Vibrations Education – Striving for a Resonance in Learning

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Significant innovations and changes have been made in teaching vibrations and mechanics in the past 15 years at Rose-Hulman Institute of Technology. In this article, we discuss how changing prerequisite courses and using technology has enhanced the vibrations course. We show how to effectively use tools such as Maple, Working Model, MATLAB, and Simulink and how to involve students more in the educational process using methods such as cooperative learning, plus-deltas, and readiness assessment tests.

According to the dictionary, resonance is "a vibration of large amplitude in a mechanical or electrical system caused by a relatively small periodic stimulus of the same or nearly the same period as the natural vibration period of the system."[1] Thus, a large motion can result from a very small stimulus if it is at just the right frequency; that is, at the natural frequency of the system. Is there an analogous phenomenon in learning? Do some teaching strategies result in a larger amount of learning or a 'resonance' in learning than others? How does one achieve this resonance?

According to the National Research Council report *How People Learn: Brain, Mind, Experience and School*,[2] one aspect of *effective* learning is its durability; that is, does the learning have long-term impact in the ways it influences other kinds of learning or performance? Five key conclusions were presented in this report on the concept of durability. These conclusions, translated to the context of vibrations education are:

1. Skills and knowledge must be extended beyond the narrow contexts in which they are initially learned. For example, knowing how to solve a differential equation in a math class or to formulate an equation of motion in a course on system dynamics may not translate into being able to do these activities in a course on vibrations. Thus, when trying to improve understanding in a vibrations course, it is important to consider what has happened in all the courses prior to it. In this article, the prerequisite courses to vibrations are discussed. These prerequisite courses emphasize the concepts of identifying a system for analysis and applying fundamental principles to obtain equations of motion.

2. It is essential for a learner to develop a sense of when what has been learned can be used – the conditions of application. Failure to transfer is often due to learners' lack of this type of conditional knowledge. If the problems examined in a vibrations course are always presented in the context of idealized mass, stiffness and damping elements (or looking nothing like a realistic system), then it will be difficult for students to apply the concepts discussed in the course. For many students, Vibrations is simply another course in solving differential equations. If students view the course this way, then we educators have failed. Laboratories are an excellent way of helping students develop this sense of when the material learned can be used. Design problems also accomplish this purpose.

3. Learning must be guided by generalized principles to be widely applicable. Knowledge learned at the level of rote memory rarely transfers; transfer most likely occurs when the learner knows and understands underlying principles that can be applied to problems in new contexts. When a book or instructor tells students to "use equation . . . ," then students are not relying on fundamental principles. A sequence of prerequisite courses at Rose-Hulman Institute of Technology (RHIT) were developed to focus on fundamental principles and their application.

4. Learners are helped in their independent learning attempts if they have conceptual knowledge. Studies of children's concept formation and conceptual development show the role of learners' mental representations of problems, including how one problem is similar and *different from others and understanding the part-whole relationships of the components in the overall structure of a problem.* This conclusion is also addressed in part by a sophomore curriculum at RHIT.

5. Learners are most successful if they are mindful of themselves as learners and thinkers. A learner's self-awareness as a learner and the role of appraisal strategies keep learning on target or help keep the learner asking if he/she understands. Learners can become independent learners who are capable of sustaining their own learning – in essence, this is how human beings become lifelong learners. This conclusion speaks to the role of an educator as a motivator and highlights the responsibility educators have to help our students obtain the necessary self-awareness and to take responsibility for their own learning.

Another topic discussed here is the characteristics of expert teachers. One characteristic of expert teachers is that they are sensitive to those aspects of the discipline that are especially hard and those that are easy for new students to master. This sensitivity allows the teacher to spend more time on the difficult concepts and to go through the easy concepts more quickly.

We also discuss how new technology can aid in learning; the key conclusions related to new technologies are:

1. Because many new technologies are interactive, it is now easier to create environments where students can learn by doing, receive feedback, and continually refine their understanding and build new knowledge.

2. Technologies can help people visualize difficult-to-understand concepts, such as differentiating heat from temperature. Students are able to work with visualization and modeling software similar to the tools used in nonschool environments to increase their conceptual understanding and the likelihood of transfer from school to nonschool settings.

3. New technologies provide access to a vast array of information, including digital libraries, real-world data for analysis, and connections to other people who provide information, feedback, and inspiration, all of which can enhance the learning of teachers and administrators as well as students.

At RHIT, three elements are critical in the attempt to achieve a resonance in learning as it relates to vibrations:

- Focusing on the prerequisite courses so students have knowledge and skills that they can transfer to vibrations.
- Effective use of technology.
- Engaging students in the learning process.

Although these elements were used long before I was aware of the National Research Council report, I believe they address many of the conclusions presented here.

Focusing on Prerequisite Courses

The Sophomore Engineering Curriculum (SEC). RHIT, as part of the NSF-sponsored Foundation Coalition, implemented a new sophomore curriculum starting in the 1995-96 academic year. The sophomore curriculum primarily concentrates on engineering science material that is traditionally covered in courses such as Dynamics, Thermodynamics I, Fluid Mechanics and Circuits I. Even though basic principles such as conservation of energy and conservation of linear and angular momentum are encountered in these courses, the notation and methodology often make it appear that the principles look different in different classes. Therefore, subsequent courses do not reinforce the material taught in previous courses. At RHIT, this material has been repackaged into a new

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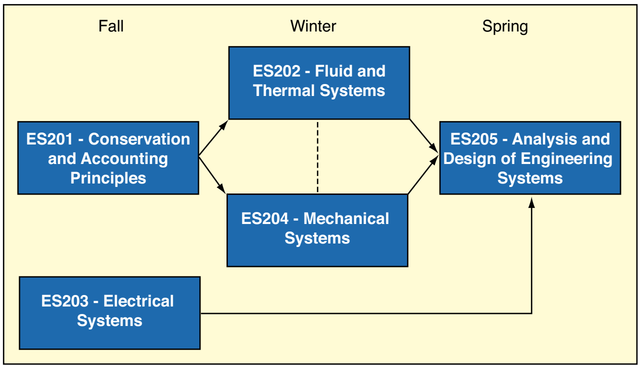

Figure 1. Summary of current sophomore engineering curriculum (SEC) at Rose-Hulman; sequence of three courses can be used since Rose-Hulman is on the quarter system.

sequence of courses called the Sophomore Engineering Curriculum (SEC), as shown in Figure 1. One purpose of the curriculum is to teach engineering science in a more cohesive and internally consistent manner. A quantifiable improvement in student learning took place when this curriculum was implemented in 1995.[3,4]

In the fall-quarter Conservation and Accounting Principles (ES201), students are taught the basic principles for both open and closed systems. That is, we discuss conservation of mass, charge, linear momentum, angular momentum, and energy and the accounting of entropy. We also teach a problem-solving methodology and homework format that is used in all subsequent courses. Electrical Systems (ES203) is also taught this quarter.

In the winter quarter, students take two courses that build on ES201. These courses are Mechanical Systems and Fluid and Thermal Systems. Here more detailed applications of the conservation principles are discussed as well as some of the additional topics required to solve problems such as properties in fluid and thermal systems and kinematics in mechanical systems.

In the spring quarter, the material is brought back into a single course called Analysis and Design of Engineering Systems (ES205), a system dynamics course in which multidisciplinary problems are studied. There is also a lab associated with this course. Since the material is distributed over a sequence of courses, it is frequently revisited and continually being reinforced at a higher cognitive level.

Mechanics in the SEC

ES201: Conservation and Accounting Principles. Topics typically covered in a traditional dynamics class are spread throughout the new sophomore curriculum and many vibrations topics appear in ES205. In the first course, Conservation and Accounting Principles (ES201), much of particle dynamics is covered as applications of conservation of linear momentum, conservation of angular momentum and conservation of energy. Approximately seven lectures discuss linear and angular momentum, and three cover applying conservation of energy to mechanical systems. One significant difference between how the material is covered in a traditional dynamics course and how it is covered in ES201 is that in ES201, the principles are applied to both open and closed systems. In dynamics, the problems typically involve only closed systems. The rate forms for conservation of linear momentum, angular momentum and energy as presented in the course are listed in Table 1. The finite-time forms of these principles are also discussed in the course.

Table 1. Basic mechanics principles (rate form) and corresponding equations presented in Class ES201 – Conservation and Accounting Principles.

Conservation of linear momentum:

$$\frac{d\vec{P}_{sys}}{dt} = \sum \vec{F} + \sum_{in} \dot{m}_i \vec{v}_i + \sum_{out} \dot{m}_o \vec{v}_o$$

Conservation of angular momentum:

$$\frac{d\vec{L}_{sys_o}}{dt} = \sum \vec{M}_o + \sum_{in} \vec{r}_i \times \dot{m}_i \vec{v}_i + \sum_{out} \vec{r}_o \times \dot{m}_o \vec{v}_o$$

Conservation of energy:

$$\frac{dE_{sys}}{dt} = \dot{Q} + \dot{W} + \sum_{in} \dot{m}_i \left(h + \frac{v^2}{2} + gz \right)_i + \sum_{out} \dot{m}_o \left(h + \frac{v^2}{2} + gz \right)_o$$

To be consistent with all the conservation principles presented in the course, assume that any energy coming into the system is positive (or makes the energy in the system increase) and that any energy leaving the system is negative. For this reason, work into the system is considered positive in contrast to the sign convention typically used in most thermodynamics texts. The finite-time form for linear momentum for a closed system is applied to problems involving impacts, and the finite-time form for energy is applied to problems involving mechanical energy.

One feature of ES201 is that the course imparts both a clear understanding of how conservation of energy is applied in most thermodynamics applications (rate or finite-time form for open and closed systems), dynamics applications (finite-time form for adiabatic, closed systems) and fluids applications (rate form for an adiabatic open system). The way springs are handled is also clearer for the students. If the spring is inside the system, then it is treated as an energy term, and if it is outside the system, the work the spring force does needs to be calculated.

ES204: Mechanical Systems Course. In the winter course, Mechanical Systems (ES204), the basic principles introduced in ES201 are applied in more detail to dynamics problems. In this course, students learn the kinematics necessary to apply the conservation principles to more difficult problems. The students also perform three labs as a part of this course.

A consequence of the basic principles being introduced in the first quarter of this curriculum is that material can be reordered in the winter quarter so that as kinematics concepts are taught, they can immediately be applied to kinetics problems, thereby motivating the kinematics and reinforcing the kinetics. For example, when normal and tangential coordinates are introduced for particles, problems involving kinetics can be solved. These problems may involve one or more of the conservation principles. Another advantage of this approach is that students are required to apply the principles "out of context." Typically in dynamics, students know what principle to apply based on the topic currently being discussed in class. With this new arrangement of the material, students need to decide which conservation principle is most applicable, thereby helping them attain a higher level of learning as described by Bloom's Taxonomy of Cognitive Learning.[5]

ES205: Analysis and Design of Engineering Systems. In the spring quarter, the material is brought back into a single course, Analysis and Design of Engineering Systems (ES205), where multidisciplinary problems are studied and students are introduced to product design specifications. The following discussion centers on the mechanics material covered in this course, although it is important to note that electrical, thermal, electromechanical, fluid and hydraulic elements are also covered. The mechanics material covered in this course is similar to that covered in a traditional systems class. Equations of motion are obtained for multidisciplinary systems involving mechanical elements such as springs, masses and viscous dampers. Both translation and rotation problems are examined, and the differential equations are obtained. For single-degree-of-freedom systems, topics discussed include free response, step response and response due to harmonic excitation and general periodic forcing, frequency response plots (Bode plots), transfer functions, and Fourier series. The concepts of natural frequency and damping ratio are discussed in addition to performance specifications such as time to steady state, percent overshoot and settling time. Clearly the mechanics material in the area of vibrations is significantly more than what is covered in most sophomore dynamics texts.

Laboratories Applicable to Vibrations

There are four laboratories in ES205 that are directly applicable to the Vibrations course. The first lab is a Simulink tutorial designed to teach students how to draw a Simulink block diagram after they

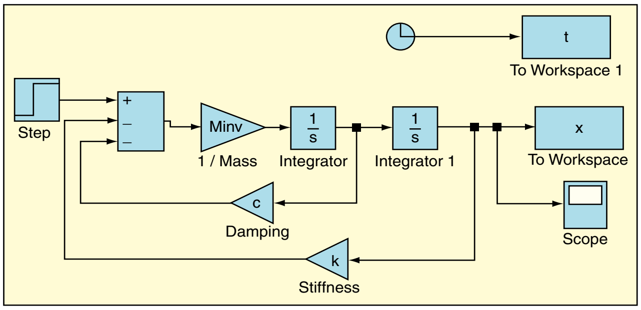

Figure 2. Block diagram of a single-degree-of-freedom spring-mass-damper system.

have derived the governing differential equation for a system. A single-degree-of-freedom system governed by Equation 1 has a block diagram as shown in Figure 2.

$$m\ddot{x} + c\dot{x} + kx = f(t) \tag{1}$$

In this lab, we require the students to use a step input, but this can easily be changed if the forcing happens to be harmonic, general periodic, or any other type of input. This skill in using Simulink is used throughout ES205 and when the students take the Vibrations course.

After developing the model shown in Figure 2, students are asked to explore how changing each of the three parameters (m, c and k) affects the system response of the spring-mass-damper model created. This exercise is designed to help students develop their intuition.

The second lab in ES205 that helps build a foundation for Vibrations involves system identification. In this lab, students are given several blocks (see Figure 3). Inside these blocks are unknown transfer functions that are inaccessible to the students. The students are required to put a known input into the system and to identify the order of the system and, if the system is second order, to identify the natural frequency, the damping ratio and the static gain. If they determine that the unknown system is most likely first order, they determine the time constant and static gain. After identifying these system parameters, they are required to write the transfer functions for the unknown systems.

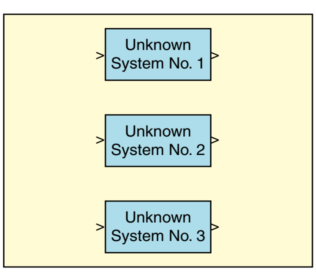

Figure 3. Block diagram used for system identification.

The third lab uses hardware located in the RHIT system dynamics and controls laboratory. This laboratory is used for several controls courses, ES205, and starting in 2006, Vibrations. The hardware plant used in this lab is the educational control products (ECP) rectilinear control system,[6] as shown in Figure 4. This is a translational mass-spring-damper system driven by a DC electric motor that provides up to three degrees of freedom of motion. The springs between carts can be changed to the user's liking. A variable air damper can be connected to any of the masses. The plant also provides for varying the system mass by adding or removing 500-g masses. Therefore, the *differences* in mass between possible configurations are well known, but the equivalent mass of the cart, transducer and springs needs to be identified.

In this lab, students investigate the effects of varying the parameters of a physical spring-mass-damper system similar to the first lab, except now they are using actual hardware. Students also identify system parameters by minimizing the difference between the experimental data and a theoretical model.[7] A typical result is shown in Figure 5. In this figure, the experimental data for a single DOF spring-mass-damper system are compared to the theoretical results where the system parameters were identified by minimizing a performance index, as shown in Equation 1.

$$J = \frac{1}{n}\sum_{i=1}^{n}\left(x_i^{model} - x_i^{test}\right)^2 \tag{2}$$

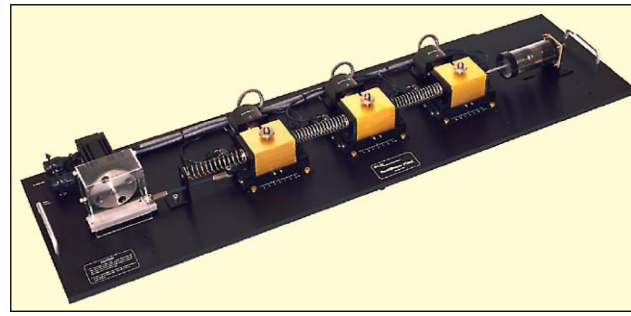

Figure 4. ECP rectilinear control system.

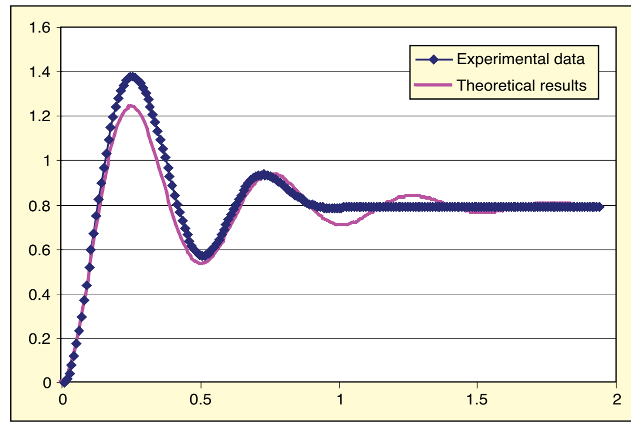

Figure 5. Typical results comparing theory to experiment for a SDOF system.

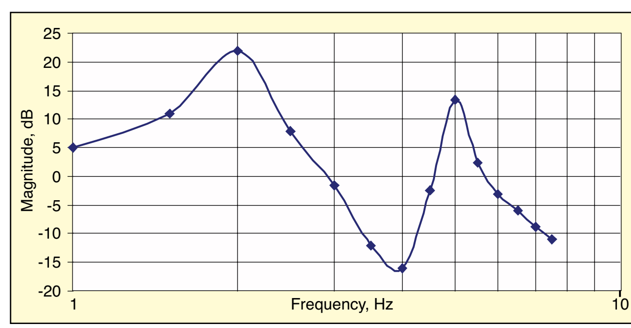

Figure 6. Frequency response plot for a 2-DOF system.

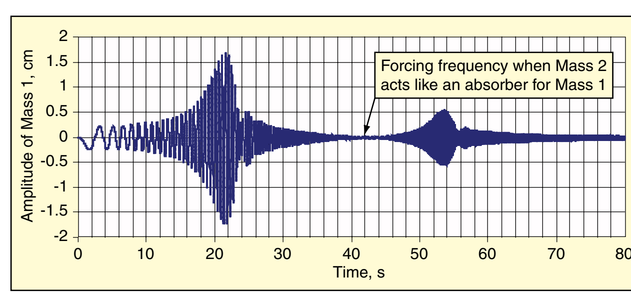

Figure 7. Swept sine results.

Figure 5 makes it is clear that there are other sources of energy dissipation in the actual system, since the experimental data go to zero before the theoretical model. This may be due to coulomb damping in the system. This experiment is valuable, because even in this very simple system, one that looks very similar to the spring-mass models we start looking at in class, the model is only approximate.

The final experiment in ES205 that directly relates to Vibrations and to the knowledge and experience students bring to the course from prerequisite courses is one on frequency response. In this lab, students experimentally determine the frequency response of a mass-spring-damper system and then construct a frequency response plot to visually convey this information. Students again use the equipment shown in Figure 4, except with two carts con-

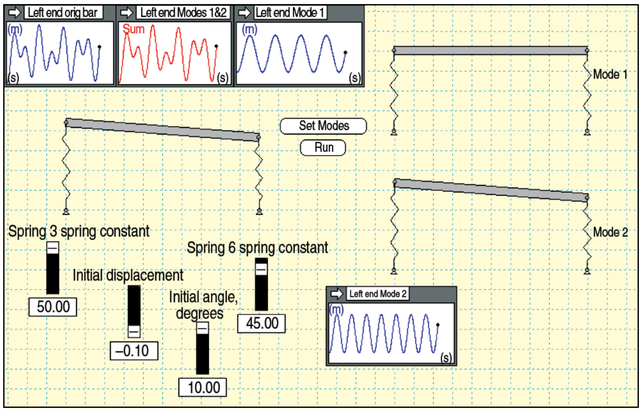

Figure 8. Working model simulation of a 2-DOF system.

nected by springs. To measure the frequency response, an input sinusoid with a known frequency and known amplitude is applied to the first cart via a rack-and-pinion mechanism. The system records the amplitude of this input signal as well as the positions of each of the carts in the system as a function of time. These cart positions initially display transient responses that decay. The cart positions eventually oscillate with the same frequency as the input signal, however there is usually a phase shift and amplitude change between the input signal and the positions of the carts. This process is repeated for a number of different frequencies. The resulting data can be plotted, and a typical magnitude plot is shown in Figure 6.

This lab fits very well with the in-class lectures on Bode plots and allows students to observe the response of a system due to harmonic forcing. They observe that at steady state the system has the same frequency as the forcing frequency, but with a phase difference and an amplitude change, just as we discussed in class. After collecting this data, and after experiencing how tedious and time consuming the process was, students input a chirp signal. A typical result is shown in Figure 7. The students clearly see the resonances, and they can observe the two modes of vibration during this process. It is also possible for them to notice when the second mass acts like a vibration absorber for the first mass. This frequency is labeled in Figure 7.

Because of the SEC, students enter Vibrations with better problem-solving abilities and strategies. In this curriculum, we drill into them the importance of defining a system for analysis, and they bring this skill to Vibrations. Students also have a stronger understanding of modeling concepts, step and harmonic forcing of second order systems, and frequency response plots than they had prior to implementing the SEC.

Effective Use of Technology

Computer Algebra Systems. For more than 15 years, all students at RHIT have been taught Calculus I, II and III and Differential Equations I and II using the computer algebra system Maple or Mathematica. The mathematics department eventually adopted Maple for use in all mathematics courses. As a result, engineering courses can exploit students' capabilities in using this tool. This allows students to focus on applying basic principles (not just looking for an equation) and the derivation of the governing equations. After the governing equations are derived, they can then be solved using Maple or by hand.

An example in Vibrations that lends itself well to the use of a computer algebra system is the design of vibration absorbers. Students no longer have to "look for formulas in the book" to solve the problem; they often end up using a formula that has assumptions that might not be valid. They can now simply formulate the governing equation for a 2-DOF system, solve the resulting eigenvalue problem and choose design parameters based on problem constraints such as resulting natural frequency locations.

Another problem ideally suited for solving using Maple is general periodic forcing of systems. These problems are usually solved using Fourier series and superposition. Unfortunately, except for cases with a relatively simple input force, such as a square or triangular wave, the resulting integration to obtain the Fourier coefficients is fairly difficult. Maple completely eliminates this problem and allows the students to focus on interpreting and understanding the resulting response to any general periodic input.

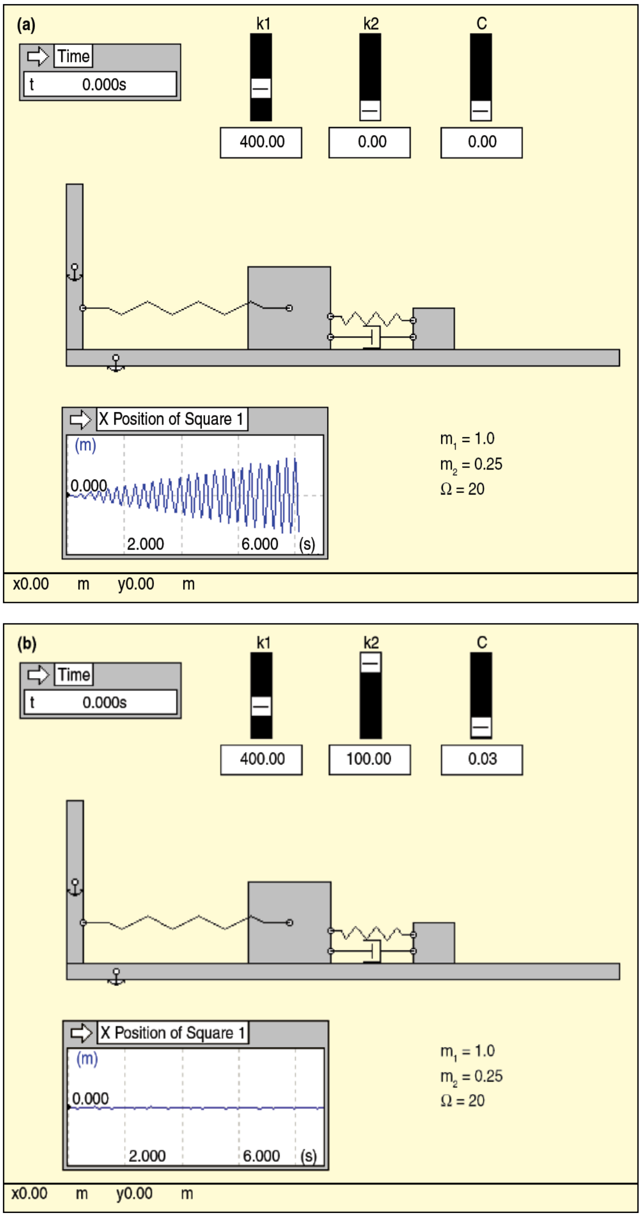

Figure 9. Working model simulation of mass forced at resonance without an absorber (a) and with an absorber (b); response is shown in Figure 9b.

Dynamic Simulation Programs. In addition to Maple, a dynamic simulation program called Working Model is used extensively in many courses at RHIT. In Mechanical Systems (ES204), Working Model is used as a way of introducing dynamics concepts, working on students' intuition, and problem illustration, for example. In Vibrations, Working Model is useful in helping students gain a better intuitive understanding of natural frequencies and modes as well as allowing them to see the effect of adding a vibration absorber to a system. Figure 8 is a snapshot of a Working Model simulation of a standard 2-DOF system. This simulation allows the user to change initial conditions and to see the resulting system response. The beam shown on the left in this figure is the actual motion of the beam. The two additional beams on the right correspond to the motions of the two natural modes of the beam. One of the points illustrated by this simulation is that the resulting motion can be viewed as a superposition of the two natural modes. The spring constants of the two springs can also be changed and the resulting mode shapes displayed.

Figure 9 is a snapshot from a Working Model simulation that shows the effect of adding a vibration absorber to a mass. The left side of Figure 9 shows the unbounded response of a single DOF system without damping when forced at resonance. The right side is the same system, except with a small vibration absorber. The time response for each system is shown in the "x-position" plot near the bottom of each screen shot. The scale is the same for both figures, clearly showing that the mass with the absorber hardly moves at all. It was necessary to add a small amount of damping to the simulation to eliminate the transient response of the system.

MATLAB and Simulink. The final computer tool used extensively in Vibrations is MATLAB and Simulink. MATLAB is used primarily for calculating natural frequencies and modes for MDOF systems. Rather than requiring students to determine the frequencies and modes by hand, MATLAB allows them to focus on the physical interpretation of the modes, how they can be used, and the orthogonality of modes and how they can be normalized. Simulink is used to numerically integrate equations of motion.

Many times students perceive Vibrations as a course in mathematics and differential equations. Computer tools help develop students' intuitions and allow them to focus on the results of an analysis rather than on the steps required to obtain a solution. Simulink, for example, enables students to easily integrate equations of motion, allowing them to spend more time focusing on the meaning of the solution.

Analytical solutions to shock response spectrums are typically difficult for students to follow, but Simulink allows them to easily generate shock response spectra numerically. MDOF systems can also be integrated and compared to analytical solutions using the same block diagram used for SDOF systems (see Figure 2). All students have to do is change the gain blocks to be matrices rather than scalars. Comparing the Simulink results to analytical calculations leads to a fruitful discussion concerning the assumptions in the analytical solution. Often when solving for the steady-state solution of a system analytically, even in the case of zero damping, the homogeneous solution is ignored. This is because we know that all systems actually have some damping. In Simulink, however, if the system has zero damping, the homogeneous solution is not transient, so the analytical result and the Simulink result will be different. It is necessary to add a small amount of damping to the model to make the homogenous solution decay to zero.

Engaging Students in the Learning Process

Engaging students in the learning process clearly takes place when students perform laboratories or homework, but it needs to take place during lectures also to maximize learning. If a professor sees his or her role as writing information on the board or the modern-day equivalent of presenting information using PowerPoint, and students are simply expected to copy down the notes or passively listen to a presentation, then I think that this is a waste of time for everybody involved. A more efficient method of presenting material in this way would be to put voice annotated slides on the web or to use streaming video of the lecture also posted on the web. Several methods I have found very useful in engaging students during a lecture are:

- Learn students' names and call on them by name.
- Use "Plus/Deltas" for feedback
- Use informal or formal cooperative learning techniques
- Use daily quizzes
- Use interactive example problems.

Learning Names. I am starting with the presupposition that, in general, students want to be known and that they do not want to be merely one of many unknown faces in a class. When they know the professor knows who they are, it is my belief that they are more engaged in the class. Therefore, I believe it is very important to learn students' names. I recognize that this can be quite difficult, especially as class size increases. To overcome this problem, I use a seating chart in all of my classes. On the first day of class I pass it around and ask them to please sit in the same seat for the entire quarter. I rarely have complaints from the students when I explain that the sole reason is to help me learn their names. If they want to change seats, I tell them I do not mind as long as they let me know, so I can update my seating chart. Until I learn their names, I always have the seating chart in one hand during class. Instead of asking general questions to the class, I direct questions to specific students, being sure that I distribute the joy of being called on to them all. If students are unable to answer a question, it is important not to embarrass them, but rather simply call on another student. I regularly have students comment that, though they do not really like being called on, they believe that the interactive nature of the class is beneficial and helps them stay attentive.

Plus/Deltas. At the conclusion of every course at RHIT, students fill out a course/instructor evaluation. The purpose of the evaluation is to give students an opportunity to provide feedback on the course and the quality of instruction. Unfortunately, any changes the professor might make as a result of the feedback are too late for the students who just completed the course. Also, after teaching a course several times, the comments on the course are really quite predictable, such as, "too much homework," "goes too fast," "grades too hard," etc. An effective way to get intermediate feedback on one's teaching is the use of Plus/Deltas.

Plus/Deltas afford students the opportunity to give feedback during a course and for the professor to make midcourse corrections or to respond to the feedback. I do not know who originated the term and usage of Plus/Deltas so I cannot reference their work, but I have found them to be extremely useful in helping students understand the competing demands on a professor when teaching a course. If on a Plus/Delta, for example, three students say "OK pace" and four students say "goes too fast" and one says "goes too slow," then when this is shown to the students, they can see the difficulty I have when trying find the appropriate pace in the course. It also allows me to reiterate the fact that there is a certain amount of material I need to cover.

Plus/Deltas also give me the opportunity to clarify policies that some students do not like. For example, I do not go over or even answer questions on homework during class time, and I also require a fairly rigid homework format. Some students complain about these policies even though I give a clear explanation of my policies and the rationale behind them the first day of class. When some students complain about these in a Plus/Delta, it gives me the opportunity to once again explain the reasons for my policies.

For example, I do not answer homework questions in class because:

- I want students to come by my office so I can better answer their question and clear up any confusion
- Some students have already done the homework or have already talked with me for help, so answering questions in class is not an efficient use of their time.
- I would rather use class time to work on a different example that covers the same basic principles.

I also explain that learning to ask questions one-on-one is a valuable skill that they need to develop. Once I explain this again, I rarely get comments at the end of the course on this policy. Similarly, when I get complaints on the homework format, I can emphasize the importance of not only getting the correct answer, but also communicating the solution to someone else and that the homework format is part of learning how to communicate a solution clearly.

To do a Plus/Delta, I have students take out a piece of paper, draw a line down the center and put a '+' on the top of one column and a 'Δ' on the top of the other. In the plus column, I ask students to list aspects of the course that are going well and in the delta column, to list what needs improvement as well as suggested ways to improve the course. I have found that having one or two Plus/Deltas a quarter is more than adequate. I typically allow about five to 10 minutes for them, and they usually replace a daily quiz, which is the next topic of discussion.

Informal Cooperative Learning. In my classes I use what I call informal cooperative learning, in contrast to formal cooperative learning, where students may be assigned to a particular group for an entire quarter. The group work in my class tends to be "ask your neighbor or the person behind you." The two primary ways I engage the students using cooperative learning are daily quizzes and in-class examples.

Daily Quizzes. I give what I call "daily quizzes" or "readiness assessment tests" (RATs), both of which are misnomers. For the first week of the course, the quizzes are best categorized as readiness assessment tests. They are primarily very basic questions on the reading assigned for that day. As the course progresses, the RATs gradually become a blend of basic questions on the reading and questions over previously covered material. At this point, I think of them more as daily quizzes. After teaching a course such as Dynamics or Vibrations several times, it becomes clear which topics and concepts are most difficult for students or about which they have misconceptions. Some of these may not even be related to vibration, such as the use of English units.

One major advantage of the daily quizzes is that I can ask questions on these topics before an exam, allowing students to strengthen their understanding. I also start to make the quizzes "open neighbor;" that is, I have them work on the quizzes individually for about five minutes, while I pass back the previous day's quiz, and then make them "open neighbor" for another minute or two. Since they have already been thinking about the problem and recognize their lack of understanding, if they were unable to solve the problem, they are ready to learn. By having students discuss their answers with their neighbors, they are required to explain or defend them, thereby enhancing their understanding. My classes are small enough, less than 30 students, that I can personally grade the quizzes. However, if they were larger, I would probably not collect the quizzes, but rather spend a few minutes discussing them after the "open neighbor" discussion.

In-Class Examples. The second way I use informal cooperative learning is through in-class examples. In courses like Vibrations, I believe examples are crucial to helping students learn how to apply the material. Like Einstein said, "Example isn't another way to teach, it is the only way to teach." Therefore, my classes are characterized by a large number of example problems.

When I first started teaching, I would write the example problem on the board and then proceed to solve it while asking students questions. The copy machine has changed this somewhat. I believe that there are very few, if any, pedagogical advantages in having students transcribe the problem statement. When written by hand, the problem statements are typically messy, since students are writing quickly, thereby limiting their value in studying for exams, and it takes class time that could be used in solving the problem. For these reasons, several years ago I started making copies of the problem statements for the examples that I pass out to the students. Therefore, time previously used for transcribing is now used in solving problems.

Depending on the example and how much time is available in class, the method for solving examples will range from having students work on the problems individually, then in groups, and then together as a class, to simply having them come up with a strategy to solve the problem. After this, I lead the students through a solution by calling on them by name. I believe use of the copy machine has been a significant factor in helping improve the effectiveness of in-class examples. The obvious downside, which is not insignificant and is of major concern to administrators because of the cost, is that I obviously make a large number of copies. One possible solution, though I have not tried it, is to have students buy a "course guide" that has any handouts or example problem statements all together in one package. This, of course, means that the entire course needs to be planned out well before the first day of class, which is not always possible.

Laboratories. Laboratories to enhance learning can be helpful in developing students' intuition, in reinforcing the material and in showing students how to apply the material they are learning to real problems. Starting in the 2006-2007 academic year, the Vibrations course included a scheduled laboratory. This will reduce the number of lecture hours from 40 to 30 and there will now be ten 3-hour labs. It was my intent to design these labs to build on the ones previously done in ES205. For example, the system identification lab discussed previously will include the addition of coulomb damping to see if that improves the comparison between theory and experiment. Also, the frequency response lab, which had previously been designed to help students have a better conceptual understanding of frequency response, includes the next logical step of requiring students to identify system parameters. The necessary signal processing and analysis is done in MATLAB. I also intended to include more concepts of signal processing and experimental modal analysis than I had traditionally done in the past.

Conclusions

I have discussed here how I attempted to improve vibrations education by enhancing the prerequisite courses, by effectively using technology and by engaging the student in the learning process. The prerequisite courses were improved when a new sophomore curriculum built around the concepts of conservation and accounting was implemented. The main benefits of this program are:

- Students having better problem solving skills
- Students build on experiences in previous courses
- Students have a stronger understanding of modeling concepts
- Students have the tools that enable them to solve more difficult problems
- Students are more actively engaged in the learning process both inside out outside the classroom.

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