

INTEGRATING EFFECTIVE GENERAL CLASSROOM TECHNIQUES WITH DOMAIN-SPECIFIC CONCEPTUAL NEEDS

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Introduction

Instructors are increasingly made aware of techniques that can be of benefit to their student's learning. These include: having students play an active role in their own learning¹⁻³, allowing students to benefit from collaboration with one another⁴, integrating assessment into activities so as to give students feedback on their learning⁵⁻⁷, and offering students concrete physical referents or examples corresponding to concepts which they are learning⁸. Yet, what are concrete ways in which these techniques can be employed in the classroom?

In addition, these are general techniques, potentially applicable to many subjects. These techniques need to be infused with content, but the instructor has to decide what content is appropriate for his or her course. In this regard, another general tenet of learning can be helpful: students learn by making connections to that which they already know⁹. This has commonly been taken to mean that an instructor should have an understanding of the knowledge with which a student enters course. Yet another interpretation is that the progression of ideas in a course should be build upon each other. That is, ideas addressed first should help in understanding later ideas.

In this paper we present examples of how these techniques can be used to help students build their conceptual understanding in several engineering subjects, namely Statics, Dynamics, and Mechanics of Materials. These techniques are encapsulated in what we term Learning Modules: these may include objects to manipulate or examine, PowerPoint Presentations and Concept Questions¹⁰⁻¹¹. The instructor controls the PowerPoint Presentations which step students through a variety of ideas or questions related to the objects. The Concept Questions are akin to Mazur's ConcepTests¹²: these are multiple-choice questions that assess student understanding of concepts, and which require little or no analysis. Students vote for the different answers through manual or electronic means.

In our classrooms, voting is done through the raising of colored index cards, which are handed out at the beginning of the semester. Often, for the first vote we will ask students not to confer with colleagues, but to answer relying only on themselves. When many students vote for the wrong answer, we invite them to argue the question with one another and, if available, to manipulate the object in question.

Examples of Classroom Learning Modules

We believe the techniques described above can be effective in a wide range of engineering and science courses. Here, we present examples of these techniques for the classes that we typically teach, namely Statics, Dynamics and Mechanics of Materials. However, the vast majority of our work has been directed towards Statics, and more examples for that subject can be found in the companion paper in this conference¹³.

Statics

We have revised our teaching of Statics thoroughly, both to take advantage of the techniques presented here, and to reflect the particular conceptual challenges of learning Statics. Learning Modules have been developed for most of the major concepts in Statics, including forces, moments, couples, static equivalency, free body diagrams, equilibrium in 2-D and 3-D, and friction. Here we show an excerpt from a Learning Module which addresses the conditions of equilibrium in 3-D, including both forces and couples (torques). Students are asked to consider direction of the couple that needs to be applied via the screwdriver to maintain equilibrium, given that the fingers apply upward forces at the other points (Fig. 1-2).

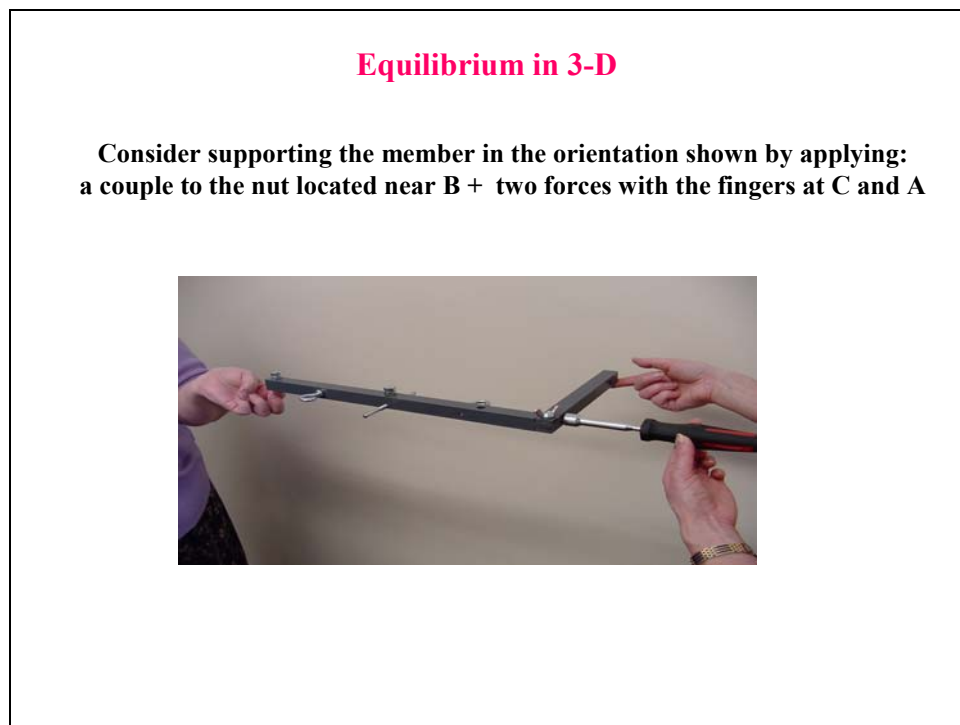


Figure 1

Equilibrium in 3-D

Consider supporting the member in the orientation shown by applying:
a couple to the nut located near B + two forces with the fingers at C and A

The couple applied to the nut to maintain equilibrium is described by:

$$M_x > 0 \quad \text{Gr}$$

$$M_x < 0 \quad \text{Pi}$$

$$M_y > 0 \quad \text{Bl}$$

$$M_y < 0 \quad \text{Ye}$$

$$M_z > 0 \quad \text{Wh}$$

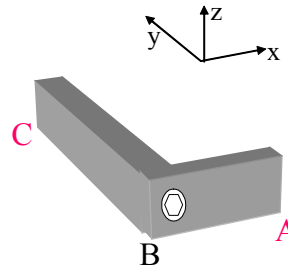


Figure 2

Dynamics

Here we show an excerpt from a Learning Module, used in a dynamics class, which addresses the concept of moment of inertia and its relation to angular acceleration. Students are asked to consider racing two cylinders by rolling them down an incline – one cylinder consists of a steel core and wooden tube, the other consists of a wooden core and steel tube. Since the core and tube have the same volumes, the two cylinders have the same mass, but different moments of inertia and therefore different accelerations and velocities (Fig. 3-7).

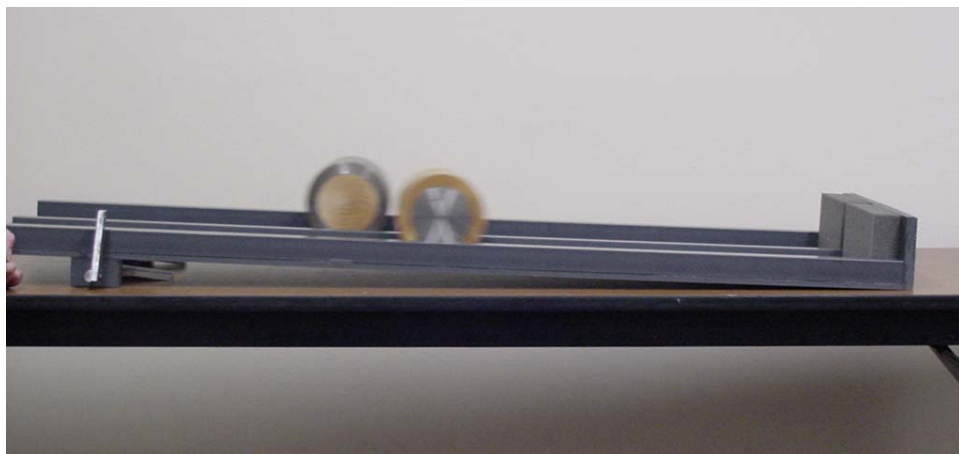
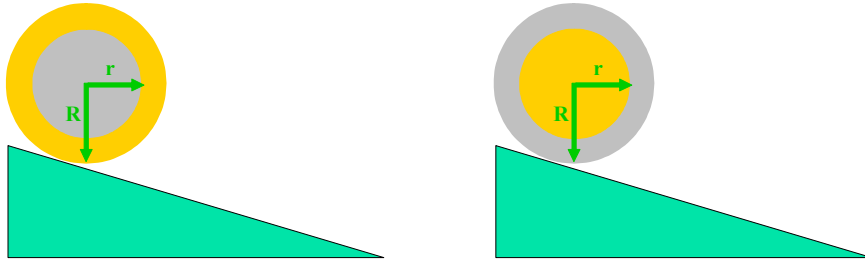


Figure 3

Mass Moment of Inertia

Two cylinders with same length and diameter roll down a ramp (without slipping)



Each consists of a core and a tube of equal volume

“a” has steel core and wood tube

“b” has wood core and steel tube

Which cylinder will reach the bottom first?

“a”

Pi

“b”

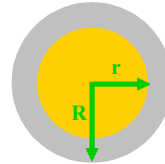
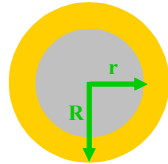
Gr

Figure 4

Mass Moment of Inertia

“a” has steel core and wood tube

“b” has wood core and steel tube



- The cylinders have same length and diameter
- Each consists of equal volumes of steel and wood
- Both have the same weight

Why would they accelerate differently?

They have different mass moments of inertia!

$$I = \int_m r^2 dm$$

Cylinder with larger mass moment of inertia will accelerate less!

Figure 5

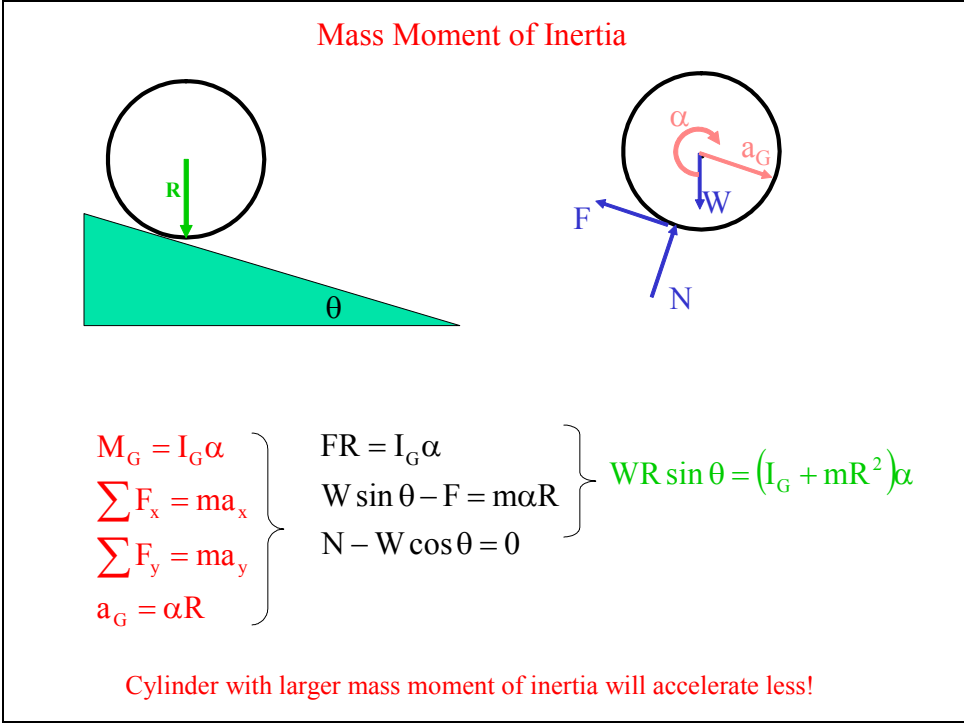


Figure 6

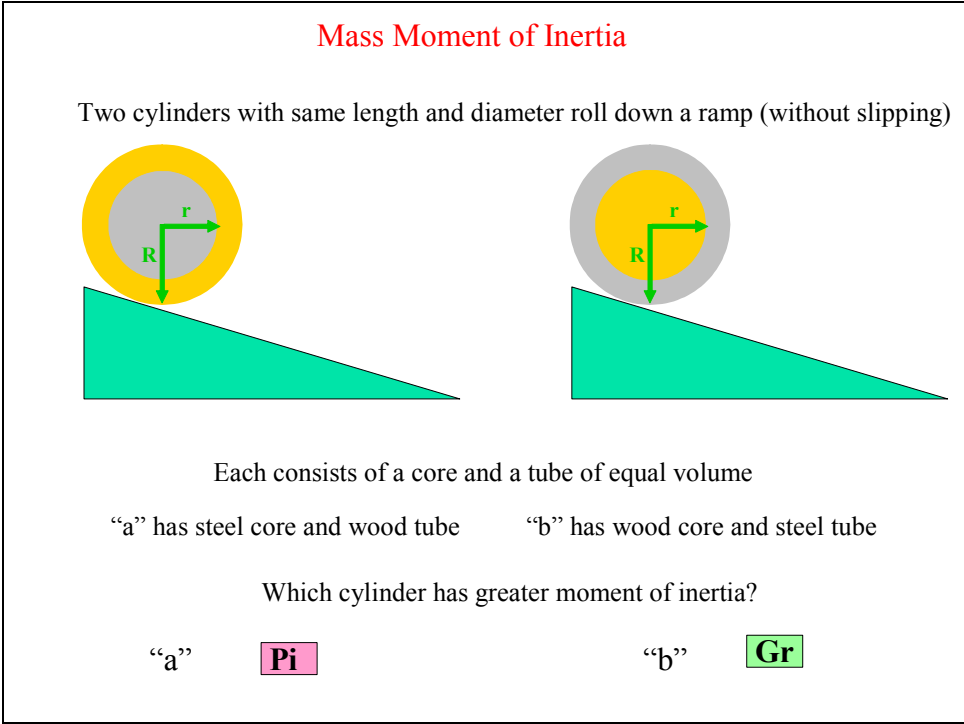


Figure 7

Mechanics of Materials

Here we show an excerpt from a Learning Module, used in a mechanics of materials class, which addresses the concept of stress transformation and principal stresses. A set of squares at different orientations is drawn onto a deformable rubber sheet. The sheet is stretched and students are asked first to consider the changes in length of the sides of differently oriented squares; this involves the concepts of Poisson ratio, Young modulus, and their relationships to elongations (Fig. 8-11). Then students are asked to use stress transformation equations to predict the lengths of the sides of the deformed squares (rhomboids), and to compare their predictions with the actual measurements.

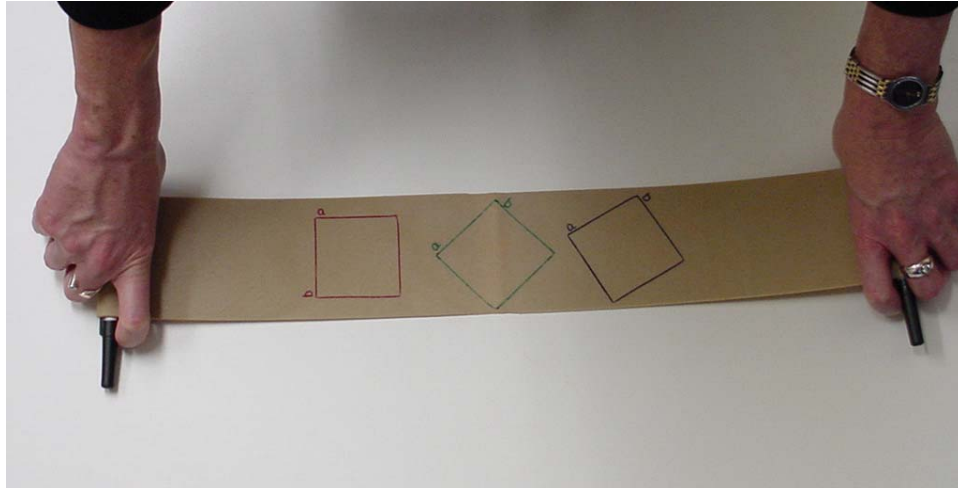


Figure 8

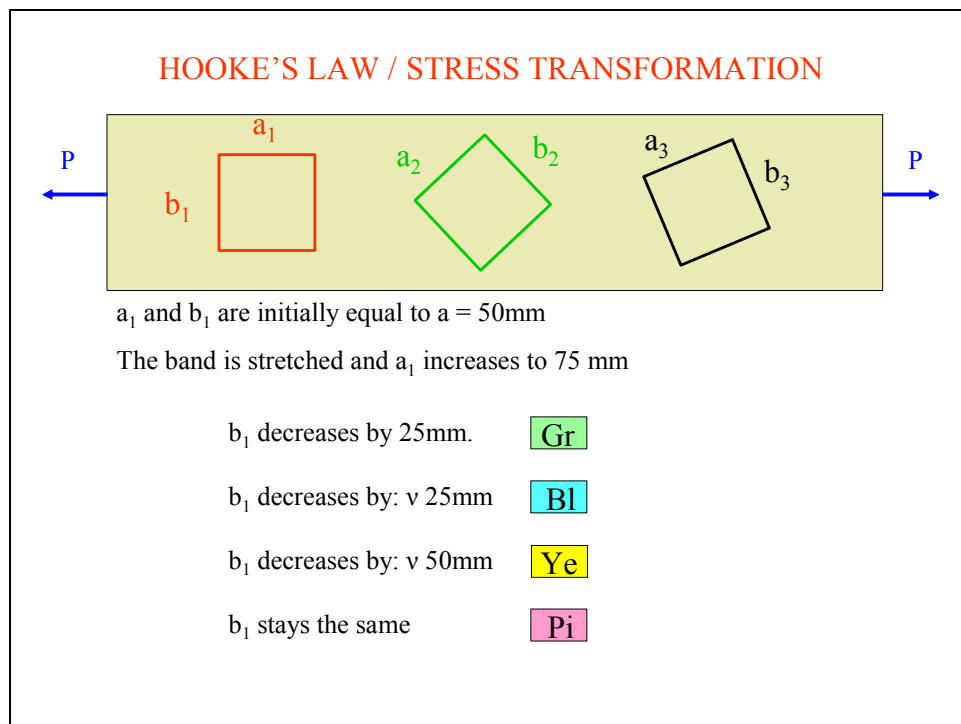


Figure 9

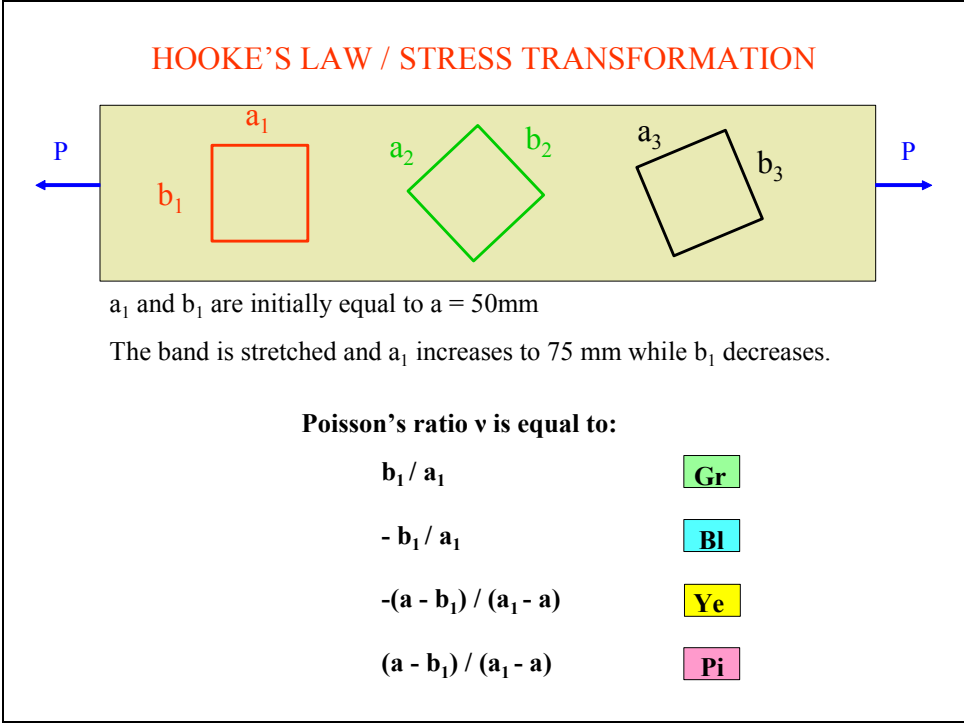


Figure 10

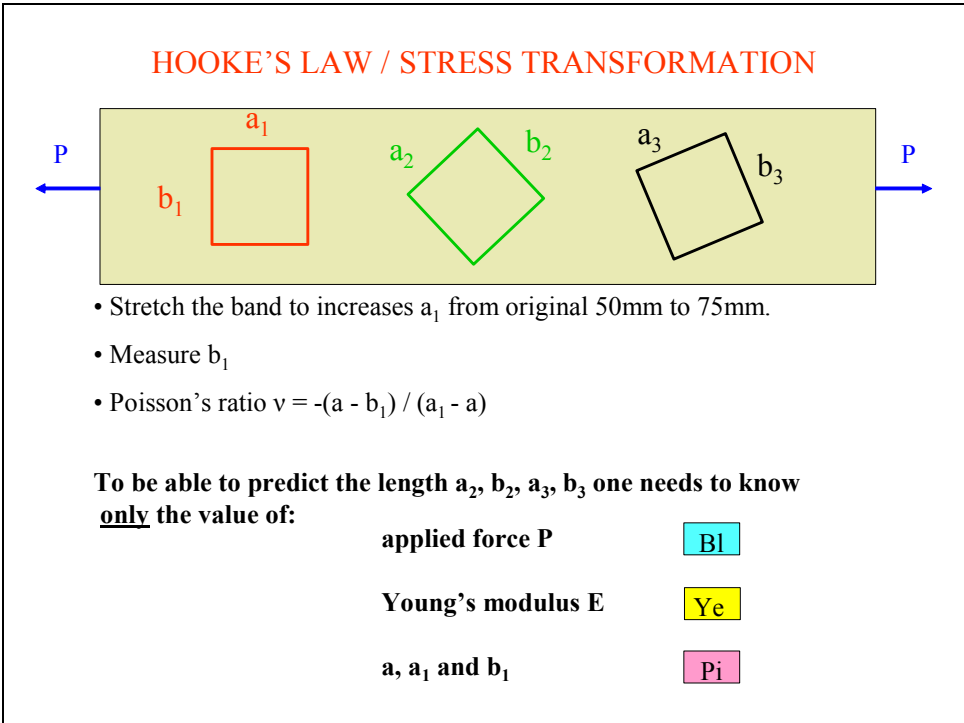


Figure 11

Next students explore the concept of principal stresses, for the case of torsion. We use an easily deformable foam shaft with two squares marked on it; one has sides parallel to the axis of the shaft, the other is oriented at 45° . The deformation of the two squares marked on the shaft is visibly different. Students can observe that the sides of the red square remain at right angles (not shearing), while two of its sides elongate and the remaining two shorten (Fig. 12-13).

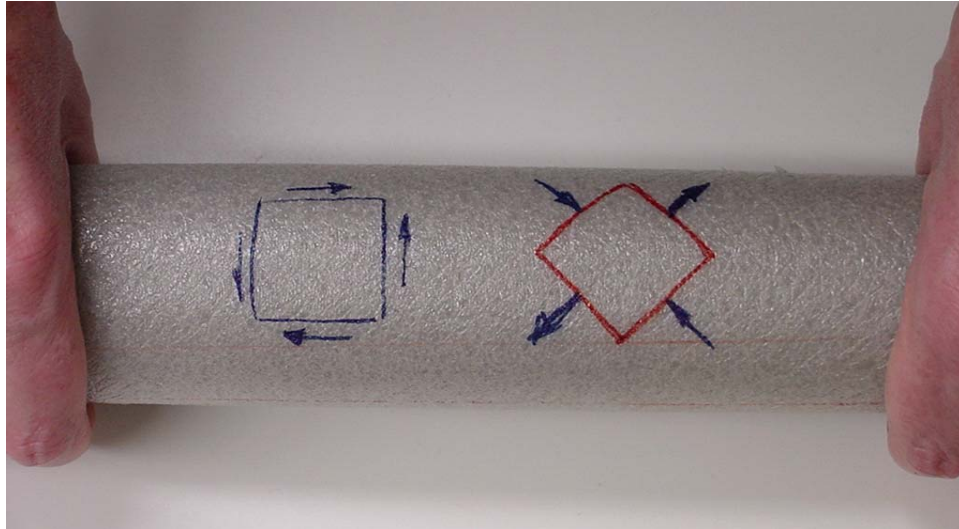


Figure 12

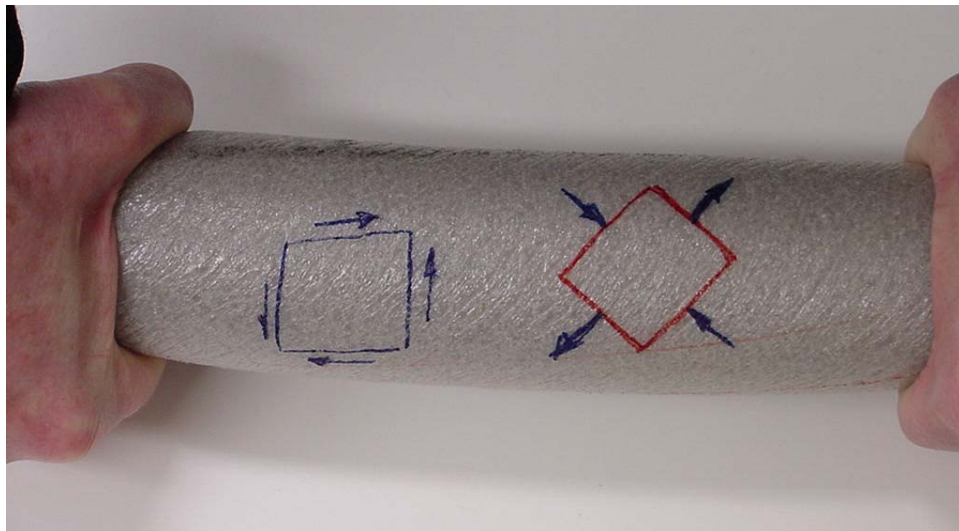


Figure 13

Issues in Classroom Implementation

Making this approach work well in the classroom is in large measure an art; however, it is not difficult to have at least a modestly successful interaction. Here we address issues associated with student voting in response to questions. Students by and large are extremely happy to participate, both because they want to be tested (with nothing at stake) and because it offers a welcome diversion from other activities. In devising questions to be used for Learning Modules,

it is important to achieve the right level. Ideally, one should be asking questions at a level which students are expected to master. How they fair in answering these questions should give students genuine feedback as to grasp of the ideas that the instructor thinks are important. In addition, it is probably most effective to begin with easy questions and have subsequent become progressively more difficult. In this way, most students gain some confidence at least with the early questions, and they feel that the more difficult questions are fair game in that they are a natural progression. Having relatively challenging questions leaves students with a sense that there is serious thinking to be done in the course.

Once a question is posed, the instructor is left with several decisions, including how long to wait until voting and how to proceed once votes are in. As to waiting, instructors want to give a significant majority of students enough time to reason to an answer; typically, we allot roughly 1 minute to a question. One can judge this by watching students, trying to detect whether their attention has shifted to something else. One can also explicitly ask students: how many of you would like some more time to think about this?

Determining how to proceed once the votes are in is the most challenging aspect. One should never lose an opportunity to model a correct way of thinking. So even if most or all students have the right answer, it can be very beneficial to recap very quickly why the right answer is right and/or why other choices are clearly wrong. Even if students voted correctly, their reasoning to that answer may not be sound, and clearly those who voted incorrectly need to have their understanding corrected. This need not be done when all students answer correctly on subsequent questions that rely on a similar line of thinking.

If sufficient numbers of students are wrong, even as low as say 20%, it is may be worth having them discuss the question with peers. Even if students are correct, forcing them to articulate their explanation to their neighbors can be beneficial. One can alternatively choose to open the discussion to the class, particularly if there are significance numbers with the wrong answer. This can include asking students with different answers to explain their logic to the class. The follow-up can have many possibilities, for example allowing other students to comment on the explanations proposed by their peers, or having the instructor chime in when an important point needs to be made.

As a final note, while we have not worked with electronic voting in our own classrooms, we can surely see the benefits if the technology is available. Particularly if voting is assigned to names, students can feel more compelled to participate (in a large class, participation of students can vary). In addition, the instructor probably receives a more honest reflection of what students think, since students don't have the option of looking around at how others are voting. We try to get around this in the non-electronic voting by insisting that students not reveal their votes (raise a card) until after a signal is given. Finally, when a large majority choose an answer (which is correct), it is harder to get student to debate this question vigorously when they know how their peers in the majority voted; the secrecy of the electronic voting would appear to preclude this.

Summary

A wide variety of classroom techniques are being advocated to increase learning: active learning, collaboration, integration of assessment and feedback, and the use of concrete physical manipulatives. These techniques must be transformed into practical tools and be infused with content from the subject area. In this paper we demonstrate applications of these techniques to building student conceptual understanding in several engineering subjects, namely Statics, Dynamics, and Mechanics of Materials. These techniques, which ought to be applicable to a wide range of engineering and scientific domains, feature a thoughtful breakdown of the subject into component concepts, together with objects constituting concrete examples of the concepts in action. Moreover, students contemplate these objects in the light of conceptual questions focusing on salient aspects and debate these questions with peers. A number of issues associated with the implementation of voting on conceptual questions in a large classroom have been highlighted.

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