AC 2007-3082: DID YOU EVER WONDER IF ANYTHING COULD MAKE DYNAMICS FUN?

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Introduction

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. In addition, the course includes the demonstration of physical models; the use of simulation; team based projects & incorporates civil engineering examples and real-world applications with much more emphasis on vibration than in a traditional dynamics course.

The increased emphasis on the vibration material keeps our civil engineering students more engaged in the course. There is an initial resistance to learning the material when all students see are box-spring examples when first going through the derivation of the equation of motion for single degree of freedom systems. Instead of starting with the simplified model, a one-story building is presented to the class and the first step in solving the problem is the development of the analytical model for the system. This also serves to connect the concepts of the dynamics course with other courses in the curriculum.

Course projects are based on realistic civil engineering examples, with an emphasis on the assumptions required to develop the analytical model. The projects are team assignments and rely on numerical analysis, a pre-requisite for the course. These projects have several objectives: (1) to allow students to tackle a larger and more realistic civil engineering dynamics problem, (2) expose students to computational tools used in solving dynamics problems for which a closed form solution does not exist, (3) evaluate critical thinking and communication skills. The projects also allow for the introduction to advanced engineering concepts, such as seismic response.

This paper presents the implementation of this course for all civil engineering undergraduate students. Course content and structure, materials (including projects); student acceptance and performance; and course assessment and evaluation are addressed in the paper.

Course Overview

Development and Current Content: Addressing Civil Engineering Needs

The dynamics/systems sequence for undergraduate engineers has traditionally started with separate statics and dynamics courses. Texts for the introductory dynamics courses "customarily downplay the pervasive nature of differential equations as dynamics natural language"[3]. The original concept and course was developed to: (i) incorporate team learning, and (ii) teach from a general conservation-principles concepts towards specific examples. Much of the remaining gain comes from the guidelines which were established for developing this *dynamics and vibrations* course:

- *(i)* Prerequisites include both statics, numerical methods, and differential equations;
- *(ii)* The course would cover dynamics of particles, rigid bodies (planar motion only), and 2DOF vibration; and

(iii) Reliance on MATLAB™ assignments and projects for the solution of **many** of the differential equations of motion (including the solution of linear simultaneous equations, solution of nonlinear algebraic equations, eigenanalysis, etc.)

This approach also contributes to the ability to include *traditionally* advanced topics (those most easily tied to civil engineering) by:

- kinematics coverage that emphasizes direct differentiation of vector components to obtain velocity and acceleration relationships in Cartesian, polar, or path coordinate systems; **and** transformation of answers to the remaining two systems;
- a parallel analysis of the same examples using *free-body diagrams, conservation of energy* approaches to derive the equations of motion; and
- including vibrations material and examples (including eigenvalues and eigenvectors).

One of the challenges of teaching dynamics to civil engineering students is motivating them as to the relevance of the topic to their profession[4,7]. Traditional undergraduate courses use examples from the mechanical engineering field have no vibrations content, which is more relevant to civil engineering problems. To address these issues, the authors have adapted the mechanical engineering course content to incorporate civil engineering examples and applications, and to place more emphasis on vibrations. An important part of this change is a discussion of how civil engineering systems can be modeled as simple systems that superficially appear to be purely mechanical. For example, when first going through the derivation of the equation of motion for single degree of freedom systems, there is an initial resistance to learning the material when all students see are box-spring examples. Instead of starting with the simplified model, a one-story building is presented to the class and the first step in solving the problem is the development of the analytical model for the system. Once students are shown how a building can be modeled as a system of boxes and springs, student interest sharply increases.

In order to be able to present civil engineering specific course content, some of the material is not covered in the same depth as that in the mechanical engineering course, such as dynamics of linkages. However, whereas mechanical engineering students have seen particle dynamics in two previous courses, freshman engineering physics and a statics plus particle dynamics course, civil engineering students take a statics only course. This means that our students only have the dynamics from freshman physics. Minimizing time spent on these topics that are only minimally relevant to civil engineers allows for greater discussion of additional topics in vibrational response, such as damping in multi-degree of freedom (MDOF) systems and model reduction. Additionally, when particle kinematics was pulled back into the civil engineering dynamics course, the coverage of rigid body systems was reduced.

Course Structure and Approach

The current course benefits from the following features:

- 2-2 Format:

This three credit hour class meets twice a week for two hours each time, resulting in an extra contact hour a week with the students. The extra contact hour is used to work more example problems, as well as tackling more realistic and complex problems. The extra hour in class saves faculty time previously used in office hours to answer questions individually. Also, complex problems would otherwise not be something the students would see. Since these types of problems are explicitly "covered" in class, students expect and are more prepared to tackle realistic problems in homework and exams.

- Active Problem Solving,

The extra hour in class allows for inefficient problem solving to occur. An example that could be shown in 15 minutes now takes 30 minutes. While more time is spent on the problem, more is accomplished. In the 30 minutes, students discover what they know and uncover what they don't know. Particularly as problems get complex, students initially are overwhelmed and frequently state "I don't know how to start the solution." Active problem solving helps them piece together smaller problems that they do know how to solve in order to reach the solution of the complex problem. This also leads to more efficient office hours, where students come as a group with an attempted solution to various problems.

- Instruction Team (PT, TA, Profs):

A coordinated effort by the two instructors, teaching assistant, and peer teacher results in office hours that span the entire week. Students are repeatedly told they can see any person involved, including professor from other section. This team approach allows for students to get help more easily, as well as seeing different approaches to solve the problems.

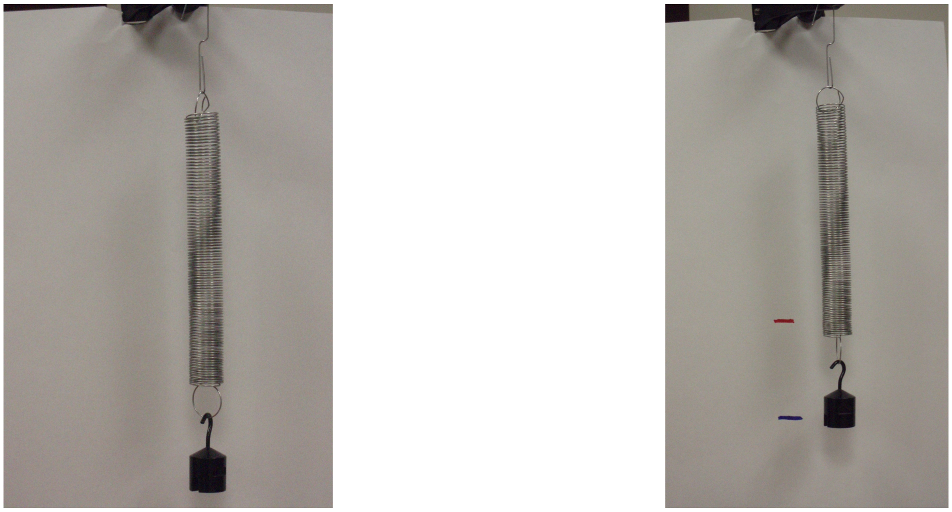
Learning Activities and Assessments

- Physical Demonstrations

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.

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

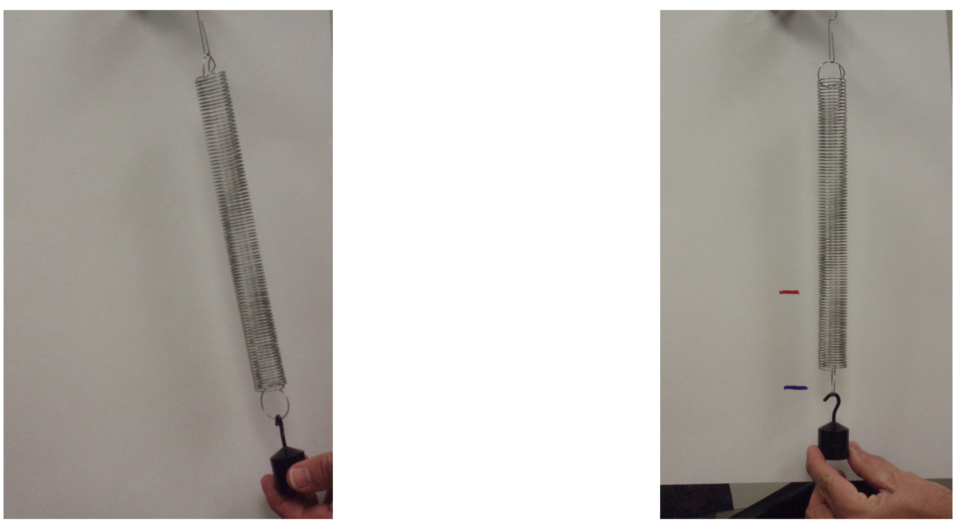
The system is shown to the students and they are asked to create a simplified physical model, something like what they see in a typical textbook example definition. They are then asked to predict what the mass will do if the spring is pulled "down". This first step typically brings out discussions about 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.



(a) (b)

Figure 1. Demonstration of Free-Vibration Response and Coordinate System Selection

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 2a 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 2b. 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) (b)

Figure 2. Repetition of Demonstration after Initial Class Discussion

- Homework, Quizzes and Exams.

You cannot expect students to independently tackle complex problems for the first time during an exam or quiz. The structure of the course allows complex problems to be first modeled in class. Students then practice those skills on homework problems, where access to the instructional team is available. These are further refined during quizzes and finally demonstrated during exams. While in the beginning students are intimidated, they leave the course empowered and much more confident in their problem solving skills.

- Project

The course also uses three computational projects using civil engineering applications. These projects have several objectives: (1) to allow students to tackle a larger and more realistic civil engineering dynamics problem, (2) expose students to computational tools used in solving dynamics problems for which a closed form solution does not exist, (3) evaluate critical thinking and communication skills[2,8]. The projects are designed to solved by student teams, who are told they are acting as consultants on the project posed. The projects are all centered on different real civil engineering systems and present a discussion of how to create a simple model for that system. Particular emphasis is paid to the assumptions made in the modeling process. MATLAB is then used as the framework within which the numerical solution will be achieved. The students are given template MATLAB scripts that must be customized to their particular problem. A co-requisite for this course is a numerical methods coursed where MATLAB is also used, exposing our students to the necessary skills to use this tool. The student teams are required to evaluate at least 2 possible designs and make a recommendation in their final report. This approach forces the students to think about the significance of their results, rather than blindly crunching numbers.

It is essential that the instructor balance the student need (or desire) for explicit instructions with the learning which comes from struggling with:

- Choosing the best approach/theory to tackle the problem;
- Making appropriate assumptions; and
- Evaluating (often conflicting) results.

It also should be emphasized that the link between the theories and concepts presented in class and the real world projects ***is not obvious to the students!*** Some students fail to see any connection between the homework, exams & the projects even when links are made explicit in the class. Similarly, we have found it necessary to emphasize the links between the content of other courses (past, concurrent, and future) and what is happening in our classes and class projects. The authors strongly recommend emphasizing to the students that projects are not meant to serve as tools to master basic concepts, rather they serve to tie different concepts together and see how they are used to solve realistic concepts."[5,6]

Perceptions of Students in Course:

At the end of the semester, students are surveyed regarding the course; including questions related to how much the course met the specified ABET outcomes and how different course components enhanced their learning of the material. Although we still get a few "as a civil engineer I will never need or use this!" comments; more often we hear:

- "I finally am taking an engineering course where I feel like I can or will use this in the 'real-world'"
- This class should be taken because it will give an insight into how the real world works

under many types of conditions. Dynamics effects everything.

- "One of the best things was when you showed how this directly applies to a civil engineering problem" (referring to how to model civil systems using a masses and springs MDoF model)
- “The projects really helped to bring concepts to life”
- “The projects were the heart of my interest for the class. Without civil application I could care less about dynamics.”
- Even though this class was difficult, I enjoyed it more than CVEN 305 – Mechanics of Materials and ENGR 221 – Statics, because I feel I can use a lot of what I learned in this class in the real world. And, in the end, I feel I understood this class more than the other two.
- I liked learning the things that that are real world applications. I know it is important to know the basics like, energy and angular acceleration and the stuff we began the semester doing, but I really enjoyed the class once we got into modeling building structures.
- I really enjoyed the class a lot more than I intended to, and most of that had to do with the teaching style and organization of the material. Because of the second project, I feel more comfortable with my ability to model physical system responses using computer simulations.
- This class is like a class derived from all specific classes before. It is the synthesis of all the education that students have accrued until this point. Seeing how all the theory really works is truly a very interesting and satisfying practice - for once students can see how the theoretical and real-world can be combined to create marvels of engineering that will confound the general public for years to come - all of which is practical science. I may not remember all of the information, but I know where to look and how to approach problems.

Students also see a gain in the critical thinking and problem solving skills:

- My problem solving ability has improved because of the complexity and difficulty of the problems needed to be solved in this class.
- really liked the class as I look back on it. It was definitely challenging, but we all need that. We need to keep raising the level of complexity in the problem that we are required to solve.
- The problem solving in this class is great. I have approached many problems and scenarios in which seemed impossible at first, but eventually I was able to complete them.
- This field combines all major engr classes taken thus far. It's neat to know that all can intertwine into one class and one problem. It helps one to remember what they've learned previously and keep it in practice.
- This class has tied all my knowledge from the last few years together and has taken a step to get me away from just using books and thinking freely.
- Honestly all engineering courses add to the skills, however this class combines the skills and tools learned from other classes and provides an increase in the overall understanding of solving problems (Example CVEN 302 for numerical methods, ENGL 210 for technical reports, ENGR 221 for solving problems, MATH 308 for differential equations).

Table 1 shows the results of the questions regarding ABET outcomes (ABET 2000) from the Fall 2006. In general, students agree that both courses do add to their knowledge and skills in the specified ABET outcomes. Table 2 shows student ranking of what contributes to their learning.

Table 1: Student Perception on Course Adding to their Ability in Specific ABET Outcomes

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Ability to apply knowledge of basic mathematics, science, and engineering					
CVEN 363	29	73	6	3	0
Ability to function on multi-disciplinary teams					
CVEN 363	40	51	12	6	2
Ability to formulate and solve civil\ocean engineering problems					
CVEN 363	25	76	10	0	0
Ability to communicate effectively (verbal & written)					
CVEN 363	6	37	55	11	2
Ability to use computers to solve civil\ocean engineering problems					
CVEN363	19	54	29	8	0

Table 2: Student Perception on Course Contributions to Learning

Not Applicable	No Help	Little Help	Moderate Help	Much Help	Very Much Help
Interactive problem solving in class					
0	4	13	25	40	26
Discussion in class					
0	1	10	28	47	24
Class presentations (including lectures)					
0	0	7	29	50	24
Use of physical models in demos					
0	2	13	24	48	23
Teamwork					
0	5	18	24	42	21
Homework					
0	1	14	24	51	19
Group work in class					
0	3	21	35	25	15
Realistic problems and projects					
0	3	19	37	36	15
Use of computer simulations in demos					
0	3	16	32	37	14
Review Sessions					
0	14	16	29	22	13
Report Requirements					
1	13	21	41	29	5

Mid-term and final course evaluations for this class reflect that, though students find the course challenging, they indicate that these are courses where they see how the material relates to the practice of civil engineering, and that these connections enhance their learning of the material. Table 3 shows the student's responses to questions regarding course overall.

Table 3: Results from Final Course Evaluation in Fall 2006

\	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Course emphasizes understanding vs. memorization					
CVEN 363	63	43	5	0	0
Use of CE examples played a large role in learning the material					
CVEN 363	30	52	21	6	2
Relevance of dynamics to civil engineering, even if outside area of interest					
CVEN 363	47	45	13	6	0
I have learned a great deal in this ourse					
CVEN363	37	57	16	1	0

The one consistent complaint from the students is the time required to pull the projects together. Mid-term and final course evaluations for this class reflect that, though students find the course challenging, they indicate that these courses are one where they see how the material relates to the practice of civil engineering. The results from three questions related to the project are presented in Table 4.

Table 4: Student Perception on How Projects Enhanced the following

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Critical Interpretation Skills					
CVEN 363	17	49	38	6	1
Connection Between Concepts					
CVEN363	16	59	31	4	1
Motivation for Course Concepts					
CVEN 363	11	45	43	9	2

Former Student Perceptions:

As students reflect back on their experience with the course, things become more positive as the long-term benefits become more apparent. One student recently emailed one of the instructors the following:

"I was actually using some of the stuff that I learned in [this course] the other day at work to determine where I needed to move a pin location so that a hydraulic cylinder on a backhoe would not interfere."

Other students see the impact of the improved problem solving skills in other courses, even though not “dynamics” in content.

Faculty Perceptions

As students see the connection of the course material with actual application in civil engineering practice, they are more engaged in learning the material. During the course of the semesters several seminars are presented that relate to dynamics applications in different civil engineering specialties. While these seminars are geared to graduate students, undergraduates in this course are encouraged to attend and offered a small amount of extra credit for writing a summary of the key topics. These summaries indicate that the students do follow the key ideas presented in most cases, and the better students frequently come and discuss the ideas with the instructor after class.

This exposure to cutting edge design and research opens the students to the possibilities for research. The projects also increase student confidence that they can successfully tackle larger problems that deal with advanced topics. Several undergraduate students who took the course were recruited to participate in research on structural dynamics, structural health monitoring and structural control. Very few undergraduates participate in undergraduate research within our department, and none were involved in dynamics research in any meaningful way prior to this course. These students each worked on a research project for about a year. At the end of their experience, some also wrote a short conference paper and gave a presentation at a seminar for undergraduate research. Several continued their studies in graduate programs, both at our university as well as others. One student completed his Honors thesis in dynamics. Most students explicitly stated that this course was their motivation for advanced studies.

Student Performance in Later Courses

1. Performance in graduate structural dynamics course:

One of the motivating factors for switching to the new course rather than traditional undergraduate dynamics was the performance of students in the graduate structural dynamics course. Students struggled with the concepts and complained that it had been too long since they have seen and used the necessary mathematical concepts required, such as differential equations. We are now seeing students who had taken the undergraduate course in dynamics and vibrations who are now in graduate school and enrolled in the graduate structural dynamics course. The table below shows the average grade point averages for three different groups: (1) the entire class, (2) all students who had taken any vibrations based dynamics course (including ours), and (3) only those students whose prior exposure to dynamics was our course when they were an undergraduate. As expected, prior exposure to the topic improved their performance. The second group includes two Ph.D. students who had taken a graduate dynamics course and, as expected, have the best performance in the course. However, the students whose only exposure was our course also performed extremely well. The students who had no prior exposure to the material floundered, with 5 of them earning C’s.

Table 5: Breakdown of Student Performance in Graduate Structural Dynamics.

	Entire Class	Taken a Vibrations Course Before	
		Any Previous Course	Our Course
Number of Students	30	7	4
Grade Point Average	3.30	3.86	3.75

Conclusions

Based on these results, the course content, structure, and learning activities lead to improved student motivation and performance. Not surprisingly, students do not value the writing component of the course or its contribution to their learning. What students valued most were interactive problem solving and discussion in class. Even the high ranking of class presentation is partially due to the fact that it includes those components, as well as the demonstrations of physical models. Even teamwork was ranked higher than homework.

At the end of the course, when asked to reflect on what they had gained, comments now include:

> "More problem solving techniques, taking what I know and applying to a problem that I have never seen or thought of working."

Additionally, some do begin to enjoy the material, as evidenced by comments such as:

"I truly enjoyed the course and loved learning about dynamics of structures."

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