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Embedding Laboratory Experience in Lectures

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ABSTRACT

Demonstrations can be very effective at enhancing student learning and represent a mechanism for embedding laboratory experiences within a classroom setting. A key component to an effective demonstration is active student engagement throughout the entire process, leading to a guided laboratory experience in a lecture setting. 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; and comparing observations to predictions, as opposed to simply passively watching a demonstration. 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. Depending on when they occur, different types of learning outcomes are achieved. This paper presents a model for infusing demonstrations into an engineering science class and the use of this model. Assessment includes components from both faculty and students, as well as from a faculty development professional who is an instructor in a different discipline.

Keywords: physical models, active learning, real-world connections

I. 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 [2]. 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.

The material presented in the dynamics course relies heavily on the prerequisites discussed in the previous paragraph and connects concepts in new ways. The breadth of the prerequisites is very wide and includes material from physics, math, engineering science, and numerical methods. 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. However, in dynamics students are expected to not only remember the material from diverse courses, but be able to apply and integrate it in a new context.

Knowledge transfer of 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 learn best when they [14]:

- have opportunities to acquire information in a context that allows them to see how course material relates to the real world (concrete); and
- process information in an environment that allows them to fail safely (active).

Thus, many are not well-served by a traditional lecture approach. Active learning is an attempt to expand the single one-size-fits-all lecture approach to one which allows more students to operate within their comfort zone at least part of the time. Including demonstrations and active experiments expands the lecture to provide ample opportunity for concrete representations of information in an environment that allows them to fail safely and also perform self-assessments on the state of their own learning and understanding.

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 (p. 185)." 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. The real outcome of such activities lies in metacognition—thinking about thinking. By forcing students to predict, observe and then reflect on how their predictions modeled reality, on why their predictions match (or do not match) reality and/or theory students are able to confront their learning gains. In this way, they also build engineering judgment, and intuition about how and when theories work to describe dynamic behavior [16].

This paper describes the implementation and the results of an active-learning approach applied to a Civil Engineering dynamics course. By engaging students throughout the demonstration, the process provides a mechanism for embedding a laboratory experience within the classroom. As the process is guided by the instructor through questions into their analysis and predictions, difficult concepts and misconceptions can be more directly addressed. Something significant cannot be added without thoughtful consideration of what should be deleted. The depth of learning and skill development that can come from interactive-engagement is well worth the sacrifice by reducing or eliminating selected topics [17]. The results of selected demonstrations occurring at different times during material presentation are discussed, as well as assessments of student and faculty perceptions as well as from a faculty development professional who is an instructor in a different discipline.

II. IMPLEMENTATION OF DEMONSTRATIONS

Active demonstrations incorporate the benefits of active learning with those of a traditional laboratory experience within a traditional classroom setting. To be successful, active demonstrations must be structures such that the following components are present:

- Short segments of student activity and reflection—as students lose focus after approximately 10 minutes, having activities and question segments allows for greater retention of information [18].
- Self-assessment—by evaluating the status of their learning and understanding, this process helps improve metacognition.

Depending on the specific learning goals, demonstrations should occur at different stages of the material presentation. A discussion of these issues in the development of an active demonstration are presented in the following sections.

A. Structure of an Active Demonstration

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; bring misconceptions to the surface. Gamma [19] describes a pre-task reflection stage as needed to help students gain awareness of the resources, strategies, and detail necessary to tackle a new problem. This structure is based on work done by Tobias and Everson [20].
- **During:** keeps them engaged and invested in the learning process. This idea is captured by a Chinese proverb [21]: "Tell me something, and I'll forget. Show me something, and I may remember. Involve me, and I'll understand."
- **Post-activities:** get them to explain—explicitly address misconceptions. The post-task reflection stage [19] is potentially the time of greatest learning (if the student has been engaged during the previous two phases) in that it allows the students to compare the steps needed, and results obtained to those explored during the planning (pre-activity) stage. It is here that they are able to explore answers to the "if my predictions did not match my observations, why not?" questions.

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 laboratory experience. The process also allowed for discussions on how to take measurements, how to ensure reliability in the data, and adapting existing materials and set-up to collect the desired information. Frequently, students who excel in the purely theoretical problem solving problem have never considered the limitations of a real physical system, while some students who struggle with the theoretical components of the course excel at the practical implementation requirements.

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. This process is a key component in developing metacognitive skills. The post-activity

reflection must be properly structured in order for the students to receive the greatest gains from the previous two steps. While students have been prompted through metacognitive steps in the pre-activities and during the laboratory experience, research supports the conclusion that merely spending time on those activities is not sufficient; the activities must cause the students to change their behavior [22].

B. Impact of Stage of Topic Presentation on Demo

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. Depending on the stage, the demonstration provides opportunities for different learning outcomes.

Demonstrations that occur at prior to the technical presentation of the topic most directly impact student motivation. The reason "why" a topic is important can be directly addressed, and students can "see" where the theory is leading. By seeing the "whole" picture, the students can then create a mental structure of the problem and process, which serves as a mechanism with which to connect the new information being presented. These demonstrations are, by necessity, simple in nature, which also provide an opportunity for early success with the topic. A final benefit to pre-topic demos is the ability to address misconceptions early, before they become further obscured by new difficulties.

Demonstrations can also follow in parallel with the technical exposition of the topic. With demonstrations at this stage, they can be more complex in nature and are highly interactive. They easily allow for the instructors to actively encourage the creation of connections between the physical model, the mathematical model, and the behavior of the real system.

Post-topic demonstrations serve to wrap-up all the issues that have been discussed and tackled within a topic. They also allow for explicit ties to other course topics, as well as for connections to other courses and experiences outside the classroom. As these demonstrations pull together several issues, they are also the ideal forum to discuss assumptions being made at all levels of the problem solving process.

Each stage of introducing a demonstration helps address particular learning needs and styles. Early on in the semester, while topics are fundamental, pre-topic demonstrations are more easily incorporated and help with fundamental misconceptions and problem solving skills. Pre-topic demonstrations help to activate existing conceptions and set up a "time for telling;" that is, they make students ready for instruction that will come via the lecture [18]. As the semester progresses, the problems and topics naturally become more complex. These lead to cases where post-topic demonstrations more naturally occur, where several ideas are being brought together. Over the course of a semester, demonstrations should occur at all stages of topical presentation.

III. EXAMPLE DEMONSTRATIONS

Demonstrations do not have to be extraordinarily complicated, or expensive to be effective. The simple demonstrations often are very effective at helping students to develop observation skills, and to make reasonable assumptions. Additional equipment and instrumentation have obvious advantages (allowing easy comparisons in observed and predicted values of whatever); however, the additional expense and setup time do not add to the intrinsic value of having the students develop a good qualitative prediction of what will happen during the demo; comparing observations of the demonstration with predictions from theory. The point of demonstrations is to address concepts that typically cause students difficulty and to help students connect analytical solutions with the physical situations. Demonstrations can arise from observed difficulties by students in past semesters, or from assessment with current students, either way, students are more likely to engage in the learning process; connections will be made (or reinforced); and the level of difficulty will not increase.

Several demonstrations were implemented throughout a semester-long course dynamics included at different stages of learning process. The specific demonstrations discussed in this paper are:

1. The Jumper: pre-topic demonstration
2. Vibrating Mass-Spring: early demonstration
3. Forced Harmonic Response of Single Mass System: integrated demonstration
4. Modal Response of Multi-Degree of Freedom System: post-topic demonstration.

The details of each demonstration are presented in the following sections. During each demonstration, student responses to demonstration activities were collected. This data includes information about their pre-conceived ideas about dynamic behavior, as well as their analysis on the prediction process. The impact on student learning is also evaluated through specific questions in quizzes and exams that are tied directly to demonstration activities.

IV. INTRODUCTION TO TOPIC DEMONSTRATION: JUMPER

A common misconception among students lies in their understanding of the fundamental principle of conservation of momentum. This results in disconnects in their understanding of motion under constant acceleration, even in what many consider a very simple concept such as the relationship between time and distance traveled. A simple demonstration is developed to allow students to explore their beliefs about these concepts. The students are given a description of a video they are about to see [23] of two different jumpers, and asked to predict what will happen (see Appendix A for the

exact form of the questions). Questions are asked (or revisited) at each stage in the demonstration. Table 1 lists the steps and corresponding questions/predictions.

Following the demonstration, the students are shown force time histories that have not been normalized, and a discussion of the demonstration takes place.

Demonstration Events	Questions
Description that two people (one a dancer, one an athlete) will step on an instrumented bathroom scale & jump vertically	Predict the force time history for the jump
Show a pre take-off force time history normalized so that weight will not influence their choice, illustrated in Figure 1	Who will jump higher? Who will stay in the air longer?
Show a post landing force time history (again, normalized), shown in Figure 2	Who will jump higher? Who will stay in the air longer?
Show the video of each jumper, as seen in Figure 3	Who will jump higher? Who will stay in the air longer?
Show the entire normalized force time history, shown in Figure 4	Who will jump higher? Who will stay in the air longer?

Table 1. Sequence of demonstration events and corresponding questions.

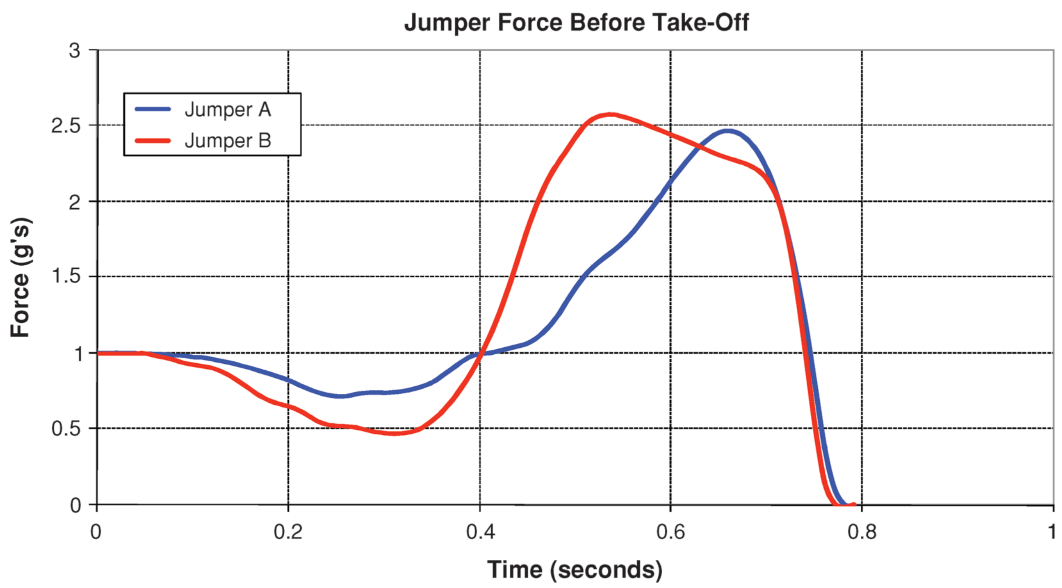


Figure 1. Normalized Force Time History of Jumpers Before Take-Off From Ground.

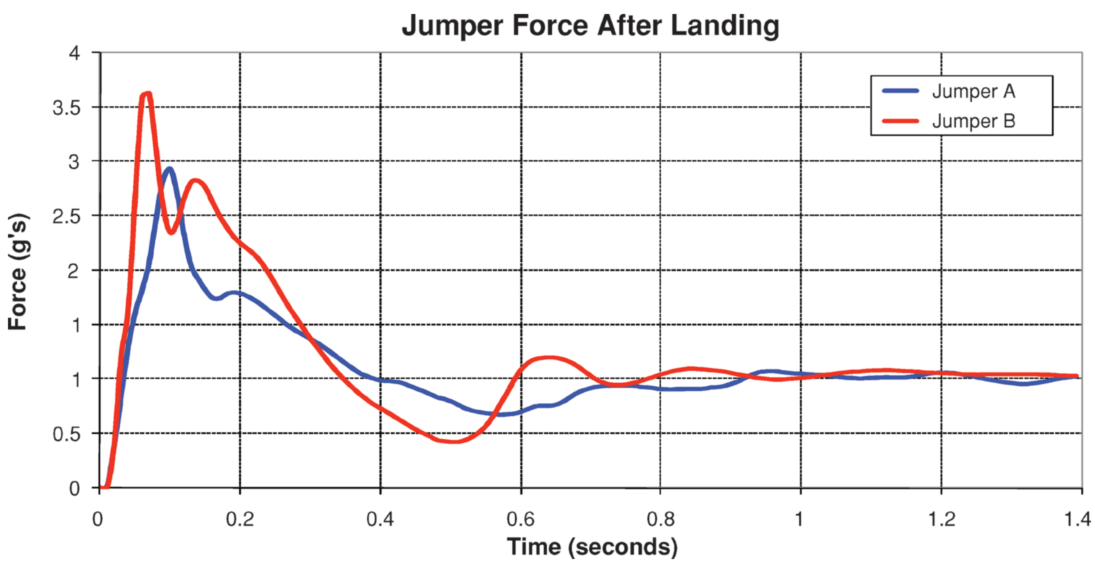


Figure 2. Normalized Force Time History of Jumpers After Landing.

Figure 3. Movies of Each Jumper: Dancer vs. Athlete (click on figure for movie).

A. Student Responses During Demonstration

When asked to predict the force time history after given a verbal description of the event. Only 8 students out of 53 predicted that there would be oscillation in the force after landing. Of these, only two students predicted a dip in force prior to take-off (both predicted this "from flexing of the knees"). It should be noted that one of these predictions had labels on the graph nearly identical to

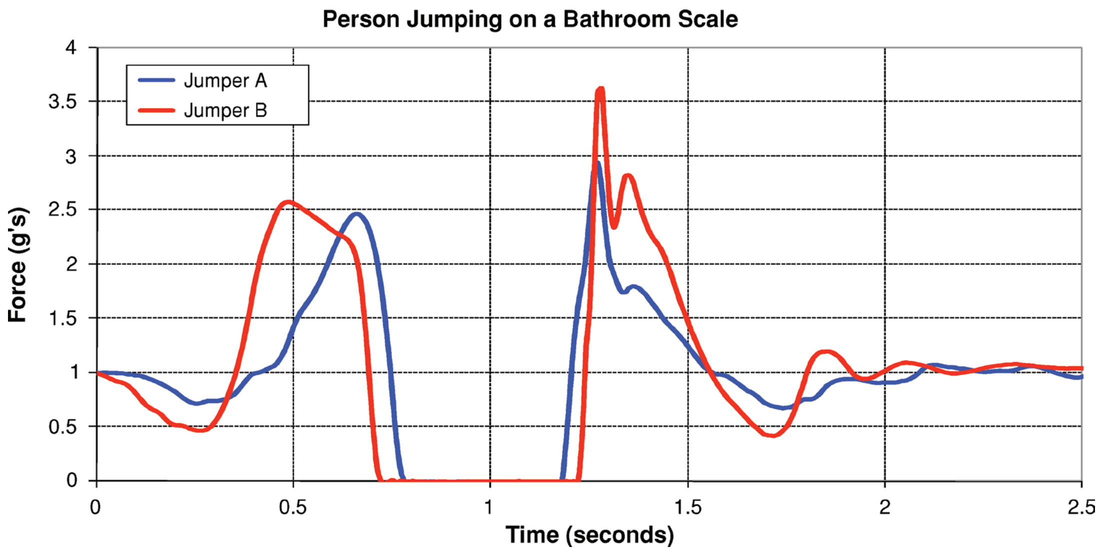


Figure 4. Complete Normalized Force Time-History for Both Jumpers.

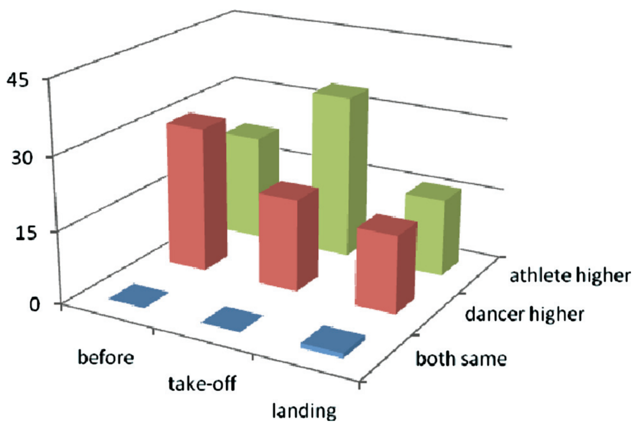


Figure 5. Student Responses: Who jumps higher?

those shown in the later force plot (both for force and (almost as good) for time). Figures 5 and 6 summarize responses to questions of who will jump higher or be in the air longer at different stages of the demonstration: (1) before seeing any force time histories, (2) after seeing only the normalized take-off force time history, and (3) after seeing the landing time history.

After seeing a picture of the jumpers, BUT before seeing the video: Sixteen people out of 53 predicted a different jumper would "jump the highest" than the jumper predicted for "longest duration jump"—of these 15 out of 16 predicted that the athlete would jump higher, and that dancer

would stay in the air longer. One person did not predict; of those who picked the same jumper for both highest and longest duration jump, 7 predicted the athlete would jump higher and longer; 29 predicted the dancer would jump high and longer (including one, who objected to the descriptors on the grounds that a dancer is an athlete).

After the demonstration videos are shown, most students realized that the (female) dancer was A and the (male) athlete was B after the combination of the plot and the movie. Most commented on the realization of how motion "in preparation for the jump" would have helped them predict the shape of the force time history before the jump. Then a non-normalized plot (including the "air-time") is shown, as in Figure 7:

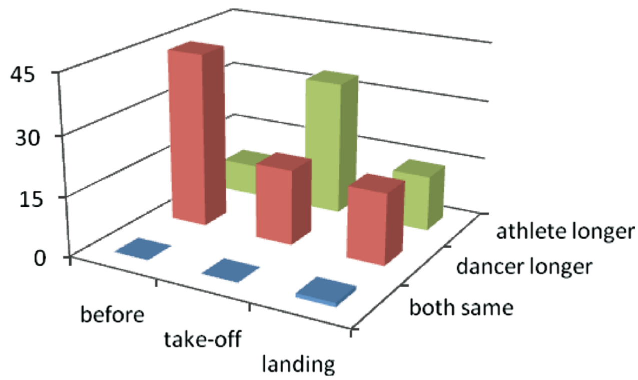


Figure 6. Student Responses: Who is in the air longer.

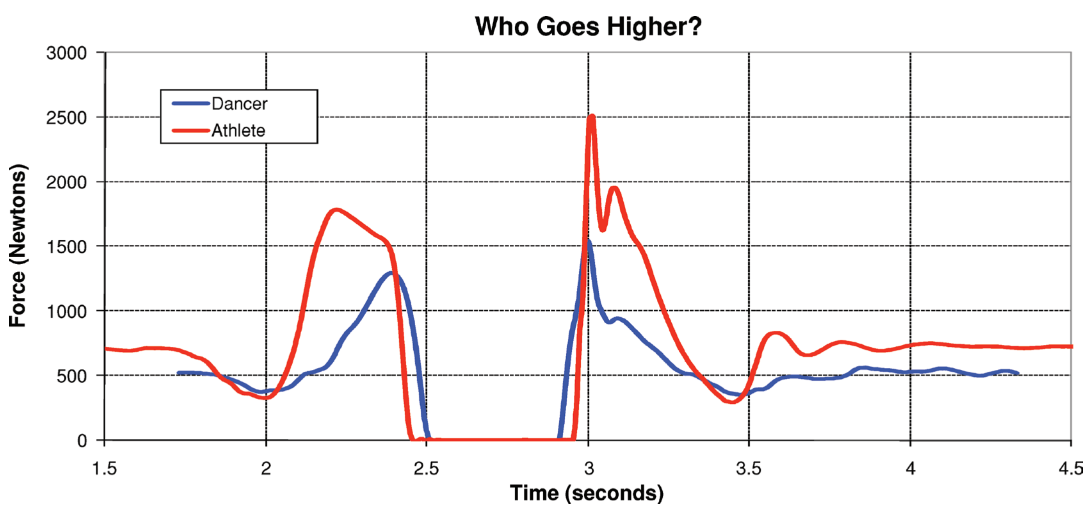


Figure 7. Actual Force Time-History for Both Jumpers.

At this point, everyone realizes that the dancer was curve A. Many commented that they "should have known" that longer and higher went together, but had assumed that higher was based on strength, whereas longer was based on grace or form. Several were disappointed that the dancer "did not try," or should have known this was a "competition!" One commented that he knew "male ego" would win the day.

B. Student Perception of Learning from Demonstration

Students were then surveyed in Spring 2008 on their experience with the active demonstration and the results are presented in Table 2. The results indicate that the majority of the class did learn from the demonstration. Additionally, the demonstration was felt to enhance the learning experience of going through example problems. One unsolicited student comment indicated that "*Test questions are much more involved than the demo,"* commenting on the value relative to preparing for the exam.

Additionally, when asked how easy it was to produce the original force vs. time prediction, the responses were: 2 students found it very easy; 20 found it easy; 21 students were neutral; and 9 students found it difficult. One unsolicited comment on this question was that though the process was easy, ultimately the curve was found to be incorrect.

V. ADDRESSING EARLY MISCONCEPTIONS: VIBRATING MASS-SPRING

One topic that students typically struggle with is the choice of reference position for the degree of freedom definition: whether to measure displacement from the un-deformed spring position or the position where the system is in static equilibrium. A simple demonstration used has a mass

Question	Nothing	Little	A Bit	Some	Very Much
How much did you learn from the demonstration activity	0	1	0	39	13
How much do you think the demonstration activity aided your being able to understand the subsequent class examples?	0	3	3	26	21
How much did you learn from the class examples?	0	3	2	33	15
What is the value of the demo compared to working another example problem?	0	2	4	21	26

Table 2. Student feedback on Jumper demonstration.

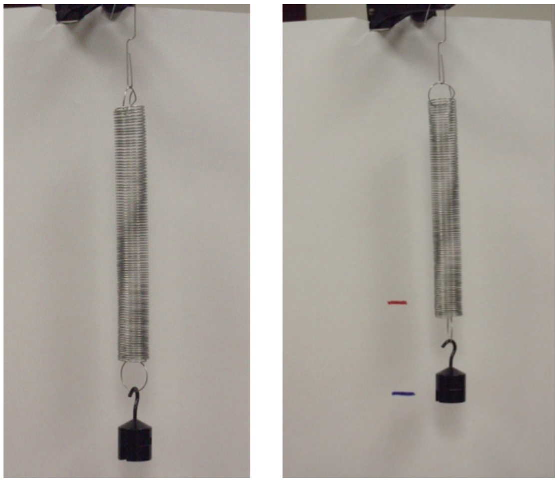


Figure 8. Demonstration of Free-Vibration Response and Coordinate System Selection (click left figure for movie).

hanging from a spring, as illustrated in Figure 8 below. The location of static equilibrium is marked in blue while the location where the spring is un-deformed is marked in red.

The system is shown to the students, and they are asked to create a simplified physical model, as may be seen in a typical textbook example definition. They are then asked to predict what the mass will do if the spring is pulled "down". This first step typically brings out discussions about damping, and how while no physical element looks like a dashpot in the real system, some mechanism for energy loss needs to be incorporated into the models being built.

Once they have finalized their model and created a sketch of the time-history of the response, a clarifying "experiment" like that shown in Figure 9a is done. This leads to a class discussion on their assumption of the deflection initially being "straight down," which may not be the case, and how the different situations could be addressed. The demonstration is then repeated "as they assumed for initial deformation," more like that shown in Figure 9b. We then discuss how the plots look when measured from the different locations and how both resulting equations and plots describe the same physical phenomenon.

A. Student Perception of Prediction Process

The students also were asked whether making a prediction of the system response was an easier process than for the previous demonstration. As desired, previous practice and exposure to the process of making predictions was beneficial and 45 students did indicate the process was easier, as compared to 6 students who did not find it easier than the previous time.

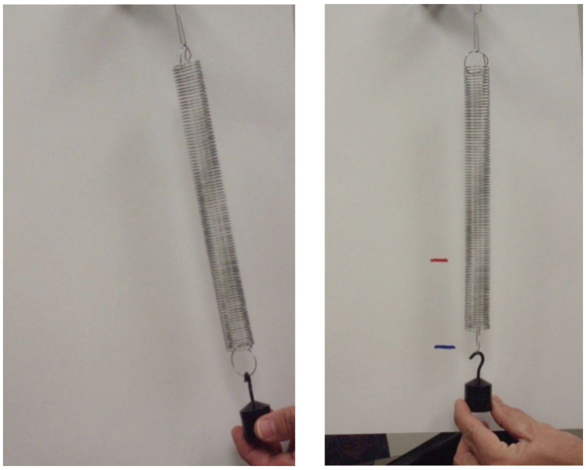


Figure 9. Repetition of Demonstration after Initial Class Discussion (click left figure for movie).

Question	Nothing	Little	A Bit	Some	Very Much
How much did you learn from the demonstration activity	0	1	7	34	9
How much do you think the demonstration activity aided your being able to understand the subsequent class examples?	0	0	8	30	13
How much did you learn from the class examples?	0	0	4	35	12
What is the value of the demo compared to working another example problem?	0	4	5	23	19

Table 3. Student feedback on Spring-Mass demonstration—Full Class Results.

B. Student Perception of Learning from Demonstration

Students were then surveyed in Spring 2008 on their experience with the active demonstration and the results are presented in Table 3. The perception of the benefit of the demonstration is very similar to that of the results after the Jumper Demonstration and do indicate that the majority of the class did learn from the demonstration. Again, the average response for all questions lies between 'Some' and 'Very Much.' As this demonstration occurs later in the semester, students are better able to judge the benefit of multi-modal material presentation and the positive connection between demonstrations and ability to work example problems is promising, indicating potential skills transfer.

Tables 4 and 5 break down the student feedback on the value of the demonstration based on whether the prediction process was perceived to be easier the second time around. No significant difference is present in the responses between the two groups, so the ease of making a prediction is not perceived to impact the value the students see in the demonstrations.

VI. DEMONSTRATION INTEGRATED WITH TOPIC DISCUSSION: FORCED HARMONIC MOTION

Another set of concepts the students will typically struggle with are the concepts of resonance and the shape of a response amplification curve, which leads to results that are contrary to their intuition. The connection between the mathematical model and the physical response is the main

Question	Nothing	Little	A Bit	Some	Very Much
How much did you learn from the demonstration activity	0	0	5	31	9
How much do you think the demonstration activity aided your being able to understand the subsequent class examples?	0	0	6	27	12
How much did you learn from the class examples?	0	0	2	32	11
What is the value of the demo compared to working another example problem?	0	4	3	20	18

Table 4. Feedback on Spring-Mass demonstration—Students who Did Find Prediction Easier.

Question	Nothing	Little	A Bit	Some	Very Much
How much did you learn from the demonstration activity	0	1	2	3	0
How much do you think the demonstration activity aided your being able to understand the subsequent class examples?	0	0	2	3	1
How much did you learn from the class examples?	0	0	2	3	1
What is the value of the demo compared to working another example problem?	0	0	2	3	1

Table 5. Feedback on Spring-Mass demonstration—Students who Did NOT Find Prediction Easier.

challenge. Students do have a general sense of the concept of resonance, but they do not connect that idea with the mathematical equations/models. While the students can follow the mathematical derivation of the response equation, the physical interpretation of the mathematical terms and how to utilize the response amplification curve to make decisions is difficult.

The demonstration used at this point is shown in Figure 10. It is easy to discuss the mathematical expressions for the harmonic response of a system when done along with this demo. The solution to the differential equation describing harmonic motion is presented and discussed in class prior to the demonstration.

The physical demonstration set-up is then presented to the class and the source of the harmonic force on the system discussed. The students are asked to estimate responses at several different frequencies and based on those results to predict the shape of the curve. The demonstration is run at the various frequency ranges discussed with the students, specifically:

- Slow excitation frequency (below resonance)
- Resonant frequency
- Fast excitation frequency (above resonance)

They are then asked to compare their predicted curve with that observed from the demonstration, and also to the analytically derived amplification formula.

A. Student perception of prediction process

When asked "How easy was it to predict response vs. frequency curve," students were mostly neutral about the difficulty or did find it somewhat difficult. Specific responses were:

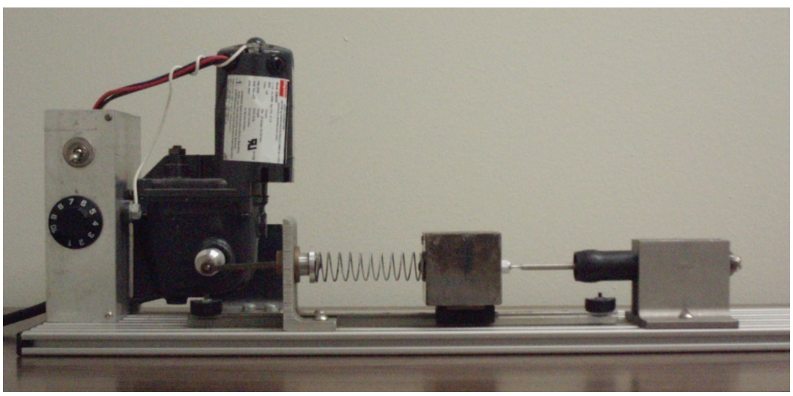


Figure 10. Forced Harmonic Response of SDOF System (click on figure for initial displacement response).

- Very easy: 0 students
- Easy: 4 students
- Neutral: 26 students
- Difficult: 19 students
- Very Difficult: 5 students.

An important note is that 3 of the top 5 students in the course indicated that the prediction in this case was very difficult. This result correlates with the fact that in comparison with previous responses, the behavior of this system is very complex. The students who are at the top of the class have a better understanding of how complex the relationship is and are more aware of what knowledge they have mastered vs. the areas in which they are weak. Part of the demonstration process at this point then includes a discussion on how the students can use these results to evaluate their own learning and identify their own knowledge gaps, encouraging meta-cognition.

B. Student Perception of Learning from Demonstration

Students were then surveyed in Spring 2008 on their experience with the demonstration and the results are presented in Table 6. These are the same questions as for the previous demonstrations. While the results are not as strongly positive as for previous demonstrations, most of the class again perceives positive learning gains from the demonstrations.

Some of the responses reflect the difficulty they have with the material overall rather than an actual assessment of the learning benefits of the activities. For example, the student who stated that there is no value to the demonstration compared to working another example also stated that he learned little from class examples and that the demonstration provided some aid to understanding the examples. The student who found little value in the demo compared to working examples also only learned a little from the class examples.

Question	Nothing	Little	A Bit	Some	Very Much
How much did you learn from the demonstration activity	0	3	4	34	13
How much do you think the demonstration activity aided your being able to understand the subsequent class examples?	0	1	10	26	17
How much did you learn from the class examples?	0	1	3	38	12
What is the value of the demo compared to working another example problem?	1	1	13	27	12

Table 6. Feedback on Harmonically Excited SDOF System.

VII. POST-TOPIC DEMONSTRATION: MODAL RESPONSE OF MULTI-DEGREE OF FREEDOM SYSTEM

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 demonstration used at this point is shown in Figure 11, where a motor provides a harmonic support motion to the two-dof spring-mass system. As the frequency of the motor is changed, the two mode shapes can be excited and physically demonstrated. The frequency of the excitation is slowly adjusted until the students identify:

- First mode excitation response
- Second mode excitation response

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…).

A. Student Perception of Prediction Process

When asked "How easy was it to predict the response," students were mostly neutral about the difficulty or did find it somewhat difficult. Specific responses were:

- Very easy: 0 students
- Easy: 7 students
- Neutral (Neither Hard nor Easy): 18 students

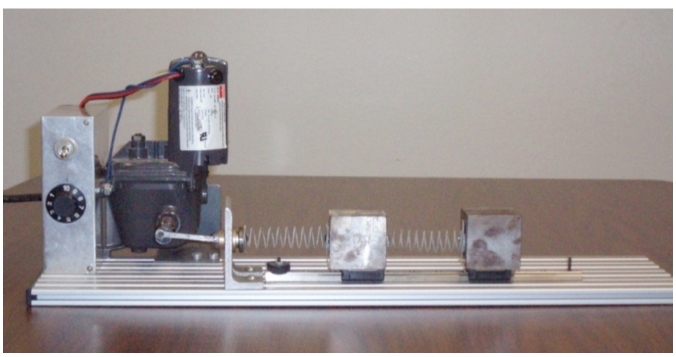


Figure 11. Demonstration of Modal Response of a MDOF System.

- Difficult: 18 students
- Very Difficult: 2 students.

With this demonstration, students were also asked how confident they were about their prediction before seeing the physical response:

- Very confident: 1 students
- Confident: 10 students
- Neutral: 6 students
- Some doubts: 20 students
- Many doubts: 8 students.

No significant correlation occurred between the ease of making the prediction with how confident the students were regarding their responses. This result appears to indicate that while they are getting more confident in trying to make a prediction, they are still uncertain about how to apply their technical knowledge to a real situation.

B. Student Perception of Learning from Demonstration

Students were also surveyed on their perception of the benefits of the demonstration. When asked "How helpful was the demonstration," students replied:

- Made things worse: 0 students
- No help: 1 students
- Just a little help: 3 students
- Some help: 10 students
- Mostly helpful: 13 students
- Helpful: 12 students
- Very helpful: 6 students.

As in previous results, demonstrations are perceived to have a positive impact on learning by the students.

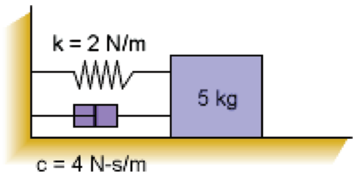
VIII. IMPACT ON STUDENT PERFORMANCE

A. SDOF Base-Excitation Demo

One final exam question is directly related to the demonstration of the harmonically base-excited SDOF system. This problem is conceptual in nature, asking the students to determine the best strategy for reducing the displacement response. The exact exam question as given in Fall 2007 is shown in Figure 12.

Problem 12: A spring-mass-damper system, like the one shown, is excited by a harmonic support motion with frequency $\bar{\omega}$ that **currently** exactly matches the undamped natural frequency of the system. If the excitation frequency cannot be changed,

Part (a): Then the *best* strategy for reducing the peak total displacement response is:



a. To increase the stiffness constant k
b. To increase the damping constant c
c. To decrease the stiffness constant k
d. To decrease the damping constant c
e. To decrease the mass

Part (b): Explain your reasoning.

Figure 12. Final Exam question on Harmonically Excited System.

This question assesses the student's understanding of harmonic response and the dynamic amplification factor as well as degree of freedom definitions. Two key phrases are present in the question: best strategy and total displacement. As the system is currently at resonance, several of answers provided will reduce the response: changing the mass or stiffness will change the frequency of the system so resonance condition is no longer the case, and increasing the damping will reduce system response if it is operating at or near resonance. However, by increasing the stiffness or reducing the mass, the system's frequency is now higher than the excitation frequency and the smallest displacement that can be achieved is equal to the ground displacement. In contrast, if the stiffness is reduced then theoretically a zero displacement of the mass is achievable. So the *best* strategy out of the options given is the reduction of stiffness, which is the opposite strategy than for the reduction of displacement under static loads.

The multiple-choice part of the question was given in four different semesters, starting in Spring 2006 when no demonstrations had been introduced into the course. Based on the student's performance on the question, students were asked to explain their answers in order to better understand the misconceptions driving student responses. Table 7 shows by semester when the demonstration was introduced into the course as well as when the different exam question components were utilized.

The responses to the multiple choice portion of the question are tabulated in Table 8, showing both the number of students who selected each option as well as the corresponding percentage of the class as the course sized varied. Overwhelmingly, students have chosen the option of increasing spring stiffness as the best strategy to reduce response in all semesters. When this result was first observed in Spring 2006, the demonstration was added in the Fall 2006 to aid students

Implementation	Spring 2006	Fall 2006	Spring 2007	Fall 2007
Demonstration	No	yes	yes	yes
Multiple-Choice Question	Yes	yes	yes	yes
Explanation of Answer	No	no	yes	yes

Table 7. Results of Exam Question on Base-Excited SDOF System.

	Number of Students				Percent of Class			
Semester	Spring 2006	Fall 2006	Spring 2007	Fall 2007	Spring 2006	Fall 2006	Spring 2007	Fall 2007
Increase stiffness	36	31	28	33	50.70	48.44	54.90	55.00
Increase damping constant	30	20	9	7	42.25	31.25	17.65	11.67
Decrease stiffness	1	8	11	18	1.41	12.50	21.57	30.00
Decrease damping constant	0	2	1	0	0.00	3.13	1.96	0.00
Decrease mass	4	3	2	2	5.63	4.69	3.92	3.33

Table 8. Results of Exam Question on Base-Excited SDOF System.

in understanding the dynamic behavior. This did change the distribution of the answers. As more students began to understand that reducing the stiffness is the appropriate strategy. However, that portion of the class was still very small and the bulk appeared to come from those who'd previously have chosen to increase the damping.

The only change between the Fall 2006 and Spring 2007 semesters was the introduction of the question portion asking students to explain their answers. The goal was to collect information to change future implementations of the demonstration and corresponding activities. Interestingly, the simple act of asking for an explanation had a noticeable change in the distribution of answers, reinforcing the concept that asking students to be active in their thinking is essential to get them to engage in critical thinking.

Based on the explanations provided in the Spring 2007, the activities with the students during the demonstration were updated. While changing spring stiffness is not feasible with the physical model, students were asked to predict how the response of the system would change if the stiffness were increased or decreased. As different examples were worked in class, ties were made to what

had been observed during the demonstration. As a result, the explanations provided to the exam question in the Fall 2007 indicated an improvement. While the percentage of the class selecting increase stiffness as the best strategy remained the same, the number of students who were including relevant dynamic concepts in their answers increased dramatically, as indicated in Table 9.

The answers do include discussions of the dynamic amplification factor. One of the common errors this group of students is making is confusion between total and relative motion. In many cases, the solution of the equation of motion when using relative displacement is simpler than the solution for total motion, and so is a solution students see and use more often. For relative motion, stiffening the spring can result in nearly zero relative motion to the support—i.e., the mass moves exactly the same as the support. Coordinate system definitions and implications is consistently a source of difficulties for the students and this result is another indicator of this issue. Future developments of this demonstration will consider how to more explicitly address this issue with the students.

B. MDOF Demonstration

Student performance data on the quiz problem related to the MDOF System Modal Response is presented in Table 10 and do indicate an improvement in student learning. Data was compiled for 6 semesters. In three of those semesters no demonstrations were utilized, while for the latter three semesters active demonstration was part of the course. The data shows that both the class average as well as the lowest score was improved in the semester with the demonstration.

	Number		Percentage	
Explanation considers	**Spring 2007**	**Fall 2007**	**Spring 2007**	**Fall 2007**
Static response	27	21	96.43	63.64
Dynamic response	1	12	3.57	36.36

Table 9. Results of Exam Question on Base-Excited SDOF System.

	No Demos			Using Demos		
Semester	Fall 2004	Spring 2005	Spring 2006	Fall 2006	Spring 2007	Fall 2007
No. Students	58	95	60	59	55	57
Average	73.1	73.7	79.4	85.2	87.55	86.7
Standard Deviation	18.8	18.4	15	15.1	13.4	13.3
High Score	100	100	100	100	100	100
Low Score	35	30	40	50	55	65

Table 10. Quiz on Mode Shapes and Frequencies.

IX. ASSESMENT OF STUDENT PERCEPTIONS

The effectiveness of active-learning approaches depends on student willingness to engage in the thinking, experimentation, and conversation with peers that these approaches involve. Understanding student response to the demonstrations is helpful in developing best ways to engage them. To gain this understanding, data about student perceptions were gathered via an on-line survey at the end of each semester, paper and pencil surveys following each demonstration, and student focus groups. Each of these assessments are described in more detail below.

A. Student Assessment of Learning Gains

At the end of the Fall 2006 through Fall 2008 semesters, 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 are presented in Tables 11 through 13.

In the Fall 2008 the demonstrations were followed-up by homework assignments requiring numerical analysis of the data. This relied heavily on their prior knowledge of numerical methods, a pre-requisite course students struggle with. This was accompanied by a noticeable increase in negative reactions to the demonstrations.

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.

Rating	(weight)	F 2006	S 2007	Sum 2007	F 2007	S 2008	F 2008	Total
Strongly agree	5	23	11	3	12	6	9	64
Agree	4	64	39	8	47	24	36	218
Neutral	3	18	37	6	22	0	29	112
Disagree	2	6	8	0	5	3	12	34
Strongly disagree	1	0	0	0	0	1	14	15
Number Students		111	95	17	86	34	100	309
Average Rating		3.94	3.56	3.82	3.77	3.91	3.14	4.20

Table 11. Student Perception that Models Helped Clarify Mathematical Model.

Rating	(weight)	F 2006	S 2007	Sum 2007	F 2007	S 2008	F 2008	Total
Strongly agree	5	22	12	1	11	8	16	70
Agree	4	61	34	8	52	22	39	216
Neutral	3	24	36	7	16	1	25	109
Disagree	2	4	13	1	7	3	10	38
Strongly disagree	1	0	0	0	0	0	10	10
Number Students		111	95	17	86	34	100	309
Average Rating		3.91	3.47	3.53	3.78	4.03	3.41	4.16

Table 12. Student Perception that Models Helped Visualize Mathematical Response.

Rating	(weight)	F 2006	S 2007	Sum 2007	F 2007	S 2008	F 2008	Total
Strongly agree	5	33	13	4	12	12	13	87
Agree	4	59	43	9	45	19	38	213
Neutral	3	12	27	3	23	0	23	88
Disagree	2	7	11	1	6	1	9	35
Strongly disagree	1	0	0	0	0	2	17	19
Number Students		111	94	17	86	34	100	408
Average Rating		4.06	3.62	3.94	3.73	4.12	3.21	4.02

Table 13. Student Perception that Models Helped Connect Course Topics.

- It was effective b/c it helped you to understand the problem better and recognize what your answer should look like.
- The demo's were quite helpful in showing responses. It was also helpful to see how our predictions compared with the actual responses.
- Demonstrations were very good and helped more than trying to prove everything through equations.

Not every student sees the benefit as strongly as others. However, these students represent less than 10% of the class, and even they didn't strongly disagree with any of the benefits. 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.

Not every student sees the benefit as strongly as others. However, prior to Fall 2008, these students represent less than 10% of the class, and even they didn't strongly disagree with any of the benefits. Some typical comments from this portion of the students are shown below: In Fall 2008, while the percentage of negative reactions increased, they were directly related to the increased workload as determined by student comments.

B. Student Focus Groups

Two themes emerged during focus groups with students following Fall 2006 and Spring 2007. First, students believed that the physical demonstrations (and computer simulations) contributed to their learning of concepts but did not help on the exams. Success on exams meant success in setting up and solving paper and pencil problems, and in the students' minds this success was not connected to conceptual understanding. This perception holds even though exams and quizzes include both conceptual and computational problems throughout the course. Part of the problem lies in that even computational problems include a conceptual component, but the students only focus on the computational aspect. 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 .Second, students believed that a framework provided to guide their problem solutions assisted them in following problem solutions during class and reproducing them later.

Both themes may be understood within the framework of the kind of learning environments called for in *How People Learn* [7]. Specifically, the need for knowledge-centered learning environments refers to a need to help students develop "maps" in their minds that connect what might otherwise be discrete pieces of information. The expert has a well-constructed mental map of foundational knowledge that makes the connection between conceptual understanding and successful problem solving obvious. The lack of such a map can make the connection invisible to the novice. Frameworks to guide student observations during demonstrations, and to guide their paper and pencil solutions to problems, can help to make the professor's invisible knowledge map explicit. The results of these focus groups led to the development of worksheets for students to use during the demonstrations such as the one developed for the jumper demonstration shown in Appendix A.

CONCLUSIONS

The results from introducing a laboratory experience into the course in the form of active demonstrations 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. The data collected during demonstrations indicate the progression students make from the first erroneous predictions to identifying their own misconceptions and assumptions. Additionally, if students are not asked to explain or in some manner support their predictions, they will rely on their misconceptions to make guesses. By consistently guiding students through the prediction/analysis cycle of the active demonstration, students start to develop their critical thinking skills and bring the knowledge from the classroom into actual applications.

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 as is demonstrated in the improved student performance results.

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 and resulting in improved student performance presented. Even in the assessment process, students need to be prompted to reflect on their knowledge before making decisions. If we do not ask them to think; they will simply guess, and (worse) rely on prior misconceptions.

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APPENDIX A – JUMPER DEMO STUDENT WORKSHEET

Worksheet – a person on a bathroom scale jumps

1. Sketch the Force vs. Time curve of a person jumping straight upwards starting from a standing position. The plot should go until after the jumper lands back on the ground and is back in a standing position. Label critical events (i.e. Jump starts, person leaves ground, etc...)
2. You have read descriptions, or seen pictures, of two different people who will perform the standing jump.
   i. Which jumper will go higher from the ground?
      Ballet Dancer ___________ Athlete ___________
   ii. Which jumper will have a longer duration jump?
      Ballet Dancer ___________ Athlete ___________
   iii. Explain your answers:
3. You have now been shown collected pre- jump data on female ballet dancer and male athlete.
   i. Which curve do you believe corresponds to the ballet dancer?
      Jumper A ___________ Jumper B ___________
   ii. Which jumper will go higher from the ground?
      Jumper A ___________ Jumper B ___________
   iii. Which jumper will have a longer duration jump?
      Jumper A ___________ Jumper B ___________

iv. Explain your answers:

4. Revisit your original Force vs. Time plot and compare with the collected data.
   i. What was different between your prediction and the actual jump?
   ii. What assumptions did you make?
5. You have now been shown collected post- jump data on female ballet dancer and male athlete.
   i. Which curve do you believe corresponds to the ballet dancer?
      Jumper A ___________ Jumper B ___________
   ii. Which jumper will go higher from the ground?
      Jumper A ___________ Jumper B ___________
   iii. Which jumper will have a longer duration jump?
      Jumper A ___________ Jumper B ___________
   v. Explain your answers:

6. Revisit your original Force vs. Time plot and compare with the collected data.
   iii. What was different between your prediction and the actual jump?
   iv. What assumptions did you make?
7. Revisit your original Force vs. Time plot and compare with the collected data within the context of movie. Questions to consider:
   i. What was different between your prediction and the actual jump?
   ii. What assumptions did you make?
8. Who is the better jumper? Why?