Classroom Demonstrations with Multiple Modes: Virtual + Reality = Enhanced Learning

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Abstract - Demonstrations can be very effective at engaging students, generating interest in a topic, and enhancing student learning. Demonstrations can occur at three different stages of a course topic: as an introduction, as a wrap-up and an aid used throughout the class discussion of a topic. A key component to an effective demonstration is active student engagement throughout the entire process. This means students are involved in discussing the purpose of the demo; predicting what will happen during the demo; discussing who developed theories to help us understand what happens during the demo; and comparing observations to predictions, as opposed to simply passively watching a demonstration. This paper presents a model for infusing demonstrations into an engineering science class and the use of this model during a semester. Demonstrations in this class incorporate both software simulation and physical models of dynamic systems. While physical models provide a concrete example, computer simulations allow the exploration of “what-if” scenarios and greater meta-cognitive activities. Assessment includes components from both faculty and students.

Index Terms - Active learning, problem based learning

INTRODUCTION

Dynamics provides a tool for civil engineers to evaluate a changing world. In the traditional approach for teaching dynamics to undergraduates, many students think that dynamics is a collection of problem-specific tricks instead of a unified body of knowledge built upon a very limited number of basic equations and principles. Texts for the introductory dynamics courses “customarily downplay the pervasive nature of differential equations as dynamics natural language [1].” Combined with the lack of connection to civil engineering applications, students cannot see the purpose and relevance of this material [1].

The civil engineering department at our university has adopted a course in Dynamics & Vibrations as the standard introductory undergraduate dynamics course. The course emphasizes model development and the use of general kinematic equations and differential equations of motion for problem solving. Students enter this course with an exposure to: mechanics; free-body diagrams, equilibrium and energy conservation principles; calculus and differential equations; and numerical methods. An overall goal for students taking this course is to model, predict and evaluate the dynamic response of civil structures. An overview of the overall problem progression can be described as: (1) Identify the real physical system (e.g. building) and loads (e.g. earthquake); (2) create a simple physical model of the system (mass-spring-dashpot); (3) develop mathematical model that represents the physical behavior and loads; (4) find mathematical solution that represents the dynamic response; (5) utilize the mathematical solution to simulate and evaluate the dynamic motion of simple physical model; (6) evaluate the dynamic motion of real physical system [2].

The material presented in the dynamics course relies heavily the prerequisites and connects concepts in new ways. Without a good understanding of those topics, learning the new material is extremely difficult. A problem arises from students’ expectation regarding the material presented in lower level courses that are frequently considered as weed-out courses. Since students do not immediately see the relevance of the material, they frequently forget that material immediately after the final exam. As such, exposure to the required material does not guarantee knowledge transfer to courses later in their degree program. From the student’s perspective, each course is an individual entity that has minimal connection to others.

Knowledge transfer to dynamic principles is difficult even when students do see a connection to previous courses. The literature on student misconceptions in dynamic principles is quite rich [3]. Misconceptions are very persistent and cannot be easily debunked by standard instruction with lectures, textbooks, demonstrations or laboratories [4]-[5]. A major challenge for students is that any intuition they developed for statics problems can lead to incorrect analysis of dynamics problems.

So the disconnections occur between courses, topics, and the student’s own experience, and the problem-solving progression discussed earlier breaks down. In evaluating the difficulties described above, the following basic pedagogical issues have been identified as underlying the difficulties most students have with this topic:

1. Forgetting, misconceptions and misapplication of prior knowledge leading to difficulties with knowledge transfer between courses

2. Difficulties developing models and connecting the response of those models to real system behavior

3. Critical thinking about complex problems and systems, both in how to break down a problem and identify appropriate simplifying assumptions, as well as how to evaluate their problem solution and system behavior
These issues are by no means unique to dynamics courses [6]. However, the nature of the material is such that these problems become more obvious in this class, and students cannot successfully complete the course without addressing these issues. The fundamental nature of these pedagogical issues is reflected by their close connection to key findings articulated in How People Learn [7]. The research synthesized indicates that if the learner’s preconceptions (including misconceptions) about a particular topic are not brought to the surface, then new concepts will be poorly learned and misconceptions will remain. Addressing student misconceptions does not have to be presented in a negative or remedial context, pre-Newtonian concepts in mechanics have had wide appeal, including Galileo [8]. Used as a part of an active, inquiry based classroom, talking about misconceptions will be as natural as talking about learning styles [9]-[10], or the fundamental principles in the syllabus [11]. The better students understand their own learning, the more successful they are likely to be [12].

Kolb’s Experiential Learning Model defines learning preferences in terms of both (a) how information is acquired (concrete experience or abstract conceptualization) and (b) how information is processed (active experimentation or reflective observation) [13]. Many engineering students fall in the range outside the boundary of traditional lecture [14]:
- **concrete** (how course material relates to the real world)
- **active** (in an environment that allows them to fail safely)

Active learning is an attempt to expand the single one-size fits-all lecture approach to teaching to one which allows more students to operate in their comfort zone at least part of the time. Including demonstrations and active experiments expands the lecture to include the active students and provide ample opportunity for them to learn in an environment that allows them to fail safely. Benjamin [15] describes active learning in this way: “Active learning connotes an array of learning situations in and out of the classroom in which students enjoys hands-on and minds-on experiences. Students learn through active participation in simulations, demonstrations, discussions, debates, games, problem solving, experiments, writing exercises, and interactive lectures.” The demonstrations and active experiments described in this paper constitute an approach that keeps most students in a “minds-on” mode. This approach also provides an alternative to the lecture that, for many students, is more compatible with their strongest mode for taking in new information. Giving students an opportunity to predict outcomes of an experiment not only keeps them actively engaged and interested in the actual outcome, it allows them to “fail safely” in that a wrong answer does not affect their grade in the course.

Educators and researchers have looked at using computers to enhance classroom instruction ever since the technology made it feasible to do so. It is now widely accepted that computer aided instruction can help students gain a better understanding of the subject matter if implemented appropriately[16]. This is particularly true for topics that involve motion of objects, three-dimensional structures or other significant visual components that are not easily represented on a black board. For example, engineering dynamics is the study of motion but this motion cannot be shown effectively using traditional teaching tools, including mechanical models, which are more qualitative but not quantitative [17].

Several researchers have investigated the use of computers, specifically simulation and visualization technology, in education. Foley had shown that computer simulation and visualization can be very effective in enhancing student learning if the interface is based on education research [18]. Foley’s study for middle school students learning thermodynamics also concluded that visualization tools facilitate understanding and retention of key concepts. Simulation programs also allow complex systems to be quickly and easily modeled and can be adapted to many different learning styles[16]

**IMPLEMENTATION OF DEMONSTRATIONS**

Demonstrations can be very effective at engaging students, generating interest in a topic, and enhancing student learning. A key component to an effective demonstration is active student engagement throughout the entire process. This means students are involved in discussing the purpose of the demo; predicting what will happen during the demo; discussing who developed theories to help us understand what happens during the demo; and comparing observations to predictions, as opposed to simply passively watching a demonstration.

- **Pre-activities:** get them to commit
- **During:** keeps them engaged
- **Post-activities:** get them to explain – explicitly address misconceptions.

Observation by a faculty development professional of class sessions during which demonstrations took place gave evidence that the intended result—student engagement—did in fact occur. Because students were asked to predict what would happen prior to the demonstration, they were motivated to pay attention during the demonstration. Students in the back of the room stood up so that they could see more clearly what was happening. The instructor’s questioning process before, during, and after the demonstration kept student attention focused on critical components of the demonstration. Further, students were asked to write predictions and write answers to post-demonstration questions and were given time to discuss observations and answers with peers. This helped to ensure that all students were engaged, not just the handful of students who are quick to participate during class.

**I. Physical Demonstration**

One topic with which students struggle is the modal response of multi-degree of freedom (MDOF) systems:

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Session S1C

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S1C-8
Although many students can accept the mathematical results of an eigenvector solution; most leave without a physical meaning for any of the numbers obtained in the process. The demonstration is done after the mathematical formulation for determining modal properties is presented and the use of these properties to find the forces response of a system is discussed. At this point, students are typically overwhelmed with the matrices and vectors and have no handle on “what the numbers mean.”

The physical component of the demonstration used at this point is shown in Figure 1, where a motor provides a harmonic support motion to the two-dof spring-mass system [19]. As the frequency of the motor is changed, the two mode shapes can be excited and physically demonstrated. This demonstration does an excellent job of helping the students tie-up loose ends, understand the concept of a mode-shape, & also has the advantage of introducing topics such as vibration isolation, tuned-mass dampers, etc (mass can easily be added to one or both masses…).

II. Computer Demonstration

Although very powerful, there are limitations of physical demonstrations. Students cannot easily explore “what if” (we do not have the ability to vary length of spring, spring stiffness, mass, etc. over a large range of values. Furthermore, the connection with their mathematical results is not obvious (an analysis results in an equation; a demonstration shows how the objects move; but what does the graph look like?).

Computer-based materials can allow students to exercise their higher-level thinking skills (Analysis, Synthesis, and Evaluation). The authors have collaborated in the development of a dynamics simulation software package that has the power and flexibility to handle the model systems normally encountered in a course in dynamics in order to address these issues. This software gives the student the ability to build, tune, simulate and evaluate a model all within a single environment. The software developed provides a “construction set” that students can use to build their own simulations of dynamic models and run them to observe their performance. This program is interactive and can be used in the classroom for demonstrations, in the laboratory for guided use, and on student’s own computers for experimentation and to complete assignments. [20]

After the physical portion of the demonstration is completed, the simulation software is started, and the corresponding two-degree of freedom model is created with the class. As the appearance of the simulation model is the same as that of the models used in textbooks and board examples, the framework forms the bridge between the physical system and the analytical models found in classroom settings. Now the dynamic response of the system can be shown under a range of dynamic conditions: varying initial conditions, external forces, or support motion.

As the last variation most closely matches the physical demonstration the students will have just observed, it is the first simulation shown. During this process, active discussions with the students include modeling limitations as well as what variables will be used to measure the response. As the physical demonstration does not come with a set coordinate system, the fact that this is a choice in the modeling process becomes more transparent.

The software provides options for a variety of graphs to be generated in real-time (see Figures 2 and 3). These graphs provide a convenient bridge between dynamic behavior and the equations resulting from dynamic analysis. Students are relatively more experienced relating equations to graphs. The ability to connect what they see to a graph enables them to close the gap between what they see and what the equations show them.

Figure 2 illustrates the screenshot for the simulation of the 2-Dof system starting with the springs in tension (which is indicated by the software through the use of the color blue). Plots for the horizontal motion of each mass were selected, where the motion is measured from the local coordinate system of each mass (in other words – relative to the chosen degree of freedom for that mass). Once the simulation is started, the masses oscillate and the corresponding values plotted in the appropriate window simultaneously. The color of the springs change to indicate tension (blue) or compression (red). Figure 3 shows a screen capture of the simulation after several cycles of response.
As these plots are being generated, a discussion on how the response is developing can occur. As the mathematical formulation for the response of MDOF system has already been presented, the students are asked to explain the shape of the response plots, which are periodic in nature but not a simple/single harmonic function.

The connection to the fact that the overall response is a result of a superposition of harmonics can be even more clearly illustrated by changing the initial conditions to more closely match that of each individual mode, as illustrated in Figures 4 and 5. In this simulation, the system has two equal 1 kg masses and two equal 25 N/m springs. To illustrate a response that is dominated by the first mode, the system starts with both springs stretched by 1m. The resulting response (Figure 4) of this system is clearly dominated by first mode behavior, with displacement plots that are close to a single harmonic function and both spring either in tension or in compression simultaneously.

In contrast, the system in Figure 5 has two equal 1 kg masses and two equal 50 N/m springs. If this system starts with spring 1 stretched 1m & spring 2 compressed 1m, the resulting behavior as seen in Figure 5 is by second mode behavior, with displacement plots that are close to a single harmonic function and the masses moving out of phase.

After the initial system has been explored to better understand its behavior, the instructor can then lead the class into an exploration of the effects of modifying system parameters, such as changing the mass or stiffness of any element. One such scenario would look at the system starting at initial conditions proportional to a first mode deflection. The students are then asked to predict how the response will change if the stiffness constants for both springs are reduced and to explain their reasoning. The result of that change can then be demonstrated immediately, together with a discussion into the expected responses and if they matched the resulting simulation. This process then ties the theoretical material to the decision making process many will undertake as designers.

**ASSESSMENT**

At the end of the Fall 2006 semester, the students were surveyed via the Student Assessment of Learning Gains (SALG) and via student focus groups. The responses from SALG regarding the physical demonstrations alone are presented in Tables I through III.

**TABLE I**

| How much do you agree that the use of physical models helped tie course concepts together? (N = 111) |
|---|---|---|---|---|---|
| Rank | Number Responses | Percentage of Total Responses |
| Strongly Agree | 23 | 20.7 |
| Agree | 64 | 57.7 |
| Neutral | 18 | 16.2 |
| Disagree | 6 | 5.4 |
| Strongly Disagree | 0 | 0 |

**TABLE II**

| How much do you agree that the physical models helped clarify the mathematical model? (N = 111) |
|---|---|---|---|---|---|
| Rank | Number Responses | Percentage of Total Responses |
| Strongly Agree | 22 | 19.8 |
| Agree | 61 | 55.0 |
| Neutral | 24 | 21.6 |
| Disagree | 4 | 3.6 |
| Strongly Disagree | 0 | 0 |
Some typical comments from the vast majority of the class (over 75%) are:

- The demo that showed resonance and the different modes of vibration was especially helpful.
- I think the demonstrations we saw helped a great deal. If we could see more demonstrations for more concepts I would have checked the Strongly Agree box for all three of these questions.
- The demonstrations helped me have a mental picture in my head when figuring out what a system would do.

Not every student sees the benefit as strongly as others. Some typical comments from this portion of the students are shown below:

- They didn't help as much for me.
- They weren't as effective as doing more problems

However, these students represent less than 10% of the class, and even they didn’t strongly disagree with any of the benefits.

Student participants in the focus group were unanimous in their belief that the demonstrations were helpful to their learning. As one student mentioned:

“You think, this is what happening when you solve the problems. It really helped, at least for me, to see in person what was going on with 1 mass or 2 masses on the spring with 2 degrees of freedom. It helped. I didn’t expect something different, but I couldn’t see it in my mind, so it was bugging me. I was always second-guessing myself.”

In focus groups specifically for the simulation software, students struggled with some of the constraints inherent with a software package still in the process of being implemented. However, they appreciated the simplicity of generating different systems and being able to see the system in motion. Some of the comments included:

- I particularly like the realtime graphs
- I like the fact that I can take systems that are covered in class and see how it will behave. The program gives me a tangible. It is nice that the position, velocity & acceleration can be graphed for each mass.
- Graphs help in understanding concepts...Also being able to turn off gravity allowed better understanding of the motion.
- This way you can model a problem and see an actual reaction which makes it a great tool for initial set ups and checking your answer.

**Session S1C**

- In class I had a hard time visualizing what the motion of a system would like just from a picture and an equation, but with this program I can see the motion and make sense of the system being evaluated.

However, the students did not believe that the demonstrations helped them do better on exams. This disconnect in their perception of “learning” and “doing better on exams” may be an indicator that while significant progress has been made in helping students connect the mathematics with the physical system, some compartmentalization remains.

Preliminary data on quiz problems specifically connected with the demonstration topics do indicate an improvement in student learning. Data on the quiz problem related to the MDOF System Modal Response is presented in Table IV. In the Spring 2006, no physical demos were utilized, and this is contrasted with the data from the Fall 2006, when the demonstration was part of the course. The data shows that both the class average as well as the lowest score were improved in the semester with the demonstration.

### Table IV: Quiz Problem on Mode Shapes and Frequencies

<table>
<thead>
<tr>
<th></th>
<th>Spring 2006</th>
<th>Fall 2006</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>79.4</td>
<td>85.2</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>15.0</td>
<td>15.1</td>
</tr>
<tr>
<td>High Score</td>
<td>100.0</td>
<td>100.0</td>
</tr>
<tr>
<td>Low Score</td>
<td>40.0</td>
<td>50</td>
</tr>
</tbody>
</table>

**Conclusions**

The results from introducing demonstrations into the course were overwhelmingly positive. These benefits come in two forms: (1) greater enjoyment of the students and faculty, and (2) a positive impact on the learning. Introducing demonstrations generally require additional class time spent on a particular topic, requiring that fewer topics get “covered” in a semester. However, these additional topics were frequently poorly grasped by the students and not used in subsequent courses. Part of the explanation for students not grasping these more advanced topics can be linked to a weak understanding of the fundamental topics. We now get better learning of fundamentals through the use of demonstrations.

In some instances, the demonstrations actually reduce the amount of time spent on a topic. Originally, discussions on mode shapes and frequencies had to be repeated numerous times. A frequent comment from the students was that they “could do the math, but had no idea what the numbers were.” With the introduction of the demo, the class quickly “sees” what a mode shape and frequency represent physically, making the math physically meaningful.

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