Collaborative Learning Techniques and their Extensions to Virtual Classrooms

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Abstract - 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. Through the construction of Learning Modules, the authors have transformed these techniques into practical classroom tools. Learning Modules often include relevant physical examples (classroom desktop experiments or demonstrations or schematics), PowerPoint Presentations and, often, Concept Questions. Students study the physical artifacts, with the instructor guiding the class through the PowerPoint Presentations so as to deliberately focus student attention on relevant aspects of these artifacts. There is clearly an increased interest in devising effective learning environments when students are distributed geographically. This paper addresses some of the challenges and opportunities for the extending our in-class collaborative learning techniques. While there are technical challenges to realizing this vision, there are also opportunities to develop environments which are, in some respects, superior to the in-class environment.

Index Terms - Collaborative Learning, Classroom Demonstrations, Concept Questions, Modeling, Statics, Virtual Classroom.

INTRODUCTION

Instructors are increasingly made aware of techniques that can be of benefit to their student’s learning. For example, students who are actively engaged in learning, learn more [1-3]. While it can be more time consuming, ideas that are reached through discovery may be more firmly grasped than those that are acquired through typical lecture or textbook. Students learn through a constant iterative process of assimilating new information and testing out their evolving understanding with feedback from instructors; thus the integration of assessment into the learning process can be of great benefit [4-6]. This process is aided when new information is placed in the context of knowledge which students have previously acquired; that is, when students build on what they already know [7]. Students can learn a great deal from one another; collaboration, if harnessed appropriately, is a powerful tool in learning [8]. Finally, for many subjects in the sciences, physical referents or manipulatives can serve to enhance learning [9].

Recently, the authors have developed and implemented classroom methods which draw simultaneously upon many of these proven approaches to improving learning [10-13]. In this paper we briefly review these methods, giving examples of them, and then discuss the challenges of extending them to distance learning scenarios.

IMPLEMENTATION – LEARNING MODULES

The approach described above has been implemented with so-called Learning Modules. These address readily perceivable physical situations using the modeling or representational approaches of the subject in question, using interactive, thought-provoking classroom methods. Learning modules often include classroom desktop experiments or demonstrations, PowerPoint Presentations and Concept Questions. When the experiment involves an object, there may be a single copy of the object for the instructor to display or one object may be shared among every two or three students. The instructor or students manipulate the objects, for example maintaining them in equilibrium, or creating their motion or deformation, trying to achieve various goals.

The instructor controls the PowerPoint Presentations that explore ideas introduced by the experiments and facilitate the transition from real objects to their models and symbolic representations. For example, the presentation may depict a physical object, how it can be balanced, deformed or otherwise manipulated; diagrammatic representations of the depicted object, such as free body diagrams, are also included. Students may load the object, see an illustration of the object under load, and finally discuss the corresponding free body diagrams. Some PowerPoint Presentations may serve as a platform on which various examples can be rapidly constructed.

Presentations often contain Concept Questions (CQ’s), akin to Mazur’s ConcepTests [14], which are multiple-choice questions that assess student understanding of concepts, while requiring little or no analysis. Students are provided with a set of colored index cards at the beginning of the semester. When a concept question is posed (in a PowerPoint Presentation), the different choice answers are color coded, allowing students to vote for a particular answer by raising a colored card. If sufficient numbers of students vote for the wrong answer, they are prompted to discuss the question with their neighbors; this often elicits rather vigorous discussion. In some cases, students also have the opportunity to reflect on the question by
manipulating the object. Students then vote again and any remaining discrepancies are discussed. Between the manipulation of objects, the verbal exchange and the eventual translation to symbolic representations, these methods can appeal to students with a variety of learning styles and enable more students to succeed.

Excerpted portions from Learning Modules are now shown which are relevant to three engineering subjects: Statics, Dynamics, and Mechanics of Materials.

EXAMPLES OF CLASSROOM LEARNING MODULES

Statics

Much of the development of Learning Modules has been done by the authors in the context of 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 Free Body Diagrams of interconnected bodies. The conceptual challenge here relates to thinking of bodies independently and recognizing the forces that they exert on one another, as well as being able to contemplate collections of bodies. This example also shows a common theme in Learning Modules – reliance on situations that students can experience first hand, through touch and vision. To focus their thinking initially, students are asked to compare the contact forces between the ground and their two feet (Figure 1). In doing this, students are asked to draw a free body diagram representing the combination of themselves and the book they are holding. Then, they are asked to consider the interactions between these two bodies - themselves and book (Figure 2). Ultimately, they are asked to draw correct free body diagrams of their body and the book (Figure 3).

As a second example from Statics, Figures 4 to 6 display excerpts from a module addressing the connections between bodies, an extremely challenging aspect of Statics. Typically, one is interested in the forces and couples that such connected bodies can exert on each other. This Learning Module reflects a conceptually more gradual approach to these ideas, in that students are first prompted to think about the relative motions that are possible between the two bodies. In addition, the use of artifacts or close-up digital images permits consideration of additional subtleties of real systems. For example, a pin joint in figure 4 is designed to carry loads primarily in the x-y plane. Yet, if called upon to do so, this joint can also resist small levels of out-of-plane loads. Such considerations are pertinent to important modeling decisions: whether to treat the joint as exerting only forces in the x-y plane or to admit representations that include out-of-plane loads. Learning Modules can also serve, therefore, to elucidate ideas that facilitate application of the basic engineering subject to design.
Connections

The following relative motion of body A and B are possible:

<table>
<thead>
<tr>
<th>True</th>
<th>False</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotation about x axis</td>
<td>Pi</td>
</tr>
<tr>
<td>Rotation about y axis</td>
<td>Pi</td>
</tr>
<tr>
<td>Rotation about z axis</td>
<td>Pi</td>
</tr>
<tr>
<td>Translation along x axis</td>
<td>Pi</td>
</tr>
<tr>
<td>Translation along y axis</td>
<td>Pi</td>
</tr>
<tr>
<td>Translation along z axis</td>
<td>Pi</td>
</tr>
</tbody>
</table>

FIGURE 4
CONCEPT QUESTION ON MOTIONS AT PIN JOINT.

Connections

The following relative motion of body A and B are possible:

<table>
<thead>
<tr>
<th>True</th>
<th>False</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotation about x axis</td>
<td>Pi</td>
</tr>
<tr>
<td>Rotation about y axis</td>
<td>Pi</td>
</tr>
<tr>
<td>Rotation about z axis</td>
<td>Pi</td>
</tr>
<tr>
<td>Translation along x axis</td>
<td>Pi</td>
</tr>
<tr>
<td>Translation along y axis</td>
<td>Pi</td>
</tr>
<tr>
<td>Translation along z axis</td>
<td>Pi</td>
</tr>
</tbody>
</table>

FIGURE 5
CONCEPT QUESTION ON MOTIONS AT ROLLER IN SLOT.

Connections

The following relative motion of body A and B are possible:

<table>
<thead>
<tr>
<th>True</th>
<th>False</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotation about x axis</td>
<td>Pi</td>
</tr>
<tr>
<td>Rotation about y axis</td>
<td>Pi</td>
</tr>
<tr>
<td>Rotation about z axis</td>
<td>Pi</td>
</tr>
<tr>
<td>Translation along x axis</td>
<td>Pi</td>
</tr>
<tr>
<td>Translation along y axis</td>
<td>Pi</td>
</tr>
<tr>
<td>Translation along z axis</td>
<td>Pi</td>
</tr>
</tbody>
</table>

FIGURE 6
CONCEPT QUESTION ON MOTIONS AT SLIDING JOINT.

Dynamics

This excerpt, from a Learning Module used in a dynamics class, addresses the concept of moment of inertia and its relation to angular acceleration. Students are asked to compare the speeds of two cylinders which are rolled down an incline (Figure 7). 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. However, the mass is distributed differently – in one case the heavier component (steel) is on the outside and in the other case it is on the inside. This produces different moments of inertia, and therefore different accelerations and velocities (Figure 8-10).
Mass Moment of Inertia

Cylinder with larger mass moment of inertia will accelerate less!

FIGURE 9
ANALYSIS RELEVANT TO 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 has greater moment of inertia?

“a” PL “b” GF

FIGURE 10
QUESTION RESTATED TO FOCUS ON MOMENT OF INERTIA.

Mechanics of Materials

Learning Modules are also used in mechanics of materials classes to address a number of concepts. First, we show an excerpt from a Learning Module that addresses the concept of stress transformation and principal stresses. A set of squares at different orientations is drawn onto a deformable rubber sheet (Figure 11). 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 (Figure 12-13). 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.
Next, we show an excerpt from a Learning Module that focuses on the stresses which prevail under conditions of combined loading (Figure 14). Here, the bar is subjected to a load that produces both bending and twisting. Students are asked to contemplate the stresses a various points on the surface of a circular bar. One of the difficulties students face is recognizing that such a loading produces both bending and twisting (Figure 15). A second issue is distinguishing the three-dimensional stresses that are present when each of these distinct types of loads acts (Figure 16).

ISSUES OF CLASSROOM IMPLEMENTATION

Some of the issues associated with classroom implementation have been discussed in [13]. The approach must serve one primary goal of informing students and instructors of students’ conceptual progress. It is important that questions be pitched at the right level; one desires students both to gain some confidence and to be spurred on to work harder and think more deeply. Adequate time must be allowed for most students to think about questions, while maintaining an acceptable pace. Students should also be told not to vote until the full amount of time is allotted. Otherwise some students tend to look around and be influenced by the thinking of their classmates, lending the instructor an incorrect picture of their own thinking.

It is crucial to determine how to proceed after initial voting; such decisions must be made on the fly. Even if many students vote correctly, it is important for correct reasoning to be reinforced. So, unless very few vote for the wrong answer, it is often wise to ask students to talk with one another to debate their votes. After final voting, one can still ask students for explanations; discussion can focus both on why wrong choices are clearly wrong and why the right choice is right.

The response of students to these learning materials and collaborative techniques has been extremely positive. Since these changes have been conducted in the context of significant changes in content as well, determination of the educational benefits is extremely difficult given the complexity and long-term nature of the interventions. However, as emphasized earlier in the paper, the proposed classroom methods are directly based on combinations of techniques that have previously been demonstrated by others to produce learning gains.

EXTENSION TO VIRTUAL CLASSROOM

There is an increased interest in devising effective learning environments when students are distributed geographically. In
this section, we explore the opportunities for the extending our approach of learning modules to the virtual, distance or distributed classroom, and potentially enriching those experiences. One can envision various scenarios, including students learning entirely on their own at their own pace, as well as students learning as part of a class, with activities being synchronous or asynchronous.

There are a variety of efforts to achieve the scenario of students learning on their own. For students who are learning entirely on their own, the increasingly accepted notion that assessment be integrated into learning becomes paramount. Under this scenario, there is no instructor to observe the nodding of students’ heads, nor even to give feedback on student work. The learning environment must provide cues necessary for students to gauge their learning. We are partially en route to fulfilling this need, with a variety of concept questions already available.

Such feedback needs to be thoroughly distributed throughout the learning. One can envision small amounts of reading material, interspersed with examples, concept questions, problems for students to solve and so forth. A part of this must be a sophisticated diagnostic capability in which performance of the student on, say, concept questions is used to point students to material to review or to appropriate remedial material.

As pointed out above, another critical aspect of our reformulated Statics course is the use of tangible objects through which the concepts of mechanics can be experienced first hand. In our classrooms, we provide carefully designed objects, approximately one to every three students, which can be used as part of a variety of learning modules. These objects are often the subjects of concept questions on which students vote. How is this experience offered to students learning on their own? Early versions of our reformulated Statics course were based on students manipulating simple household objects, such as a shovel, a spoon and so forth. One can envision identifying a set of objects which are likely to be found in any home, and which also can be used to illustrate the concepts featured in each module. Since many Statics Learning Modules have been based simply on an L-shaped bar (and often on a straight bar), it would seem quite feasible to identify suitable household items. As can be seen above, the distance learner can likely gain additional insights, at least in Statics, by focusing on situations involving balancing one’s own body in various positions. For conveying ideas in mechanics of materials, a swim pool noodle can be used to great effectiveness. In addition to actual artifacts, a distance course, as well as a traditional course, can benefit from photographs, movies, and simulations of engineering hardware, as shown in some examples above.

Finally, we wish to address how to empower students to share thoughts with peers as they contemplate conceptual questions raised in the classroom. Consider first the synchronous variant in which all students are logged into class simultaneously, but from various locations. While there are technical challenges with realizing this vision, here we focus on some of the pedagogical issues. There is an opportunity here, we believe, to take advantage of the geographically dispersed environment and provide improvements over the traditional in-class environment.

There is one disadvantage in the traditional classroom: students, of necessity, must have their discussions primarily with their immediate neighbors. Yet, the students sitting next to one another may not be in a position to have the most stimulating discussion. For example, students sitting next to one another may have voted the same (whether right or wrong), and thus are unlikely to engage each other in a way that causes serious reflection. By contrast, one can imagine a geographically distributed classroom, in which students vote electronically (unaware, of course, as to how their classmates voted). Then, a central server that organizes the class uses information on how students voted to group them up dynamically to engage in an electronic chat to discuss the particular question. One strategy might be to insure that at least some students in the group have voted differently than the others; such a system might facilitate more productive discussions. Indeed, additional factors can be utilized in grouping students, for example previous success in answering questions correctly.

Since the chat runs through a central server controlling the process, it is possible to capture and later analyze conversations pertaining to various concept questions, and to preserve those which are most stimulating (even if not always correct). A bank of such arguments could be built up over time. Such a capability could be used, for example, to inject stimulating arguments into groups in which discussion has not yet been adequately sparked. Also, consider a student participating in a remote course, who cannot be present during the class period in which classmates confront and discuss questions, or the student who is learning entirely independently. Even such students can have the benefit of at least one-way peer interaction. As they contemplate a particular concept question, they can elect to hear the arguments of students made in the past with respect to the same concept question, arguments that may be correct or incorrect. Moreover, since such arguments were culled from previous student interactions, there is the opportunity for instructors who design the learning environment to devise explanations as to why the wrong arguments are indeed wrong. This can be used to benefit students after they have participated in voting and are, say, later reviewing the same material. As they see the question again, they can hear student arguments for various answers, and they can obtain explanations as to why certain arguments are correct and others incorrect.

**SUMMARY**

In this paper we demonstrate applications of a variety of widely accepted classroom techniques - active learning, collaboration, integration of assessment and feedback into classroom activities, and the use of concrete physical manipulatives - to building student conceptual understanding in several engineering subjects, namely Statics, Dynamics, and Mechanics of Materials. With the development of Learning
Modules which include objects to manipulate or examine, PowerPoint Presentations and Concept Questions, the authors have transformed these techniques into practical classroom tools. The notion of Learning Modules is applicable to a wide range of engineering and scientific subjects.

Recognizing that there is an increased demand for learning environments in which students are distributed geographically, the authors also have addressed some of the challenges and opportunities for extending the concept of Learning Modules effectively to the distance classroom. In particular, the increased necessity of embedding assessment and feedback into course materials has been highlighted. Providing the distance learner experiences with physical artifacts is important; this need may be satisfied with everyday household objects; digital images, movies and simulations can also play roles. Finally, collaboration between students is a key strength of Learning Modules. Means of enabling such collaboration in the distance classroom are discussed, including ways of making the distance classroom in some respects superior to the in-class environment.

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REFERENCES