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Developing a Dynamics and Vibrations Course for Civil Engineering Students Based on Fundamental-Principles

LUCIANA R. BARROSO

and

JAMES R. ("JIM") MORGAN
Zachry Department of Civil Engineering
Texas A&M University
College Station, TX

ABSTRACT

This paper describes the creation and evolution of an undergraduate dynamics and vibrations course for civil engineering students. Incorporating vibrations into the course allows students to see and study *real* civil engineering applications of the course content. This connection of academic principles to real life situations is in itself a critical learning stage for the students, and addressing the creation of these connections led to the incorporation of active demonstrations into the course. The course also focuses on developing skills through various active learning strategies that can be transferred to other non-structural engineering courses, such as problem solving and critical thinking, as well as ABET skills such as teamwork and the utilization of computer tools. This paper presents how designing a course structure and implementation with the explicit consideration of developing these critical skills aids students in mastering both course content and in enhancing their educational development. Results of increased student performance due to the synthesis of strategies incorporated into the course are presented, including performance in a later course as well as in the dynamics portion of the Fundamentals of Engineering exam.

Keywords: dynamics, vibrations, active learning, project-based learning, cooperative and collaborative learning, real-world connections, learning communities

INTRODUCTION

Progressive faculty see dynamics and vibrations as a unified body of knowledge built upon a very limited number of basic equations and principles. Nevertheless, thanks in part to the traditional approach for teaching introductory dynamics, many undergraduate students see dynamics is a collection of tricks, one for each type of specific problem. It should be no surprise that *problem solving* is seen by the students as a search for a similar example problem and/or the magic formula that will give an answer. Given this approach to dynamics, it also should be no surprise that students dread and dislike the course, the material, and by extension the faculty who teach the course. Most introductory textbooks for dynamics courses *"customarily downplay the pervasive nature of differential equations as dynamics natural language* [1]." It is not surprising that civil engineering students do not see the relevance of the material or its connection to civil engineering since almost all examples are rooted in mechanical engineering. As a result, civil engineering students traditionally view the undergraduate dynamics course as a weed out course that is totally unrelated to their major, and they do not see vibrations until graduate school.

A basic goal of this course is to help students perceive dynamics as tool for evaluating an ever changing world. That they do not is particularly troubling to faculty in earthquake engineering and controls areas of civil engineering, but it is also troublesome in teaching the capstone design class. While it is true that most code based load calculations are in terms of *equivalent static* procedures; it also is true that understanding dynamic behavior allows students to recognize the applications and limitations of these procedures. The basic principles also provide a foundation for non-structural engineering content, such as fluid dynamics, and as such are not limited to any one area of civil engineering.

Striking real-life visual demonstrations can also be used to reveal theoretical phenomena. Imagine the reaction of a group of students in a fluid mechanics course without a laboratory (and no demonstrations, videos, etc.) to the concept of a hydraulic jump. Some very fundamental things do not make sense without seeing them, no matter how many times the equations are derived, or how many hands are waved. Theory is a description of physical behavior and it rarely exists without the observation from the physical world. In much the same way, the concepts of resonance and mode shapes seem like mathematical tricks until or unless the physical behavior is demonstrated, experienced, and confirmed. Until they become physically real in the minds of the students, such phenomena are but magic, or at best mathematical tricks (whether elegant, neat, or cool).

The traditional path within civil engineering is to have particle dynamics in physics, followed by a course in rigid body dynamics in engineering. Originally, Mechanical Engineering developed a sequence of dynamics and vibrations courses for their students that included Mechanical 363. The course was preceded by particle dynamics in physics as well as a course combining statics and particle dynamics. The course was then followed by a course dealing with topics such as: Control of dynamic systems; Feedback control; Time and frequency domain analysis; stability; PID control; root locus; and implementation of computer-based controllers, control of dynamic systems; feedback control; Time and frequency domain analysis.

This mechanical engineering course sequence was adapted into a single course in dynamics and vibrations for civil engineering students (initially numbered as Civil 489 before getting the official number of Civil 363), preceded only by particle dynamics in physics and a course in statics [2]. The course emphasized model development and "covering" the following broad topics: (1) dynamics of particles, (2) vibration of a particle connected to the world by springs and dampers, (3) dynamics of a rigid body, (4) vibration of a rigid body connected to the world by springs and dampers, (5) vibration of multiple particles and connected rigid bodies. In order for the content to fit within a one-semester course offering, rather than trying to present a broad and superficial coverage of the above topics, the choice was made to focus on specific cases and emphasize depth of mastery. So under the dynamics content, the emphasis was on the development of the differential equations and the response of select fundamental cases. The specific response cases considered were: free vibration, harmonically forced vibration (from directly applied harmonic forces and unbalanced loads), and numerical solution to arbitrary forces in real civil engineering structures such as ground motions.

Our students now take particle dynamics in physics, followed by a course in statics and this new course in dynamics and vibrations. The focus of this course is on 2nd order ordinary differential equations (ODE) descriptions of the dynamic behavior of physical systems with examples drawn from the area of expertise of the specific instructor for a given semester. The examples used in the course are mostly structures examples when taught by structural engineering faculty; they would be mostly fluids when taught by a water faculty and mostly traffic flow if taught by a transportation faculty.

The outcome for students in this course is to be able to use first principles to model, predict and evaluate the dynamic response of civil structures. The overall problem-solving progression emphasized in this course is to: (1) Identify the real physical system (e.g. building) and loads (e.g. earthquake); (2) create a simple physical model of the system that captures the key behaviors utilizing masses-springs-dashpots; (3) develop mathematical models that represents the physical behavior and loads; (4) find mathematical solutions representing the dynamic response; (5) utilize mathematical solutions to simulate and evaluate the dynamic motion of simple physical model; (6) evaluate the dynamic motion of real physical system. This structure allows students to see connections to earthquake engineering, wind engineering, and dynamics of offshore structures (eliminating one source of student resistance to the topic of dynamics).

COURSE DEVELOPMENT AND DESCRIPTION

One of the challenges in developing and teaching this course is its heavy reliance on pre-requisite material. This material covers a wide breadth and comes from courses in several different departments and different semesters in their education. While instructors clearly see the link and progression from first-semester physics and calculus through the coursework sequence into engineering science and vibrations, most students don't see the direct relevance of that material to future engineering problems and consider lower-level courses solely as weed-out courses to be survived. As a result, that material is frequently forgotten after the final exam, and the knowledge transfer to dynamics principles is compromised. Though the issue is by no means limited to dynamics courses, the 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 further complication is that dynamics requires that students synthesize the material from many diverse courses (such as differential equations, numerical methods, physics, and strength of materials) to tackle new problems. Synthesis is a challenge for even the best students, as it requires deeper levels of learning and mastery than most other activities. Instructors need to help with the process and guide students through knowledge integration and synthesis. Instructors also need to design learning sequences targeted at developing skills in problem solving and critical thinking. Gains made in these skills will aid in the development of the synthesis process and vice-versa, ideally creating a feedback loop that results in overall educational development.

The potential for the skill development described above and the connection to real civil engineering applications were essential criteria for selecting course topics. Topical content was chosen to provide a basis for the skill development described above and to connect the learning to actual civil engineering applications. Additional goals were to provide motivation for the students and to begin developing the skills to translate theory into practice. The breadth of the dynamics and vibrations field is extensive, and instructors never suffer from a shortage of topics. Focusing on a critical subset of topical content and ensuring student learn those topics well should also allow them to pursue those topics not explicitly covered on their own. This course design fits naturally with the goals and outcomes specified by the Accreditation Board for Engineering and Technology (ABET), which additionally consider such skills as teamwork and the application of computer tools to solve engineering problems.

Guiding Principles for Course Design

The course is based on the application of fundamental principles, such as Newton's Laws and Conservation of Energy, combined with knowledge of differential equations to "derive" the governing equations of motion (EoM) for a system, whether starting from a "free-body" diagram, or from energy methods. Once the governing EoM is determined, the response equations are then the solutions to differential equations. The solutions can either be found through exact methods from their differential equations course or from the application of numerical methods. This approach is valid for a wide range of problems given its foundation on basic principles. This contrasts sharply with traditional dynamics textbooks and courses that provide a "toolbox" containing a vast array of special purpose formulas that are customized for each type of problem that might be encountered. The "pick the correct formula" approach can work for students accustomed to memorization as a strategy for academic success. However, it does not necessarily result in more than perfunctory solving of routine problems, and often results in a superficial understanding of the content. The new course also presents the students with a dynamics toolbox, but this toolbox contains only a few tools. Some of these tools are fundamental principles; some of them are common assumptions; some of them are skills; and ***very*** *few* of them are formulas!

The incorporation of ***skills*** is as important as topical ***knowledge,*** a fact recognized by the Accreditation Board for Engineering and Technology (ABET) in their outcomes. While knowledge of math, science and engineering is critical, the ability to **apply knowledge of mathematics, science, and engineering**; and ability to **identify, formulate, and solve engineering problems** are equally important, and no less important are the **ability to analyze and interpret data** and **a recognition of the need for, the ability to use the techniques, skills, and modern engineering tools necessary for engineering practice,** and **an ability to engage in life-long learning** [6]**.** Knowledge is virtually unimportant without the ability to use and apply that knowledge.

In designing the course, explicit statements of learning outcomes, including both topical knowledge and skills, are used to drive the "teaching" and to facilitate the "learning." Students should know what to study, as well as what types of problems they are expected to solve, and the skills they will be required to master. While topical content is easy to list in the syllabus, and students can readily find the topics in a textbook index or table of contents, the skills being developed are frequently not explicitly addressed. Students need to be reminded frequently that they are developing critical skills, and how well they master these skills is part of how they are assessed. When students complain that a problem is "tricky" or complex, they are focusing on their perception of the knowledge covered by the problem. It is up to the instructor to remind them that the complex problem is evaluating not only their knowledge but also their problem solving and critical thinking skills. This skill development, of course, cannot happen only during an exam – it must be integrated into all course experiences, from in-class activities, through homework assignments, and into exams.

Designing Course Topical Content

One cannot add to a course without removing something as the resources are limited, particularly in terms of time available for both faculty and students. In order to choose what topics and skills will be included in the course, instructors need to focus on the learning outcomes and be brutal about the decisions being made regarding what to include in the course. These choices cannot be made in isolation and must consider courses downstream as well as the future academic and professional paths students are most likely to take. The decisions must consider both the required topical knowledge as well as engineering skills that will be required in the future. For this course, the choices were made easier by deciding to emphasize a ***few*** fundamental principles; in addition, class time focuses on:

- Solving problems that connect to relevant *civil engineering* content, so that relatively little time is spent on mechanisms or rotating coordinate systems that are more critical for mechanical engineering students. The time that is spent on these topics leads toward such relative motion problems as rotating unbalanced mass shakers; ground motion; etc.
- Developing a simple idea that is needed for a more complicated concept that can be connected to civil engineering practice

Care must be taken to make connections to civil engineering applications explicit to the students. For example, tuned-mass dampers and control systems used in earthquake engineering greatly expand the list of relevant "mechanical engineering" problems with applications to civil engineering applications. While this is obvious to course instructors, students will not see the connection unless it is made explicit and frequently reinforced by the instructor.

Resources

Finding a single textbook to fill the needs of this course is extremely challenging, as material coverage ranges from basic particle kinematics to rigid body vibrations. Relatively few introductory dynamics textbooks include significant coverage of vibrations; the coverage they do have is relegated to the end of the book and treated in a highly superficial manner. The one major exception to this trend is a textbook by Dr. Childs titled "Dynamics in Engineering Practice" [7] that starts after particle dynamics and focuses on a thorough introduction to vibrating systems as well as introducing rigid body dynamics. The drawback of the book for use with civil engineering students is its focus on mechanical engineering applications. This requires that instructors develop supplemental handouts that require time to prepare and to "debug." Also, as the book assumes prior knowledge of particle kinematics, that material must also be supplemented either through a second textbook or the development of additional notes and handouts.

The instructors also developed several examples with detailed portfolio examples available online to the students. These examples serve to reinforce approaching problems from basic principles, comparing alternative solution approaches for the same problems, and providing a focus on civil engineering applications and approaches. Making these examples available to the students runs the risk of students using posted solutions as yet another "template" to be memorized. Instructors must take care from the very beginning to present a wide variety of problems to make it clear to the students that while the fundamentals are broadly applicable, memorization will not work as a "crutch" to get through the class.

Instructor preparation for the course is significantly different than for a traditional lecture format course. Traditional notes that are developed for lecture are now compiled as supplementary notes for the students, so that time is not eliminated. Additionally, selecting the best class problems to highlight topical knowledge as well as to develop the needed skills is not insignificant. The development of problem solving and critical thinking skills needs to be explicitly considered in the problem selection as well as in determining how to approach the class interaction. As students are to be actively engaged in the solution process of in-class problems, it can be extremely difficult to predict how long it will take to solve any given problem. One approach is to focus on only one problem during a class hour, allowing the students to fully explore all the different choices possible in approaching the problem as well as allowing them to make mistakes and guiding them through identifying the problem when impossible answers result. If this approach is taken, a frequent student complaint is that not enough examples were provided, requiring supplemental examples to be posted. Alternatively, the instructor can tackle multiple problems but only focus on specific parts of the solution approach or only one solution strategy. If this approach is taken, the fully worked-out solutions should be made available as students can be thrown into confusion if they haven't seen the solution from beginning to end.

An artifact of the changes made to this course has been that more students come to office hours to master the course material. Also, more students stay at office hours as long as you let them. Office hours then changes from the case where a student comes to a few specific questions to one where groups of students are present working through the course material. As a result, interactive learning is also a characteristic of office hours, where the instructor can answer a specific student question or a question for an entire group of students. Even the questions raised by a single student benefit all students present. Also, as students help one another with the material, it optimizes the instructor time to those issues that are most critical to most students. It is important that students quickly realize the instructor is not simply going to tell them what to do to solve a specific homework problem. Rather, the same types of guiding questions used during class time occur during office hours. And when weaknesses in understanding become clear, this provides the perfect opportunity to re-teach the material.

PEDAGOGICAL APPROACH

A critical step in designing the course is the identification of the issues students have with the course, as well as the skills that students need to be developing at this stage of their academic career. The following issues have been identified as underlying the difficulties most students have with this specific course:

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

The above issues are fairly common in most analytical engineering courses [8], indicating that the core pedagogical strategies to be used are also applicable to various different courses. 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* [9]. 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 by Galileo [10].

A critical component of the class is the active engagement format utilized throughout the course [11]. This approach emphasizes encouraging students to accept/take possession of their learning and allowing instructors to move toward the role of facilitator during the learning process [12-13]. Research has shown that the learning process of most engineering students is enhanced when students [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**).*

The expectation is that everyone comes to class prepared to actively engage in the learning process. It is critical to clarify to the students this expectation; just stating that they need to "come prepared" is frequently not sufficient as they are more comfortable/familiar with being observers in the classroom. As a result, during the first couple of weeks of the semester, the instructor should remind the students that the students need to have completed all assigned reading as well as reviewed the class notes before the start of the next session. If material from other courses is about to be incorporated, a reminder to review that material is also useful. In order to emphasize the importance of being prepared, Readiness Assessment Tests (RATs) can be given over material not previously discussed in class as long as it was in the reading assignment or the homework assignment. It is critical that the material have been announced and made available to the students a minimum of 24 hours before class time before holding students accountable for the material.

The class is structured to allow for students to spend significant time working on examples and problems during class. Two hour long class periods are scheduled, resulting in 4 contact hours for 3 credit hours. This additional contact hour per week relieved the pressure to squeeze in examples and demos and class discussions into the course and ultimately led to the freedom to turn the class into a learning laboratory – i.e., the instructors supplement lectures with anything that might improve learning outcomes AND empower the students to help identify their learning needs. Used as a part of an active, inquiry based classroom, talking about misconceptions will be as natural as talking about learning styles or the fundamental principles in the syllabus [15]. The better students understand their own learning, the more successful they are likely to be [16]. Additional details of how active problem solving is utilized in the course are given in the section below.

The longer contact time with the students also allows for the use of active demonstrations as a means to connect conceptual material to their real-life application. The demonstrations and active experiments described in this paper constitute an approach that keeps most students in a "minds-on" mode. Providing students with an opportunity to become actively engaged through the prediction of outcomes 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 [17].

The demonstrations are further enhanced through explorations performed via computer simulations of dynamic responses. An educational software package, dConstruct (formerly Tinker), was developed for the purposes of allowing students to explore the dynamic behavior of the simple vibrating systems they analyze in the course [18]. Students can quickly explore the impacts of changing variables on the final system response. Additionally, as plots are generated in time with simulation, a more obvious link is visually created between the mathematical descriptor (the plot) and the vibrating system response. A critical lesson learned through the development of the software was the extremely low student tolerance for beta-testing the software. When originally demonstrated, the student interest was extremely high. However, when asked to utilize the software while still under development students were extremely resistant and unhappy with the process. They indicated extremely high expectations of the software, expecting it to be professional and polished before they were willing to use it.

Interaction in class

Active interaction and cooperative learning during class time are two of the active learning strategies utilized in the course. The students are asked to engage both with the whole class as well as with small groups to tackle different problems or questions posed by physical demonstrations. When working with the class as a whole, the instructor's role is to pose questions to the class, encouraging multiple approaches and theories to be presented and discussed. The questions probe the students' knowledge and skills, as well as ask them to frequently evaluate the choices being made. While the basis of active questioning is the same, it resolves itself into three different problem-solving activities that must all occur at different points of the course. These activities are:

1. Model problem solving: The instructor works through a problem highlighting assumptions, options, paths not taken, etc. The process of highlighting options can be as straightforward as a statement of "I am making this assumption because…" or it can also take the form of asking the students "how much do you think friction will impact this problem? Does it seem reasonable to neglect it?" This approach can be very similar to traditional "example" problems in a lecture; however, there is much more emphasis on why steps are taken or not taken, as well as on how to self-check answers along the way.
2. Guided Problem Solving Student Template: http://advances.asee.org/vol03/issue01/media/09-media02.pdf The instructor engages in interactive problem solving with the class. At each step of the problem, the instructor stops and asks the class:

   What do you know? What do you need to know?

   What concepts/approaches could be applied to this problem?

   (Energy conservation, Conservation of momentum, Newton's laws, etc.)

   Which concepts/approaches will work best?

   What comes next?

   What options do we have?

   What assumptions are we making?

   How do you know if your answer is reasonable?

   This approach leads to strong resistance from students who want to do pattern recognition ("can't you just tell us the correct approach to solving this problem"). One of the least popular strategies is to let students choose what to do next and for the instructor to demonstrate what happens if we do that even if the choices are incorrect. If this approach is taken, it is important to go back and discuss with the class how they could have identified that an incorrect choice was made and emphasize that this skill is part of what they are learning in this course. Additionally, it can be extremely helpful to illustrate two competing options for solving the problem so as to highlight advantages and disadvantages of different approaches.

3. Group problem solving: – A common problem is posed to the entire class, but the students are asked to work on the problem either individually or in small groups. Depending on the stage of the course and the class comfort with the material, a small discussion about how to tackle the problem might take place with the class as a whole, where main considerations and theories applicable are identified. As the students work, the instructor, TA and Peer Teacher interact with individual groups and/or students as they attempt to solve that problem. The primary role of the instructor, TA, and Peer Teacher in this approach is to ask essentially the same questions used when engaged in guided problem solving, with the addition of asking the students "Why did you do that?"

In all three cases, the goal is to engage students in critical thinking throughout the problem solving process. Though repeated applications of the methods outlined above, we hope to break the students of the cycle of memorizing and relying on pattern recognition, instead depending on learning a few fundamental principles to guide their approach to problems. The best students will realize that the instructor is facilitating learning "by making them think through the problem;" whereas the less dedicated student will say: "I had to learn it by myself." Emphasizing the skill development objectives of the course can mitigate the later, but some resistance from students will probably always occur. Our goal is to make it possible for them to learn the material however they may later describe the experience.

Project-based learning

Project Based Learning (PBL) is a pedagogical strategy centered on a significant realistic project. The project is chosen to be meaningful particularly to the students as it more closely represents real-world engineering, and it is characterized by a well-defined outcome, or deliverable, and an ill-defined task. As in a real-world engineering scenario, the project itself is generally information rich but the directions are kept to a minimum. The richness of the information is often directly related to the quality of the learning and level of student engagement. The information is often multifaceted and includes background information, graphs, pictures, specifications, generalized, and specific outcome expectations, narrative, and in many cases the formative and summative expectations. The process often results in the emergence of various learning outcomes in addition to the ones anticipated [19].

A primary goal of PBL is to engage students in real world projects through which they learn to consider the meaning and implications of the theory they are presented in a classroom setting. Students find these projects to be exciting, engaging, fun, satisfying, and meaningful, and through this method, they learn at a deeper level than they do with traditional teaching methods [20]. This integration motivates student learning, enhances the learning that occurs, and helps to provide a sense of the real-world by emphasizing what professionals actually do on their job; engineering professionals engage in complex problem-solving, often with multiple possible solutions, requiring careful evaluation of the strengths and limitations for each solution. PBL provides the contextualized, real-world experiences necessary for the students to scaffold their learning and build meaningful and powerful connections. PBL requires students to think critically and analytically and enhances higher-order thinking skills.

Additionally, the projects encourage the growth of student responsibility, initiative, decision making and intentional learning; cultivate collaboration among students and teachers; utilize dynamic, interdisciplinary, generative learning activities that promote higher-order thinking processes to help students develop rich and complex knowledge structures; and assess student progress in content and learning-to-learn within authentic contexts using realistic tasks and performances [21]. As the projects are based on real systems and situations encountered, they encourage students to utilize everything they know, including life experiences from outside of school. This creates vital connections for the students, both between different courses as well as real-life situations. The learning students experience is dynamic as students use various processes and methods to explore the project. The evidence in support of PBL is extensive. PBL has been demonstrated to significantly improve learning for lower achieving student groups, while also being of positive benefit to higher scoring students [20, 22–23]. A recent study at Colorado School of Mines [24] found statistically significant changes in the students' understanding of technical and nontechnical issues through use of PBL. This finding that PBL can be used as a means to broaden and deepen understanding of nontechnical issues, coupled with prior research on its effectiveness in mathematics and science education makes a compelling case for including PBL in the arsenal of teaching tools.

The project is used to enhance and connect all the different learning activities in the course, resulting in a project-enhanced learning environment that has been shown to be highly effective [19]. A typical project for this course provides the students with a preliminary structures being considered for a specific application. The student teams act as consultants to the project and are asked to evaluate the designs being considered as well as provide an additional structural alternative that may have better performance. The projects are designed to echo how an analysis project would be tackled in the "real world." The students must model the system, frequently having to consider a very simple single degree of freedom (SDOF) model and later a more detailed multi-degree of freedom (MDOF) model, and determine the resulting system response. A portfolio project takes the students from determining equivalent system properties for an SDOF system through the response under ground motion of an MDOF system. This project was based on an actual consulting job by one of the authors and has no unique solution. A key point of the projects is that the students must evaluate and interpret the results. Simply documenting the output of the analysis, showing moment diagrams, or documenting peak deflections does not satisfy the project requirements. The students must struggle with modeling questions as to how to simplify the structural system and how to capture the main response quantities. Finally, they must recommend modifications to the system to enhance the performance, without being provided explicit definition as to what is meant by "better performance." Again, the student teams must: work out what performance is important; consider both structural and non-structural issues; determine how to characterize the performance, and decide how to balance potentially opposing goals.

Active Demonstrations

The benefits of active learning can be combined with those of a traditional laboratory experience within a traditional classroom setting through use of http://advances.asee.org/vol01/issue04/02.cfm [25]. A successful active demonstration must be structured to include the following components:

- Short periods of student engagement (whether an activity, or in reflection) –alternating approximately 10 minute duration activity segments with 5 or 10 minutes question segments allows students to retain more information [26], and limit the loss of focus that accompanies the end of their attention span.
- *Self-assessment – improved metacognition by practicing–evaluating the status of their learning and their level of understanding.*

Demonstrations can occur at different stages of the presentation of material, including lectures, depending on the specific learning goals. Active student engagement throughout the entire process is a key component of an effective demonstration. Not simply passively watching a demonstration, students are involved first in discussing the purpose of the demo; then by predicting what will happen during the demo; (in groups or as a class) discussing who developed theories to help us understand what happens during the demo; and finally by comparing observations to predictions. The portions of an active demonstration include:

- **Pre-activities:** The purpose of a pre-activity is to bring misconceptions to the surface. The pre-activity is based on work done by Tobias and Everson [27]. A pre-task reflection stage, used as needed to help students gain awareness of the resources, strategies, and detail necessary to tackle a new problem, also follows work by Gamma [28]
- **Activities during demonstration:** The strategy during a demonstration follows a Chinese proverb [29]: "Tell me something, and I'll forget. Show me something, and I may remember. Involve me, and I'll understand." If you keep them engaged and invested in the learning process, they will understand!
- **Post-activities:** explicitly address misconceptions by getting them to explain. If the student

has been engaged during the previous two phases, the post-task reflection stage [28] is potentially the time of greatest learning. This reflection time allows the students to compare the steps needed, and results obtained to those explored during the planning (pre-activity) stage. They are able to explore answers to the question: "if my predictions did not match my observations, why not?"

Students made predictions and answered post-demonstration questions and discussed their observations and answers with other students. Not only does this help ensure engagement of all students (not just the handful of students who always answer questions during class); this process also is key in helping students develop metacognitive skills. Post-activity reflection must be properly structured to maximize learning gains from the process. Merely spending time on metacognitive activities before, during, and after the laboratory experience is not sufficient; the activities must cause the students to change their behavior [30].

Introducing a laboratory experience into the course in the form of active demonstrations produced overwhelmingly positive results [25]. Two types of benefits result: (1) greater enjoyment for both students and faculty, and (2) a positive learning gains. Data collected during demonstrations indicate learning during the transition from the first (often erroneous) predictions, to students identifying their own misconceptions and assumptions. If students are not asked to explain or support their predictions, they often rely on their misconceptions and make guesses. Guiding students through the cycle of prediction and analysis (central to the active demonstrations), students begin to develop critical thinking skills and transfer the knowledge from the classroom into actual applications.

Demonstrations often require additional class time spent on a particular topic, results in fewer topics being "covered" in a semester. However, coverage of additional topics is not beneficial if they are poorly grasped by the students, and if the topics are not used in subsequent courses, then lack of coverage may not detract from the course. Focus on fewer, more fundamental topics can result in improved student performance, **and** better understanding of fundamentals will improve student ability to grasp the more advanced topics.

Demonstrations can actually reduce the amount of time needed for a topic. Mode shapes and frequencies are an example of this–Originally, these discussions occurred repeatedly. Frequently, students commented that they "could do the math, but had no idea what the numbers were." After seeing the demo, the class quickly "understands" what mode shapes and frequencies represent physically. This makes the math physically meaningful and results in improved student performance. If they are not asked to think; students will simply guess, or (worse) rely on prior misconceptions. Even at the assessment stage of the process, students need to be reminded to reflect on their learning, and "what they know" before making decisions.

Learning Communities

As used here, a learning community is a group of students, faculty, and (sometimes) others with common interests; working as partners to improve the educational experience. Research has shown the success of an active learning environment greatly enhanced by learning communities [31–34]. Gabelnick, et al. [32] describe *Learning Communities* as entities which engage in "purposefully restructuring the curriculum to link together courses or course work so that students find greater coherence in what they are learning as well as increased intellectual interaction with faculty and fellow students." However, Learning Communities do not require the presence of cohorted courses and can be developed in the context of a single course. Different levels of learning communities can develop in the process:

- The class as a whole functions as a learning community, and
- Smaller sub-groups are encouraged to form as students collaborate in both in- and out-of-class activities.

Peers can provide non-evaluative feedback as well as providing social support and positively pressure. These can be particularly important for international students adapting to cultural changes. In addition to improved learning outcomes, one of the major benefits of Learning Communities for women students may be the change in the culture of the classroom. Studies of engineering and science classes have found competition discouraging for women [35-36]. Both of these studies suggest that active participation in class, class discussion, small group work, and cooperation will improve the learning environment for women. This probably results from positive interdependence instead of competitive interdependence, fostered by cooperative learning.

There are many good reasons to use student teams as an integrated part of a class, such as ABET and industry wants; however the best reasons for using a team are the social, emotional and academic support teams can provide for their members. This peer support has been identified as an important factor in student persistence in school [37]. Students from underrepresented groups, often left out of the informal networks that occur outside the classroom, benefit most from the inclusive environment that teamwork and small group work within the classroom builds.

Given all the research on student gains in collaborative and cooperative learning environments, faculty can, and should use student teams in many other active/cooperative learning activities in addition to projects [38]. A neighbor may be doing great things, sharing that in the community can drive constant improvement. Information is what drives the feedback loops that lead to new learning for all participants. Students in design courses using "active and collaborative approaches to teaching design reported statistically significant advantages" in three areas: design, communication and group skills "when compared with … students, who were enrolled in conventionally taught courses [39]." "These reported learning gains, moreover, persisted even when controlling for relevant pre-course student characteristics (e.g., gender, race/ethnicity, parents' education, high school grades, SAT scores, degree aspirations, and class year)."

RESULTS

Quantitative Analysis of Student Perceptions

At the end of the Fall 2003 through Spring 2009 semesters, the students were surveyed via the Student Assessment of Learning Gains (SALG) [40] and some semesters via student focus groups. The responses from SALG on questions specifically targeting the student's perception on learning are presented in Table 1. The students were asked to rate on their agreement to the statements in the table with a Likert scale of agreement, with ratings ranging from "Strongly Agree" (SA) to "Strongly Disagree" (SD). Not all statements were asked every semester the class was offered, so the total number of responses to each question does not remain constant, data that are also part of the tabulated results.

The mean responses for all questions lie above 4.0, indicating the majority of the students "Agree" or "Strongly Agree" with major course goals related to their learning. This is more clearly evident in Figure 1, where the results were analyzed according to the percentage of the responses falling into each category.

Semester	Number Responses	SA (5)	A (4)	N (3)	D (2)	SD (1)	Avg.
This course sets high levels of learning	927	569	327	23	7	1	4.571
Course emphasizes understanding vs memorization	927	481	370	56	16	4	4.411
Problem solving skills improved	754	353	306	72	20	3	4.308
Use of CE examples played a large enhanced my learning	928	401	385	107	29	6	4.235
Relevance of dynamics to civil engineering even if outside area of interest	584	226	254	67	31	6	4.135
I learned a great deal	927	355	415	115	31	11	4.156

Table 1: Student Perception on Learning.

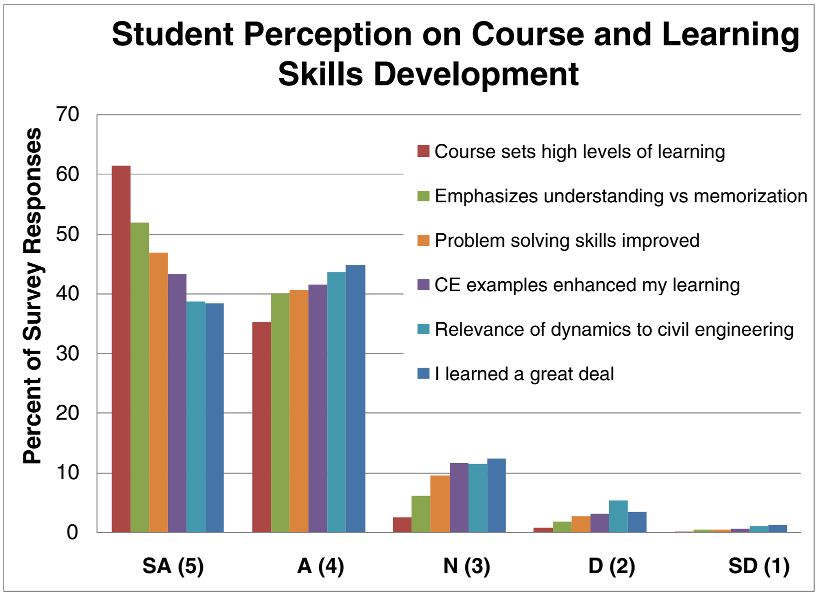


Figure 1. Percentages of Survey Responses on Course and Learning.

The student's perception of how the course met the following ABET outcomes were also assessed using the SALG instrument:

1. This class has added to your understanding and skills in applying knowledge of math, science, and engineering
2. This class has added to identifying, formulating, and solving engineering problems
3. This class has added to your skills in communication
4. This course added to your ability to use modern tools, techniques, and computational methods
5. This course has added to my teamwork skills, which was important in succeeding in the course.

The students were asked to rate on their agreement to the statements with a Likert scale of agreement, with ratings ranging from "Strongly Agree" (SA) to "Strongly Disagree" (SD). Table 2 presents data collected, showing how many students selected each rating and tabulating the numerical average weighing each response as shown. The average for four out of the five ABET outcomes lies above 4.0, where only "Communication Skills" falling below the 4.0. The distribution of the responses is shown in Figure 2, showing that all the distributions are skewed towards Agree and Strongly Agree.

Semester	Number Responses	SA (5)	A (4)	N (3)	D (2)	SD (1)	Avg.
Applying math, science and engineering	538	212	280	35	11	0	4.288
Identifying, formulating and solving engineering	538	202	286	41	8	1	4.264
Communication skills	538	67	166	224	62	19	3.372
Use modern tools, techniques and computational methods	538	164	254	94	25	1	4.032
Teamwork	538	228	223	66	19	2	4.219

Table 2: Student Perceptions on ABET outcomes.

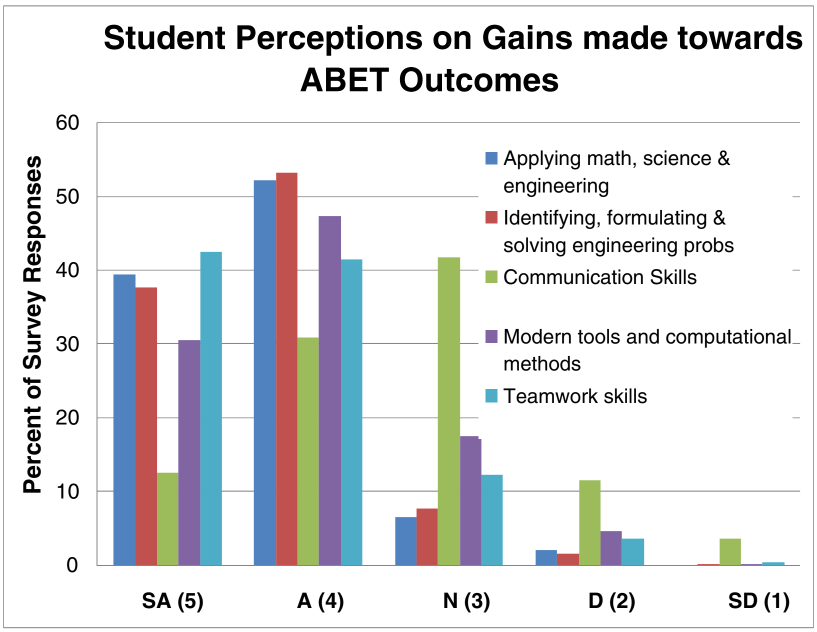


Figure 2. Percentages of Student Perception on Gains made towards ABET Outcomes.

Qualitative Analysis of Student Perceptions

SALG The student assessment of Learning Gains (SALG) instrument also contained several open ended questions, allowing the students to provide their own thoughts. Three of those questions were:

- Question 8.10 Please comment on what SKILLS you have gained as a result of this class.

- Question 10.5 What will you CARRY WITH YOU into other classes or other aspects of your life?
- Question 19.3 Any final thoughts on what you have gained from taking this course?

All data from these three questions were analyzed, using coding and then thematizing. A constant comparative method [41] was used for analysis of the responses. Emerging themes were selected, described, and analyzed simultaneously. This process resulted in the following main categories.

- Problem solving – comments particularly addressed the ability to approach complex problems, as well as how to evaluate various different approaches to the problem
- Dynamic concept – includes any specific dynamic topic such as deriving equations of motion or determining the system response
- Personal development – includes development of time-management skills, confidence, and enhanced work-ethic and responsibility
- Metacognition – responses that state a better understanding of the big-picture surrounding the course material and problems, including knowledge transfer and applicability to real life situations, as well as an enhanced understanding of their own learning process
- Study skills – some responses specifically state study-skills and knowing how to better prepare for challenging courses and to understand the material rather than just to pass the exam
- Computer skills – some responses mention computer skills while others mention specific software packages by name (e.g. Excel and MATLAB).
- Basic Process Skills – comments in this category include pattern recognition and better time management and test-taking skills.
- Critical thinking
- Teamwork
- Analysis skills,
- Self awareness
- Technical writing

Not all surveys included responses to the open-ended questions. Out of all the surveys collected, 81% percent of them included responses to those three questions. Some of the responses included multiple themes and were coded accordingly. Some responses explicitly stated 'none' for a response and are coded in that fashion. Surveys without any response are not included in the percentage calculations. Figure 3 presents the result of qualitative analysis of the open-ended responses to the three key questions.

As expected, depending on the specific wording of the question, the concentration of responses on any given theme varies slightly. For example, when specifically asked about skills gained in the course, "Computer Skills" is one of the highest ranking themes in the responses. However, when

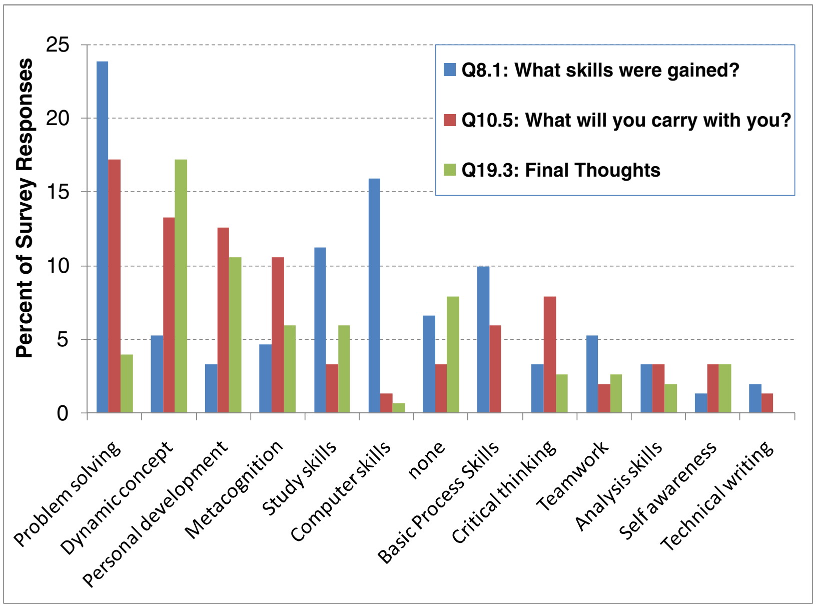


Figure 3. Open Ended Responses to Individual Questions.

asked what they would carry with them into other courses or their profession, computer skills appear significantly less important. This presents an interesting insight into the student's perception of how useful computer skills are to their profession. In contrast, problem solving repeatedly appeared in all three questions. This is directly related to the emphasis placed on understanding complex system and multiple approaches to problem solving.

Figure 4 presents the results of the analysis of the combined responses for all three questions. The foremost theme in the responses is "Problem Solving Skills", even ranking ahead of "Dynamic Concept," which is the course title. When students are typically asked what they learned in a course, they will most often state the course title or list the topics in the course syllabus. This result is particularly striking in an upper level course. At this level, most new material lies in the topical content (in contrast to lower level courses with significant student effort devoted to skill development).

A. Student Performance in the Course

1. Overall Historical Grade Distribution

The undergraduate dynamics course has a reputation as a "weed-out" course, and student myths include such things as: 1) "no one passes this course the first time" and 2) 'the prerequisite to this course is previous enrollment in this course a prior semester'. These myths have been documented

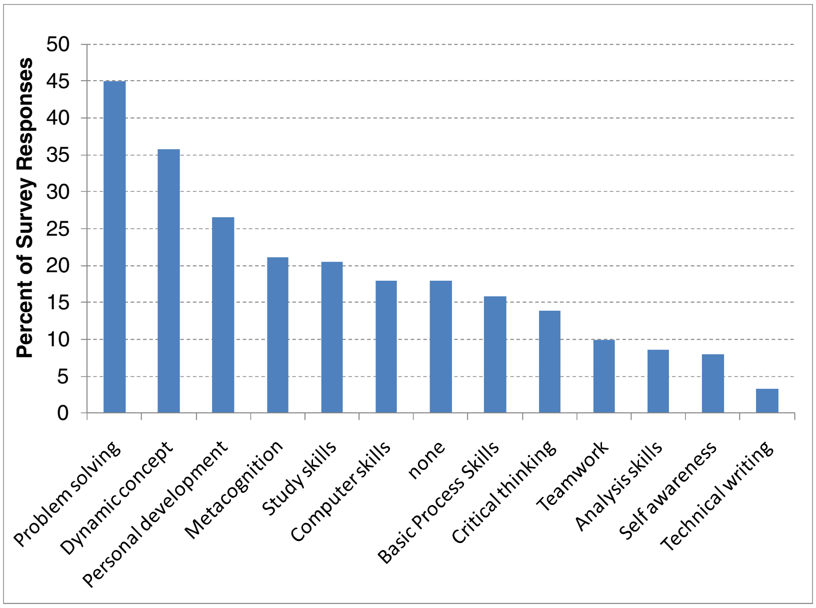


Figure 4. Open Ended Responses Total.

through conversations with students as well as comments in the student surveys and course evaluations. As can be seen in Figure 5, the rumors are greatly exaggerated. The data shown in Figure 5 includes all civil engineering student enrollments in the course, including Mechanical 363 as well as Civil 363 temporarily numbered 489 before getting the permanent 363 number, between August 2001 and December 2009. This number is greater than the number of individual students who enroll in the course as some students enroll multiple times. In fact, nearly 90% of first time students "successfully" complete the course on the first attempt. Civil engineering students are required to retake courses with grades below "C," other majors in the course (approximately 10%) can satisfy degree requirements with a "D." As a result, often, non-civil engineering students settle for a "D;" effectively reducing the "D's" and "F's" received by civil engineering students to levels significantly below those shown in Figure 5. The data shown also includes students who dropped the course by week 10 of the semester, indicated with a "Q." The 'other' category includes students who withdraw for medical or other extreme personal circumstances.

All semesters are not created equal. Grade point averages appear to be affected most by the grades in the previous semester. The typical pattern is:

- A semester of acceptable grades followed by plummeting grades (perhaps following logic such as "everyone says the course is hard BUT the grades last semester (available on the university

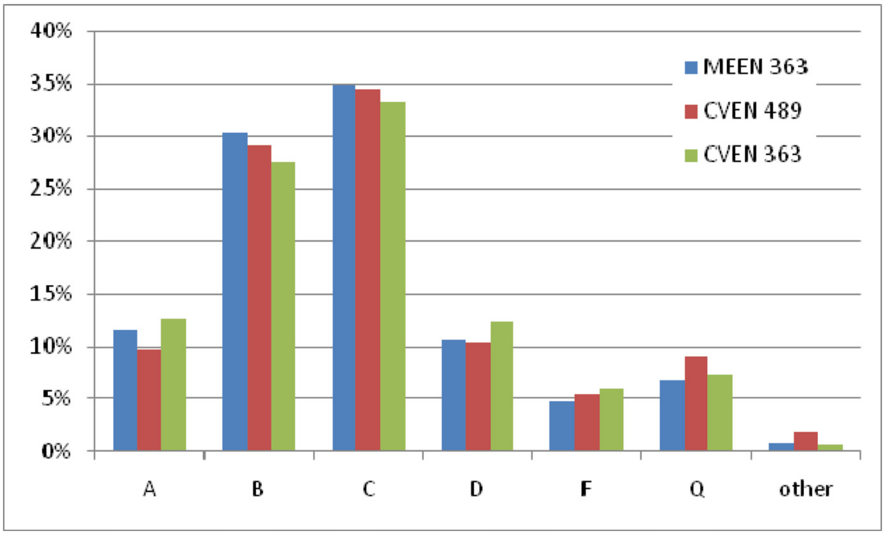


Figure 5. Grade Distributions for Course Under Different Names.

website) were not so bad; besides, I know those students and they are not any smarter than I am")

- Once GPA approaches (or drops below) 2.0 ("OMG I might have to take this course again if I don't work really hard") the grade point average increases; but
- If the GPA increases too much the pattern continues ☹.

Since our department requires a "C" (2.0) or better in all required classes, there are a larger number of students repeating the course in a semester following a low GPA. One would expect that such a class might actually do worse; but the opposite always has been the case. An explanation of this phenomenon could be that the repeating students were not less capable; rather they were less willing to work in their first attempt. In this case, their presence in the class could be a very positive thing – telling other students that "they" really are serious, validating instructor comments on what is "needed for success", etc. Evidence supporting this conclusion comes from conversations with students, both individually and as a group during the first week of classes, as well as comments in the student surveys and course evaluations.

Performance on Final Exam

The final exam is not returned to students, so some of the same questions can be reused multiple semesters. Standard question format includes a section of basic multiple choice questions as well as a section with two or three work-out problems. As partial credit is not possible in the multiple choice section, the point system is set-up such that the student need not answer correctly every single multiple-choice question and still potentially make a perfect score on the exam. The questions from this portion of the exam focus on the understanding of the basic concepts and problems of the course, from simple kinematics problems regarding projectile motion, basic impulse-momentum, and simple response of single degree of freedom vibrating systems.

The historical trend in the number of re-used multiple choice questions answered correctly is presented in Table 3. While the absolute value of the performance is low, the trend shows a noticeable improvement over time as different pedagogical elements were incorporated into the course. This improvement is due to the continuous improvement and introduction of different learning experiences for the students. As the exams are not returned to the students and no notes are allowed to leave the final exam and new multiple choice questions are added to the reused ones, the improvement in performance cannot be attributed to students knowing what the problems on the final will be. The low numerical value is also not as shockingly surprising given the nature of the questions being asked. The multiple choice questions focus on basic concepts and include both simple problems as well as conceptual questions. While the number of total questions changes, the balance between the two types of questions remains about the same. Students notoriously struggle with basic concept questions. Overcoming student misconceptions are extremely difficult to overcome, as has been illustrated by prior research projects such as seen in the documentary http://www.learner.org/resources/series26.html [42]. As such, scores on conceptual questions are typically low, as is seen in scores for various Concept Inventory exams [43–44].

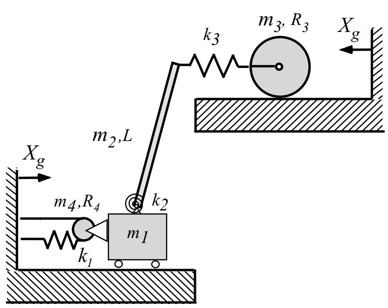
Course	Semester	Average Number of Questions Correct	Standard Deviation	Total Number of Questions	Percent Correct
MEEN 363	04c	4.54	3.13	11	41.3%
	05a	4.79	2.79	11	43.5%
	06a	5.47	2.11	12	45.6%
	06c	5.96	2.21	14	42.6%
CVEN 363	07a	4.98	1.62	11	45.3%
	07c	6.03	1.71	11	54.8%
	08c	6.33	1.34	12	52.8%
	09a	7.58	1.54	12	63.2%

Table 3: Performance on Standard Multiple Choice Section of Final Exam.

While the multiple choice section focuses on the basic concepts, the workout problems examine the students understanding of complex systems, as well as problem solving abilities and critical thinking skills. A sample final exam workout problem is shown in Figure 6. The level of knowledge and problem solving required to tackle this problem are significantly broader than what may be found in most undergraduate dynamics courses, including those that do incorporate vibrations content, such as those in Figure 7 and Figure 8. These problems focus on the development of the differential equation of motion and were taken from: http://dspace.mit.edu/bitstream/handle/1721.1/60691/16-07-fall-2004/contents/exams/final.pdf (1) an undergraduate course for aerospace engineers at MIT [45], and (2) http://ocw.alfaisal.edu/NR/rdonlyres/Mechanical-Engineering/2-003JFall-2007/AB85432A-5BCA-4450-BEC1-F57172F64DAA/0/final.pdf undergraduate course for mechanical engineers dynamics and control at MIT [46]. No similar problems were identified in undergraduate courses targeted towards civil engineering students.

All three problems incorporate the vibrations of rigid bodies and both equilibrium and energy principles are evaluated. The problems incorporate the idea of kinematic constraints as well as how to express spring forces through the relative deformation across the spring. The problem in Figure 6, however, pushes the students' problem-solving ability for complex system much further as they have several different bodies to tackle during the solution process. Additionally, the concept of total versus relative motion must be fully understood, as it impacts both the determination of the total

Work-out Problem: For the system below, the two shelves have a horizontal motion X_g, though oriented in opposite directions as shown. The disk rolls without slip on the top shelf.



(a) Derive the equation of motion for the system using equilibrium principles

(b) Formulate kinetic and potential energy expressions for this system.

Figure 6. Problem from Final Exam – TAMU CVEN Undergraduate Dynamics Course.

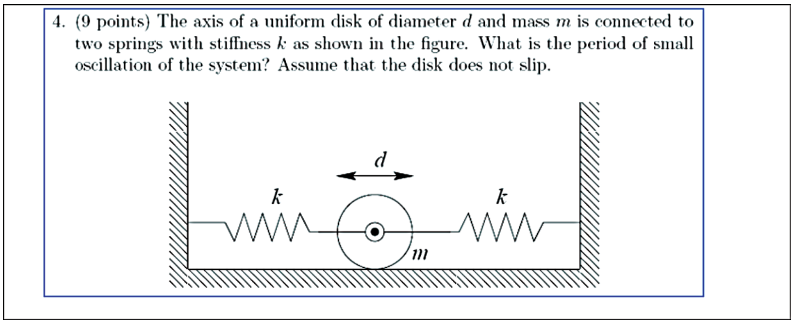

4. (9 points) The axis of a uniform disk of diameter d and mass m is connected to two springs with stiffness k as shown in the figure. What is the period of small oscillation of the system? Assume that the disk does not slip.

Figure 7. Problem from Final Exam: an undergraduate course for aerospace engineers at MIT.

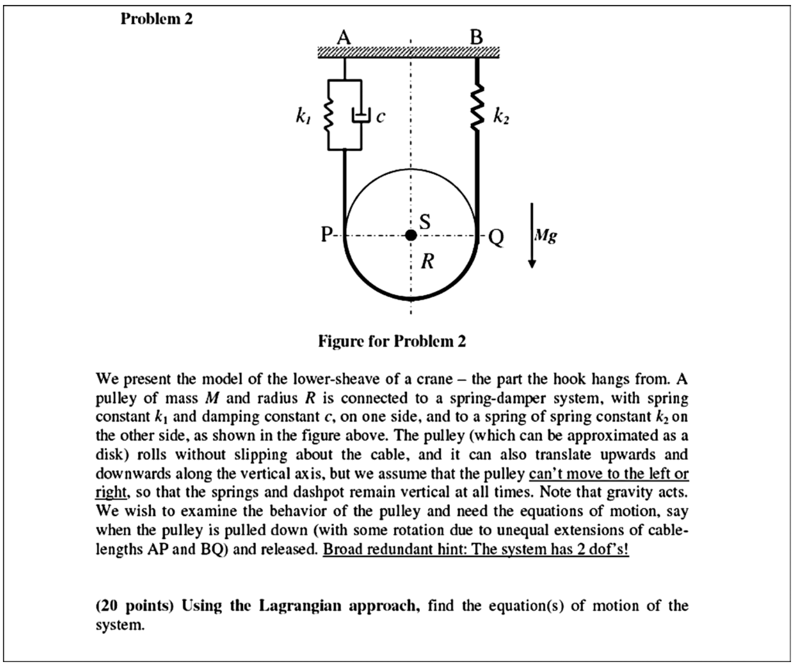

Problem 2

Figure for Problem 2

We present the model of the lower-sheave of a crane – the part the hook hangs from. A pulley of mass M and radius R is connected to a spring-damper system, with spring constant k_1 and damping constant c, on one side, and to a spring of spring constant k_2 on the other side, as shown in the figure above. The pulley (which can be approximated as a disk) rolls without slipping about the cable, and it can also translate upwards and downwards along the vertical axis, but we assume that the pulley can't move to the left or right, so that the springs and dashpot remain vertical at all times. Note that gravity acts. We wish to examine the behavior of the pulley and need the equations of motion, say when the pulley is pulled down (with some rotation due to unequal extensions of cable-lengths AP and BQ) and released. Broad redundant hint: The system has 2 dof's!

(20 points) Using the Lagrangian approach, find the equation(s) of motion of the system.

Figure 8. Problem from Final Exam: an undergraduate course for mechanical engineers at MIT.

acceleration of the masses as well as the kinematic constraints of the disk rolling on the top shelf.

Comparison of student performance on these types of open-ended problems is difficult as the topical content is significantly different in this course than traditional courses. A comparison between a final exam given in a traditional dynamics course, following a traditional format and presentation style, to the final given in this course indicated that only about 30% of the problems in the final of the new course could be attempted by students taking the traditional dynamics course. On problems that contained topical content applicable to both courses, students from the traditional course earned on average 57% of the points while students in the new course averaged 73% of the points. Furthermore, students in this new course do as well on challenging problems as students in the traditional course did on the routine problems, a sentiment which is reminiscent of a quote from Dr. W. H. Bassichis that "our students fail at problems that other students don't even attempt."

Student Performance on Dynamics Portion of the Fundamentals of Engineering Exam

Data gathered from Dynamics portion of the FE exam from April 1997 through October 2009 is shown in Figure 9. Note that October 2005 through October 2008, dynamics questions were reported as part of a combined statics & dynamics score making it impossible to extract purely dynamics question performance. These data corresponds to difference between Texas A&M University (TAMU) civil engineering students and the national average. This data are grouped in three segments corresponding to: 1) before course modifications – a traditional track, 2) differential equations-based course of dynamics and vibrations – Mechanical 363, 3) a course based on Mechanical 363 that is customized for civil engineering students incorporating the various pedagogical strategies presented in this paper – Civil 363. In Figure 9, the data is normalized by the average performance difference during the 'traditional' segment (i.e. the before Mechanical 363 and Civil 363 existed). The individual points represent each individual test offering. The data demonstrates that our students almost always perform better than the national average; only once in our time window has the performance been below the national average as shown from the single negative performance point. However, the three groups have different performance relative to the national average as shown in the figure below.

The normalized performance for students taking the exam during semesters when most civil engineering students would have taken mechanical 363 is shown in green. The primary change implemented with the mechanical 363 course is the use of differential equations for all problems and the incorporation of vibrations as a natural extension of particle kinetics,

The normalized performance for students taking the exam during semesters when most civil engineering students would have taken civil 363 is shown in red. All the basic changes from mechanical 363 were retained. The new additions include all the pedagogical developments presented in this paper plus more civil engineering examples and applications. Note that in order to add the civil engineering specific content, much of the time typically spent on the traditional dynamics questions found in the FE exam is drastically cut. Nevertheless, the average performance difference is significantly higher than for the previous groups – approximately two times better. The lack of specific data does color the potential conclusions that can be drawn. However, if combined statics and dynamics

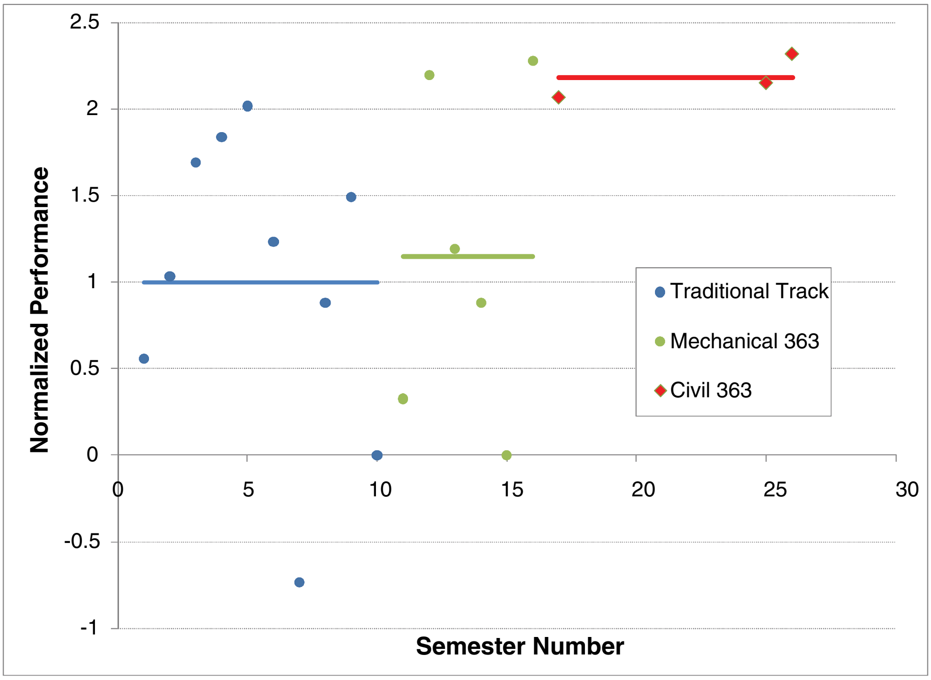


Figure 9. Normalized Performance of TAMU Civil Engineering Students on FE Exam.

data is used to "fill-the-gap" then while the scatter in the data is greater; the average performance difference also is greater at more than twice the performance of the "traditional track."

Student Performance in Graduate Courses

The impact of the course on long-term student performance was evaluated by analyzing the performance of the students in the graduate introductory structural dynamics course that is taught every fall. The graduate course description consists of: Dynamic modeling of single, multi-degree of freedom and continuous systems; frequency domain analysis; dynamic load factors; damping; modal superposition; model reduction; numerical integration; dynamic behavior of structures and structural elements under action of dynamic loads resulting from wind, earthquake, blast, impact, moving loads and machinery. While both the undergraduate and graduate courses have some similar topics, such as the development of the equation of motion and response of vibrating systems, the amount of overlap is actually small, and only about 20% of the topics in the graduate course are touched upon in the undergraduate course that is primarily focused on dynamics. Also, as would be expected from the level of the course, the level of students in the course, and the percentage of the semester devoted to vibrations in the undergraduate course, the level of mastery and complexity required at the graduate level is significantly higher than for the undergraduate course.

The students in the graduate vibrations course come from a range of backgrounds, including students from our own undergraduate program as well as from international and other US institutions. As vibrations content is typically not part of the standard civil engineering dynamics undergraduate course, most students who come from outside our program have not had exposure to that topical content. However, occasionally a student may come from a non-civil engineering background or have taken a second course in dynamics as part of their electives. Also, some international doctoral students, who have previously taken a graduate course in structural vibrations, will retake the introductory dynamics course. Depending on the student, this approach is reasonable as our course contains different methods and modeling approaches than the course they took as master students. It also provides the student with a transition to our educational system. As a result, the students were divided into four groups: 1) those with a traditional dynamics undergraduate course and no prior exposure to vibrations content, 2) those who took the TAMU undergraduate dynamics course that includes some vibrations content, 3) those who took undergraduate dynamics with vibrations content at other universities, and 4) those who have a prior graduate vibrations course.

The final course performance data of these groups are shown in the table below. The data below spans students taking the course in the fall semesters of 2004 through 2008. During that time, the course was offered by two different instructors, one of whom has never taught the undergraduate dynamics course. The overall grade distributions for all five semesters were virtually the same, with the results shown in the “Total” row of the table being representative for each semester.

While it is not surprising that students with a prior exposure to vibrations performed significantly better than students with no prior exposure to the material, it is striking that the second highest-performing group is that of the students who had the restructured undergraduate course at Texas A&M University (TAMU). This group performs nearly as well as doctoral students who have previously taken a full semester of graduate vibrations and were seeing the material for a second time with only small variations in presentation and approach. In addition to their prior exposure to the material, the doctoral students also had a richer academic background and deeper intellectual maturity. All these factors contributed to their having the best performance in the course.

These results indicate that prior exposure to the topical content improves performance. A comparison of the performance of the two groups who did have an undergraduate course with vibrations content, however, results in a significant difference in performance. The students with the TAMU undergraduate course performed significantly better than students who had undergraduate vibrations content from other programs. While the number of students in the two groups is not the same, and the smaller sample size may skew the data for the group with undergraduate vibrations at another university, the results indicate that the familiarity with the basic course material is not the only source of improved performance. The depth of mastery and problem solving abilities expected in the TAMU undergraduate course is typically much higher than what is normally expected from other undergraduate programs, as previously illustrated in Figure 6 through Figure 8, play a significant role in the student's ability to tackle the graduate level course material. Additionally, the experiences with tackling realistic projects naturally support the self-directed learning that is expected at the graduate level.

SUMMARY AND CONCLUSIONS

This paper describes the creation and evolution of an undergraduate dynamics and vibrations course specifically designed for civil engineering students, allowing students to see and study real civil engineering applications of the course content. This connection of academic fundamental principles to real life situations is in itself a critical learning stage for the students and has been shown in the literature to increase student motivation and interest in the course. The utilization of real problems also allowed for explicit connections to be made between theoretical models, whether math or physics based, to real physical systems. Creating the connections between models and theory allows for students to critically analyze answers. These connections also provide scaffolding and create a larger knowledge framework for students to build on in the future [9]. The use of fundamental principles, such as Newton's Laws and the use of differential equations, allows for the course to have a strong unifying core for all problems approached. Rather than treating vibrations as a separate topic, kinetics principles are covered as a cohesive unit that utilizes the same principles and skills to solve problems.

Achieving skill development and topical knowledge were equally important objectives in the development of the course. Explicitly addressing skills as well as topical course content is not a trivial undertaking and is not simply a matter of adding outcomes to the course syllabus. It requires that both instructors and students be willing to go outside their comfort zones and explicitly consider outcomes that are otherwise just assumed to occur, such as the development of problem solving skills. Various active learning strategies were utilized to integrate both course content and skill development for the students. The use of collaborative learning, active demonstrations, and project-based learning all came together with real-world applications to provide the framework for educational development for the students. These strategies require that the instructor select every example and assignment with the goal of explicitly developing the needed skills as well as providing exposure and practice with the topical course content. Students must be willing to come to class willing to work and make mistakes in front of their team members and instructor. It becomes important for the instructor to provide an environment for students to fail safely, and it is helpful to frequently remind the class that this is part of the process.

The course was developed so as to have an explicit focus on the development of skills that can be transferred to other structural and non-structural engineering courses, such as problem solving and critical thinking. Throughout the evolution of the course, students were asked to tackle more complex and difficult problem, resulting in the complex final exam problems such as the one in Figure 6. Explicit consideration on how to develop those skills, as well as openly discussing skill development with the students, resulted in students identifying those skills as the skills most enhanced by the course, as well as the skills most likely to be used in the future. The explicit consideration of ABET outcomes also led to a clear integration of such skills as teamwork and the utilization of computer tools into the course, and the students perceive that those skills improve as a direct result of the course [Figure 2 through Figure 4 and Table 2]. While teamwork and computer usage is used in many other courses in any engineering program, in order for them to be fully developed requires as much planning as is typically given to topical presentation and flow.

Significant gains were made not only in skill development but also in content mastery. This is clearly demonstrated by the improved performance in common final exam multiple choice questions as the course developed and different interventions were integrated into the course [Table 3]. Also, the level of work-out problems being tackled by the students is very high when contrasted with what is typically found at the undergraduate level, requiring a corresponding level of knowledge and problem solving skills [Figure 6]. The level of problems being solved increased gradually from the first implementation to the current version of the course. The increase in problem complexity corresponded to improvements and additions to the course, such as the introduction of active demonstrations or the refinement of the course project. The performance of these students in the graduate structural dynamics course, the next dynamics and vibrations course in the civil engineering program, clearly indicates the benefits achieved through the undergraduate course [Table 4], showing that they perform much better than other students with an undergraduate exposure to vibrations and nearly as well as students who have taken a graduate course in structural dynamics and vibrations. The results in the Fundamental of Engineering exam [Figure 9], which focuses on the dynamics content of the course, clearly indicates the improvement in student performance with the new course. This result is particularly encouraging as it indicates that the reduction of time spent on traditional dynamics does not decrease student performance in those topics when it is replaced by a cohesive pedagogical strategy.

Developing and running a course that is equally concerned with topical content and skill devel-

Student Group	Number Responses	A (4)	B (3)	C (2)	D (1)	F (0)	Grade Point
No prior vibrations	60	8	32	19	1	0	2.783
Undergraduate Dynamics with Vibrations at TAMU	68	58	9	1	0	0	3.838
Undergraduate Dynamics with Vibrations – Other Universities	17	10	6	1	0	0	3.529
Graduate Vibrations Course	11	10	1	0	0	0	3.909
Total	156	86	48	21	1	0	3.401

Table 4: Student Performance Breakdown in Graduate Structural Dynamics Course.

opment requires much time and effort from the instructors. Class time is also more interesting and fun for the instructor in an active learning environment, once the initial learning curve is overcome. No two classes are exactly the same, keeping things fresh for the instructor that may have taught the same course innumerable times. That excitement and discovery process, when shared with the students, also provide important gains for everyone

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AUTHORS

Luciana R. Barroso, Ph.D., is an Associate Professor of Structural Engineering in the Department of Civil Engineering, in the Dwight Look College of Engineering at Texas A&M University. Luciana has been with Texas A&M University for more than 11 years, and in that time has taught 13 different courses ranging from the freshman to graduate levels. She has received funding for her engineering education research from the Department of Education FIPSE program and from the NSF CCLI program. She also has been involved in several professional developments that were provided by the NT-STEM Center to Texas ISD teachers. Her research interests include structural health monitoring and control, structural dynamics, earthquake engineering, and engineering education, lbarroso@civil.tamu.edu

James R. "Jim" Morgan, P.E., Ph.D., is an Associate Professor of Structural Engineering in the Zachry Department of Civil Engineering, in the Dwight Look College of Engineering at Texas A&M University. Jim has been with Texas A&M University for more than 30 years, and has been active with the freshman engineering program for more than 20 years. He was an active participant in the NSF Foundation Coalition from 1993 to 2003 and has received funding for his engineering education research from the Department of Education FIPSE program and from the National Science Foundation CCLI program. He is past chair of the Freshman Chairs Programs Division, and was a past member of the executive board of the Educational Research Methods and First-Year Programs divisions of the American Society for Engineering Education. In addition to his teaching in engineering, Jim currently serves the Co-PI for the North Texas Science, Technology, Engineering, and Mathematics (NT-STEM) Center at Texas A&M University. He has conducted workshops at Texas A&M University, and at various other universities, on teaming and active learning. His research interests include structural dynamics, earthquake engineering, engineering education, and K-12 STEM education, jim-morgan@tamu.edu