipping of photos (or objects of the photos) is allowed.
- At least one member of your group must physically be in the photo. Digitally editing, or “photo shopping,” someone into the picture is not allowed.
- Loading situations should not be manufactured. Look for structures or objects that exhibit the behavior due to the actual loads acting on the structure or object.

### **STEP 2 – Model the system, structure or object**

#### **For each of your photographs:**

- Draw a simple model of the object of your photograph. STATE ALL ASSUMPTIONS OR SIMPLIFICATIONS used to develop your model.
- Draw TWO free body diagrams
  - One of the **entire** object or structure with all externally applied loads.
  - One through a section of the member demonstrating the required behavior.
- For the entire structure, **estimate** actual values of the loads. (Do some research if necessary).
- For the member, calculate the internal stresses in the member. If you cannot measure the structure, object or member, estimate the sizes to calculate the stress.
- For tension and compression, determine the change in length of the member due to your assumed loads. For beams, draw shear and bending moment diagrams of the member that is bending.

### **STEP 3 – Describe and Evaluate your system, structure or object**

#### **For each of your photographs:**

Write  $\frac{1}{2}$  to 1 page describing the object of the photograph. Include descriptions of where it is located, its function, and the material from which it was constructed or fabricated. Using your analysis results, state whether you think the design is a good one or not, and why (e.g. Was the material a good choice? Is the configuration a good choice? Are the cross-section shapes that are used appropriate? Is it aesthetically pleasant? Is the factor of safety reasonable?) Be specific; the object is to back any assertions you make. Don’t simply state opinion.

### **STEP 4 – Put it together and submit it**

Put the photos, evaluations , FBDs (including assumptions and/or simplifications) and calculations in a power point presentation, complete with cover slide and any necessary transition slides or text slides. Put the presentation on a CD and submit one for your group.

Creativity is encouraged. You are welcome to display a sense of humor. A word of warning: humor can’t replace technical content; it can merely augment it.

You must work in a group. It is your responsibility to locate and coordinate with your group. You will be asked to assess the contribution of each group member upon completion of the project. Your project will be graded, in part, on how cohesive it is. It should look like the work of a group, not a group of individual projects thrown together under a cover slide.

Figure 5 – Instructions provided to students for “Photo Shoot” project

What is interesting about the example in Figure 4 is that the student in the photo is a geological engineering student; students in this particular discipline do not have strong context for beam theory since they are not likely to use it in their field. However, this student was able to relate beam theory to a subject that was very important to her, her pet bird, and thus was able to personalize the topic. Students often choose examples from the campus, their dorm rooms or projects they are working on for extracurricular activities, such as the Formula SAE team car or human powered vehicle teams. When students choose other projects as examples for the photo shoot, they see immediate relevancy of the material in the mechanics course.

### Project Objectives and Assessment

The objectives of the project are given to the students in a project description as follows:

After completing the photo shoot, you should be able to:

- consider all of the loads and stresses that act on items or structures you see every day
- apply course concepts, such as normal and shear stress, to real world applications
- create simple models of real physical systems
- develop or apply mathematical equations based on those models
- understand the assumptions and simplifications built into those models
- evaluate a design based on your analysis
- work with a team to develop a project with a unified “voice”

Two methods of student assessment are used to measure whether the objectives are met as well as student satisfaction with the project. The nature of the team project made it unfeasible to correlate individual student exam performance with effort on the team project, so assessment is focused on student agreement of whether the objectives are met. First, individual surveys are distributed after the projects had been submitted, but prior to grades on the project being posted. Eight questions were developed to determine the students’ attitudes towards success of each of the project objectives. The survey uses the following 5 point Likert scale:

- |   |                            |
|---|----------------------------|
| 5 | Strongly Agree             |
| 4 | Agree                      |
| 3 | Neither Agree nor Disagree |
| 2 | Disagree                   |
| 1 | Strongly Disagree          |

Table 1 presents three semesters of survey results, including mean response values, percent of students that strongly agree or agree (SA/A) and percent of students who strongly disagree or disagree (SD/D). Students are given room to provide comments on the project or suggestions for future semesters.

With limited exceptions, student comments have been positive or have offered constructive criticism. The few negative comments typically suggest that the project is too much work or that it is too difficult to work in groups outside of class. The students’ constructive comments have been implemented in many cases. For example, students suggested that there be a partial submission early in the semester; this has proven to be useful for both the instructor and the students in terms of feedback, and it gives the students opportunities to meet productively with

their groups early in the semester. One common student request that has not been implemented is to allow them to pick their own team members. In part, this is based on research suggesting students' worst team experiences tended to be those in self-selected groups<sup>5</sup>. Teams are selected based on a number of criteria from best practices and class experience including:

- creating heterogeneous groups in terms of academic ability (based on scores from the first exam and homework scores);
- creating groups of similar disciplines to facilitate scheduling of out-of-class meeting times. This was changed from the first semester in which groups were purposely mixed in terms of majors, and conflicting class schedules made it very difficult for students to meet outside of class; and
- creating groups where women and minorities are not isolated, when possible.

Based on the number of comments suggesting that they be able to choose their own groups, students were allowed in Fall '06 to specifically request if they wished to work with an individual or group of students. **One** request was received from the entire class. Students are always given the option to suggest students with whom they would rather not work based on past relationships. No student has ever taken this option.

**Table 1 – Individual Student Survey Results**

|   | F 05<br>n=25 |      |      | S 06<br>n=47 |      |      | F 06<br>n=18 |      |      | Overall<br>n=90 |      |      |
|---|--------------|------|------|--------------|------|------|--------------|------|------|-----------------|------|------|
|   | mean         | SA/A | SD/D | mean         | SA/A | SD/D | mean         | SA/A | SD/D | mean            | SA/A | SD/D |
| The team project helped my understanding of how to calculate stresses and internal forces in members.                                     | <b>3.5</b>   | 64%  | 8%   | <b>3.7</b>   | 68%  | 9%   | <b>3.7</b>   | 72%  | 11%  | <b>3.7</b>      | 68%  | 9%   |
| The team project improved my understanding of class concepts by putting them into context.  | <b>3.9</b>   | 76%  | 8%   | <b>4.0</b>   | 81%  | 4%   | <b>3.7</b>   | 78%  | 6%   | <b>3.9</b>      | 79%  | 6%   |
| The team project helped put the theoretical concepts in this class into a real world perspective.   | <b>4.2</b>   | 80%  | 4%   | <b>4.1</b>   | 83%  | 2%   | <b>3.8</b>   | 67%  | 0%   | <b>4.0</b>      | 79%  | 2%   |
| I now occasionally find myself trying to figure out the behavior of objects or structures I see around me.                                | <b>3.7</b>   | 68%  | 20%  | <b>3.9</b>   | 72%  | 6%   | <b>3.4</b>   | 56%  | 22%  | <b>3.7</b>      | 68%  | 13%  |
| I feel comfortable with my ability to develop simple models of real structures or systems after completing the project.                   | <b>3.9</b>   | 72%  | 0%   | <b>4.0</b>   | 85%  | 0%   | <b>3.8</b>   | 67%  | 6%   | <b>3.9</b>      | 78%  | 1%   |
| I have a better understanding of why assumptions or simplifications are needed in engineering problems after completing the team project. | <b>4.4</b>   | 88%  | 0%   | <b>4.4</b>   | 96%  | 4%   | <b>4.2</b>   | 83%  | 0%   | <b>4.4</b>      | 91%  | 2%   |
| The objectives of the team project were clear.  | <b>4.2</b>   | 84%  | 4%   | <b>4.2</b>   | 85%  | 2%   | <b>4.1</b>   | 83%  | 0%   | <b>4.2</b>      | 84%  | 2%   |
| I would recommend the project be continued for future classes   | <b>4.1</b>   | 72%  | 4%   | <b>4.3</b>   | 81%  | 6%   | <b>4.0</b>   | 61%  | 0%   | <b>4.2</b>      | 74%  | 4%   |

Additional student comments regarding the project have been based on the students' overall experiences. Below are sample comments from student surveys:

- “I thought it was a worthwhile project because it helped to look at problems in real world applications”
- “The team project was good because it made us estimate forces and stresses on everyday objects, not just a picture on a sheet of paper.”
- “Very good idea – the work and time were well worth it”
- “I enjoyed the project – it was a nice break from regular homework”

And finally,

- “It was too much work”

Of particular interest among the survey results are the responses to questions concerning student comfort with the need for assumptions and the development of simple models. Freshman and sophomore fundamentals courses rarely have an opportunity to clearly discuss these important topics in engineering, and the majority of students believed they were comfortable in developing simple models (78% SA/A vs. 1% SD/D) and that they understood the need for assumptions and simplifications (91% vs. 2%). Typically, there will be one class period devoted to “outdoor lab” in which the class and the instructor will use structures on campus to discuss simplification for FBDs and the types of assumptions necessary to create simple models. They will also discuss possible loads and load cases.

Nearly three-quarters of all students in mechanics agreed or strongly agreed that the project was a worthwhile use of time and should be continued in future classes, whereas only 4% (3 students total over 3 semesters) disagreed with this statement. Among the questions asked, one directly addresses whether students are thinking about the course content when not directly involved in an assignment, “I now occasionally find myself trying to figure out the behavior of objects or structures I see around me.” While this question merited the highest percentage of students that disagreed or strongly disagreed (13%), nearly 70% of the students admitted to casually trying to apply course concepts in everyday situations. While there is no means of creating a clear correlation between the project and this behavior, it is considered a positive outcome that the majority of the class was considering course material in a contextual manner while not actively working on class assignments.

The second, less formal, assessment method allows students to discuss their team performance. While different team assessment methods have been tried, the simple survey shown in Figure 6 seems to produce the most useful information in terms of rewarding or penalizing students based on their contributions to the project. Students are encouraged to make comments on the form to support their answer, and students are highly encouraged to discuss any problems with team members directly with the professor. The most common responses are that the team worked well together or that one or two people deserved extra effort. After two semesters of use, the form has produced no ambiguity in assessment team member contributions.

**Team Self-Assessment**

Please mark one of the following

The team worked well together. Everyone deserves the same grade.

The team worked well together, except the following team member(s) really put in an extra effort:

The team mostly worked well together, except the following member(s) didn't pull their weight:

The team did not work well together.

**Figure 6** Team Self-Assessment Survey

#### Learning Styles Engaged by and Skills Developed by the Project

Besides the objectives presented to the students, there are two pedagogical objectives of the project:

- To develop students skills at higher levels of Bloom's taxonomy<sup>6</sup> (e.g. analysis, synthesis and evaluation) than can be reached with a traditional lecture/ homework format; and
- To engage students with learning styles (based on Felder and Silverman's categorizations<sup>7</sup>) that may not be engaged through a traditional lecture / homework format.

When considering Bloom's taxonomy, the traditional lecture, derivation, example, homework approach (in the absence of a laboratory component) rarely elevates student cognition beyond level three of the taxonomy, application. Students learn basic concepts and are able to apply those concepts to typical textbook and exam problems. While there is no design component in team project, it does require students to observe systems, determine and categorize the behavior of the system (analysis), and begin the synthesis process by considering use, potential loading conditions, material choice and aesthetics. This prepares students for future design courses by having them consider mechanics problems in a more holistic manner and by beginning to make connections between the many different factors that affect their design decisions.

In 1988, Felder and Silverman<sup>7</sup> published a widely referenced paper on learning styles of engineering students. One of the primary points is that “traditional” teaching methods do not necessarily correlate with the learning styles of undergraduate engineering students. The

lecture/homework approach, while efficient in allowing for presentation of large amounts of information, is not the most effective in reaching students with varying learning styles. However, in a required class for four different disciplines (that may be the students only exposure to the topic prior to the FE exam), a certain amount of “coverage” of material is expected, and hence the efficiency of the lecture format is necessary to a certain extent.

In order to make the subject matter as relevant to engineering students with in different disciplines and with different learning styles, the mechanics course at SDSM&T includes traditional approaches as described above, in-class cooperative approaches (such as team problem solving), the use of simple physical models, and the project, in which the students can utilize an approach which best suits their personal learning style. Because the project is team based, students can benefit from each other’s strengths as the project progresses. The four categories of learning styles are briefly discussed below for readers unfamiliar with this categorization scheme, and the method in which the project augments the classroom activities in engaging students is discussed. It is worth noting that inductive and deductive learners are not addressed, as Felder had dropped this dimension from the categorization since the paper was originally published<sup>8</sup>.

**Sequential and Global.** Sequential learners do well when taught using a logical progression of ideas; they respond well to step-by-step methodologies. In contrast, global learners often learn in jumps or Gestalt leaps and typically require the big picture to grasp a concept. Most engineering lecture and lab classes are taught in a manner that is amenable to sequential learners, despite the fact that a study by Zywno<sup>9</sup> indicates that anywhere from 30 – 50% of engineering students at different institutions are global learners. The project attempts to engage both types of learners by offering a step-by-step method and examples (provided on the web site) while presenting a comprehensive and problem that brings multiple concepts together. The inclusion of “real world” context into the problem is particularly geared towards helping students that are more global by helping them see the relevance of individual concepts in a “big picture” perspective.

**Sensing and Intuitive.** The majority of engineering students are sensors; they prefer facts, data and systematic approaches, whereas intuitors prefer more theoretical approaches. In the project, the sensors are more likely to respond well to drawing the free body diagrams and performing calculations, and the intuitors are more engaged by the process of developing simple models of complex systems. While assessment of this is difficult using the survey approach, it is evident from conversations with different students who have embraced different aspects of the project from the abstract vs. concrete perspective, and the teaming of different learning types seems to present the best results.

**Visual and Verbal.** Most instruction is verbal, whether it be lecture or assigned reading; however, the majority of engineering students are visual. Visual learners are more likely to remember what they see rather than what they hear. The project is extremely visual in nature as it requires first hand observation of an object or structure, and it provides a visual archive of the process through photography and diagrams. The act of modeling the structures also requires the students to create their own visual representations. While students rarely remember specific homework problems, they have mentioned specific examples from their project well after completing the class.

**Active and Reflective.** Most students learn by actively doing; some learn by introspective reflection. The project is geared towards active learners; however, because the project is done outside of the classroom environment, it also allows reflective learners time to process the information in a way that is meaningful for them. In reality, most out-of-class assignments are amenable to both learning styles.

## Conclusions

The project presented is part of a larger goal to increase student learning in a required, multi-disciplinary Mechanics of Materials course in which there is no lab component. The project is designed to provide greater context for students, allow for development of team skills, engage students of all learning styles, achieve higher levels of cognition based on Bloom's Taxonomy, and, ultimately, be enjoyable for students so that they expend energy on their coursework. Student surveys suggest that the project helps enhance their understanding of basic design concepts, such as modeling and assumptions, and encourages them to apply course concepts in everyday situations. In addition, the majority of students believe the project is a worthwhile addition to the class. It is simple to implement in a mechanics course. One likely improvement for the project is to provide time for students to present their projects to their peers. To date, this has been prohibited by time constraints; however, the course syllabus is being adjusted to accommodate this in future semesters.

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