Dynamics Evolution - Chance or Design

Phillip J. Cornwell
Rose-Hulman Institute of Technology

Abstract

Significant innovations and changes have been made in the teaching of dynamics over the past ten years at Rose-Hulman Institute of Technology. In this paper the author will discuss the history of these changes and how a traditional dynamics course has evolved from being primarily lecture to using cooperative learning and technology, and finally, how the course was integrated with other courses using a common conservation and accounting framework. Details will be provided showing how to effectively utilize technology such as Maple and Working Model and how to involve students more in the educational process using methods such as cooperative learning, plus-deltas, and readiness assessment tests. When Maple and Working Model were first used in the course in 1994 the students were surveyed as to how they felt about these tools. In 1999 this survey was repeated. The results of these surveys and additional assessment results will also be presented. Many changes have been made to the course, but the only significant improvement in student performance occurred when the course was integrated with other courses and the material was taught in a significantly different manner.

I. Introduction

On the first day there was dynamics and it was good.

On the second day a creature came along called “Professor”. Professor saw that dynamics was beautiful and was the foundation of all engineering science. Professor wanted to share the beauty of dynamics by shouting its praises from a mountaintop. Instead, being scared of heights, he wrote dynamics on a blackboard – unable to take his eyes off of what he was writing because of its beauty. And it was good. Thus ended the second day.

On the third day Professor was disturbed by a noise coming from behind him. He turned around and, lo and behold, there were other creatures in the same room with him. He learned these creatures were called “students”. Many of the students had glazed eyes, some were asleep, and some copied frantically everything Professor said or wrote on the board. Professor was disturbed that some would be inattentive in the presence of the beautiful dynamics so he spoke directly to one of the students much to the shock of the students. He said, “You, in the first row. What is ....” And thus began what is now known as Professor/student interaction. Professor found interacting with students to be enjoyable. Through this interaction he discovered, much to his astonishment, that not all students could visualize the motion of objects and that some students suffered from severe “intuition impairment”. To help students, he brought in some physical demonstrations to show the students. And it was good. Thus ended the third day.

On the fourth day Professor found out that it was possible for students to actually learn from and help each other see the beauty of dynamics. This radical idea was called “cooperative learning” and Professor began to use it in his class. Professor became excited about discovering that there were actually creatures that studied the process of learning. He started trying some of the ideas he read about such as “readiness assessment tests” and “plus-deltas” and “concept maps”. He also began using a wonderful device called a “copy machine” to make copies of example problems to be worked in class. By passing out the problems to students he discovered there was more time available in class for group work and discussion of the problems. And it was good. Thus ended the fourth day.

On the fifth day, Professor was talking to another creature called “Math Professor” and he learned that students had the ability to use a tool called a “computer” and more specifically something called a “computer algebra system” known only as “Maple”. It became clear to Professor that this new tool could be used to help teach students the beauty of dynamics by allowing them to focus on basic principles instead of having them get bogged down in algebra. When solving problems, the student could now focus more on setting up the problems and counting the number of equations and unknowns rather than on doing the algebraic manipulation required to get a numerical answer. Having discovered the power of the computer, Professor discovered another tool called “Working Model”. This was a dynamic simulation program that could be used to help students in visualizing motion and developing their intuition. Professor also discovered the mysterious entity known as “The WWW” and he developed a webpage for his class. And it was good. Thus ended the fifth day.

On the sixth day, Professor got together with other Professors and discovered that many of the basic principles that made dynamics so beautiful also made their subjects beautiful. They worked together and completely rearranged the material in their courses to build a newly developed course called “Conservation and Accounting Principles” that was used as a prerequisite to all subsequent engineering science courses. And it was very good. Thus ended the sixth day.

On the seventh day Professor rested from teaching and wrote a paper to tell others how he has changed the way he shares the beauty of dynamics, and more importantly, how students are learning dynamics better.

II. The Paper

One of the advantages of teaching at a school like Rose-Hulman, where the primary focus is undergraduate engineering education, is that I have the time to try new things in the classroom. The purpose of this paper is share with new professors, or even older professors at research schools who may not have the time to experiment with pedagogical techniques, what I have learned over my years teaching at Rose-Hulman. I will focus this paper on getting students engaged in a course, the use of technology in the classroom and the major curricular change that occurred at Rose-Hulman that has profoundly affected the way we teach engineering science.

III. Getting Students Involved

III.A 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 the size of a class increases. In fact, I myself am afflicted with the neurological disorder known as "namentia". This malady is a narrowly focused form of dementia that is specifically related to the remembering of names. Although this disorder is not, as of yet, recognized in the medical community as a true disorder, I have no doubt that it will be in the future. To overcome namentia 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 a student is unable to answer a question I try 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. How did I get this feedback? I am glad you asked because it leads to another way to get students involved in the class: plus/deltas.

III.B Plus/Deltas

At the conclusion of every course at Rose-Hulman 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. 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. For example, if on a plus/delta 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. Amazingly, some students complain about these policies even though I give a brilliant explanation of my policies 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: 1) I want them to come by my office so I can better answer their question and clear up any confusion, 2) some students have already done the homework or have already come by my office for help so answering questions in class is not an efficient use of their time, and 3) 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 communicating the solution to someone else and that the homework format is part of learning how to communicate a solution in a clear manner.

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 ten minutes for them and they usually replace a daily quiz. What? I have not mentioned daily quizzes? Well, that naturally leads to my next topic of involving the students through informal cooperative learning.

III.C 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". There are primarily two ways I engage the students using cooperative learning: 1) daily quizzes, and 2) in-class examples.

III.C.1 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. One major advantage of the daily quizzes is that I can ask questions on topics that I know from experience students have problems with. Quiz questions can range from finding the work of a force that is a function of displacement to locating the instantaneous center of velocity for a rigid body to sketching the trajectory of a drop of water leaving a leaking bucket of water. 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. Why don't I just go over the quiz in class at this point? I could, but I believe that by having them discuss their answers with their neighbors they are required to explain or defend them thereby enhancing their understanding.

To be perfectly honest I do not give a quiz every day because the grading can become time consuming but I try to give them as often as possible because it turns out that once you give one quiz it is easier to give them every day. Since I have to pass back the quizzes anyway, I might as well give them another quiz to work on while I pass back the previous one. Yes, it is a vicious cycle, but I really think it is helpful in correcting bad intuition and helping students recognize what is important. In addition to reinforcing specific topics, the quizzes have the added benefit of helping me learn students' names through the process of handing the papers back. Since I use a seating chart, as discussed earlier, it usually does not take too long to pass back the quizzes. The second way I use informal cooperative learning is through in-class examples.

III.C.2 In-Class Examples

In engineering science courses like dynamics I believe examples are a crucial element in helping students learn how to apply the material. 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 is very little pedagogical advantage in having the 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 which 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.

At least once in the quarter, usually near the end, I dedicate a class period to more formal group work where I will rearrange the class into groups (i.e. not just working with neighbors) and give them problems from topics throughout the course. Typically when we solve examples, we are working at the understanding/comprehension level of Bloom's Taxonomy of cognitive learning[1]. That is, students know what principle to apply because we just finished talking about it in class. By giving the students problems that require the use of multiple concepts or material covered earlier in the class they are forced to try and synthesize the material. Before, the only time I would require them to do this was on the final. In some cases I ask them to solve the problems to completion, but more often I simply ask them to state a strategy, that is, what principle or principles would they use and why. I give each group five different problems for which they have to come up with a strategy. During the last 15 minutes of class I select one member of a group to present their strategy to the class for a particular problem. We cover as many problems as time allows.

The next topic I will discuss is the way technology has changed the way I teach dynamics.

IV. The Use of Technology

The purpose of this section is to share what I have learned about effectively utilizing technology such as Maple, Working Model and the WWW in the teaching of dynamics.

IV.A Computer Algebra Systems

For over ten years all students at Rose-Hulman 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. Beginning in the 1994-95 academic year, Dynamics was redesigned in an attempt to exploit the students' expertise in using these tools. In my mind, the emphasis in Dynamics has always been on problem formulation, but in many students' minds, the course seemed to be a collection of mathematical manipulations or “finding the right equation”. Having Maple as a tool has changed the way I formulate problems and the way I teach students to formulate problems. To focus on the basic principles (not just looking for an equation) and the derivation of the governing equations, I require the students to formulate all the necessary equations prior to attempting the mathematical manipulations required to get a numerical answer. They must state what principle they are using and must keep track of their unknowns and their equations. I have them do this by using a “unknowns/equations” table where they list the unknown quantities and they keep track of the number of equations they have. They are not to proceed to a numerical solution until they have enough equations. After the governing equations are derived, they can then be solved using Maple or by hand. I model this by solving examples in class using the same method and further stress its importance by having fairly difficult exam questions being “set up but do not solve”. An example of a test problem and solution are shown in Figure 1.

Because computer algebra enables students to solve sets of equations in terms of parameters, I typically modify some of the homework problems in order to exploit the capabilities of the computer. Don’t get me wrong, students will use Maple on many of the problems assigned from the text, primarily to solve N equations and N unknowns, but most textbook problems are not written to exploit the many capabilities of computer algebra systems. Therefore, I make the problems involve plotting the response as a function of some parameter or doing a minimization problem where the derivative and its solution are quite nasty. A number of examples of the types of modifications I have done can be found in Reference 2. Not every problem is modified because typically the modified problems take more time than one selected from the textbook. In addition to Maple we use a dynamic simulation program, Working Model, extensively in class.

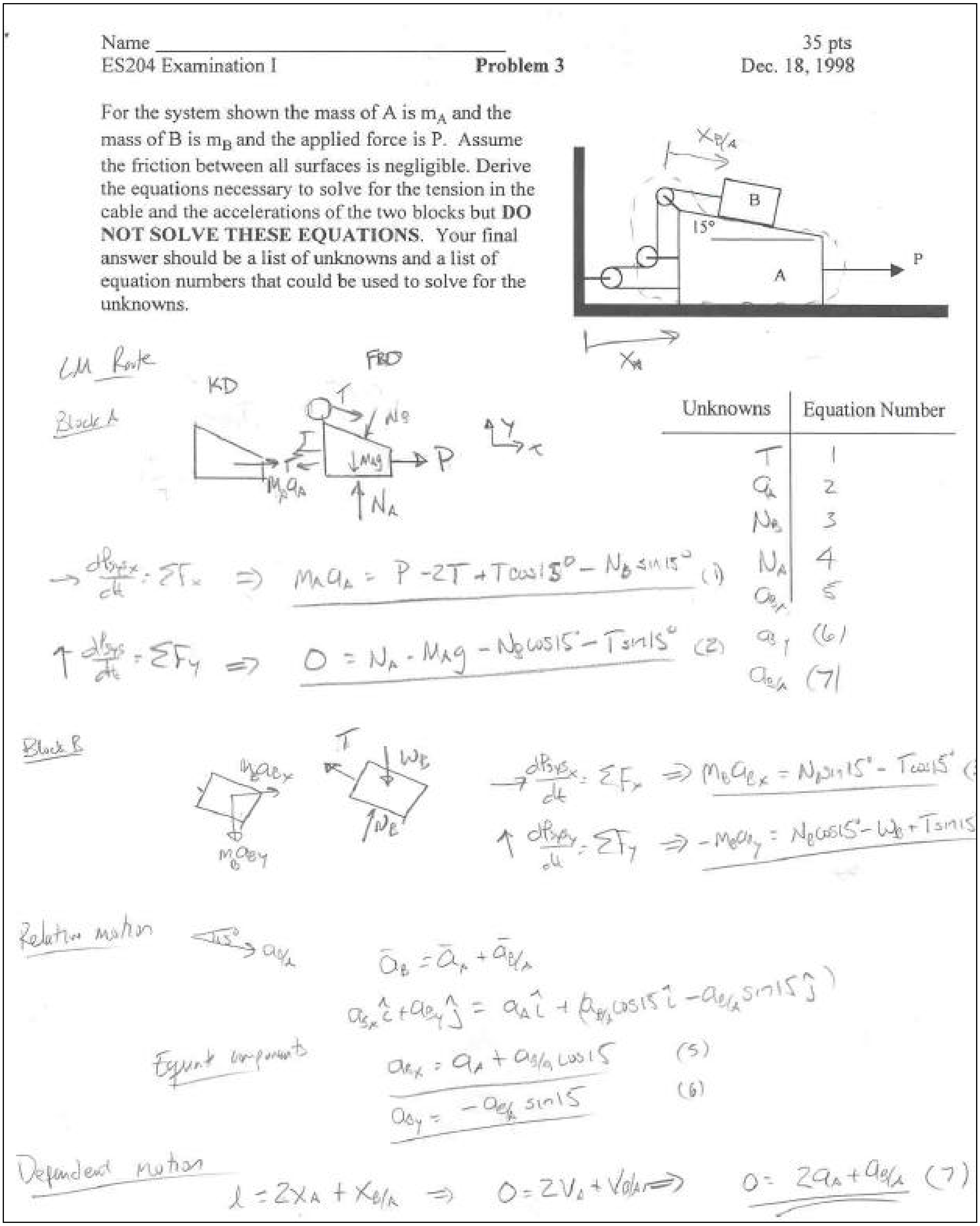

Figure 1 – Sample test problem illustrating the “set-up but don’t solve” methodology.

IV.B Working Model™

Working Model is used in Dynamics as a way of helping students visualize problems and develop their dynamics intuition. In the first few years I used Working Model I required students to solve some problems by hand and then with Working Model to compare their answers. I found that this typically required a significant investment of the students' time and it was not clear if this process helped their understanding of dynamics. Therefore, I now use Working Model primarily in class as a way of introducing dynamics concepts, working on students' intuition and for example problems. All of the classrooms at Rose-Hulman are equipped with nice projection systems so I bring my laptop to class and show the students Working Model simulations that I have developed that illustrate various dynamics concepts. Working Model is very easy to use and graphs of velocities, accelerations, and forces are readily available. These quantities can also be shown as vectors on the object. Its main value in a sophomore dynamics class is, in my opinion, in helping students visualize the motion and develop their intuition. For example, it is beneficial for students to see that even though an object is rotating at a constant angular velocity, points on the object are accelerating.

I average approximately one simulation per class period. Several of the Working Model simulations I have developed can be found in Reference 2 so I will only present one in this paper. Figure 2 shows an example of a Working Model demonstration designed to help students better understand rigid body kinematics and develop their intuition concerning the velocity and acceleration of different points on rigid bodies.

In Fig. 2, the small link on top is driven with a constant angular velocity. The velocities of several points are shown in the left side of the figure and the accelerations of several points on the right. The four-bar linkage is animated and stopped at several different times. Using the left side of Fig. 2 the instantaneous center of velocity can be found at each time and the students can clearly see how its location moves in space. At the instant shown in Fig. 2, the velocities of a number of different points are shown to illustrate that different points on the rigid bodies have different velocities. The students can also see the difference between fixed axis rotation and general plane motion. The students can clearly see that the velocities of points on the link with a constant angular velocity are constant in magnitude, whereas the velocities of points on the other two links change in magnitude indicating that the other two bars have angular accelerations. The right side of Fig. 2 is used to show that even though a rigid body has a constant angular velocity, the various points on the object are accelerating. It is also clear that the acceleration of points on the other two links have both normal and tangential components of acceleration.

In addition to its use in illustrating concepts, Working Model is also used to present approximately 40-50% of the example problems examined in class. Animating the problems helps develop the students' intuition and helps them in solving the problems.

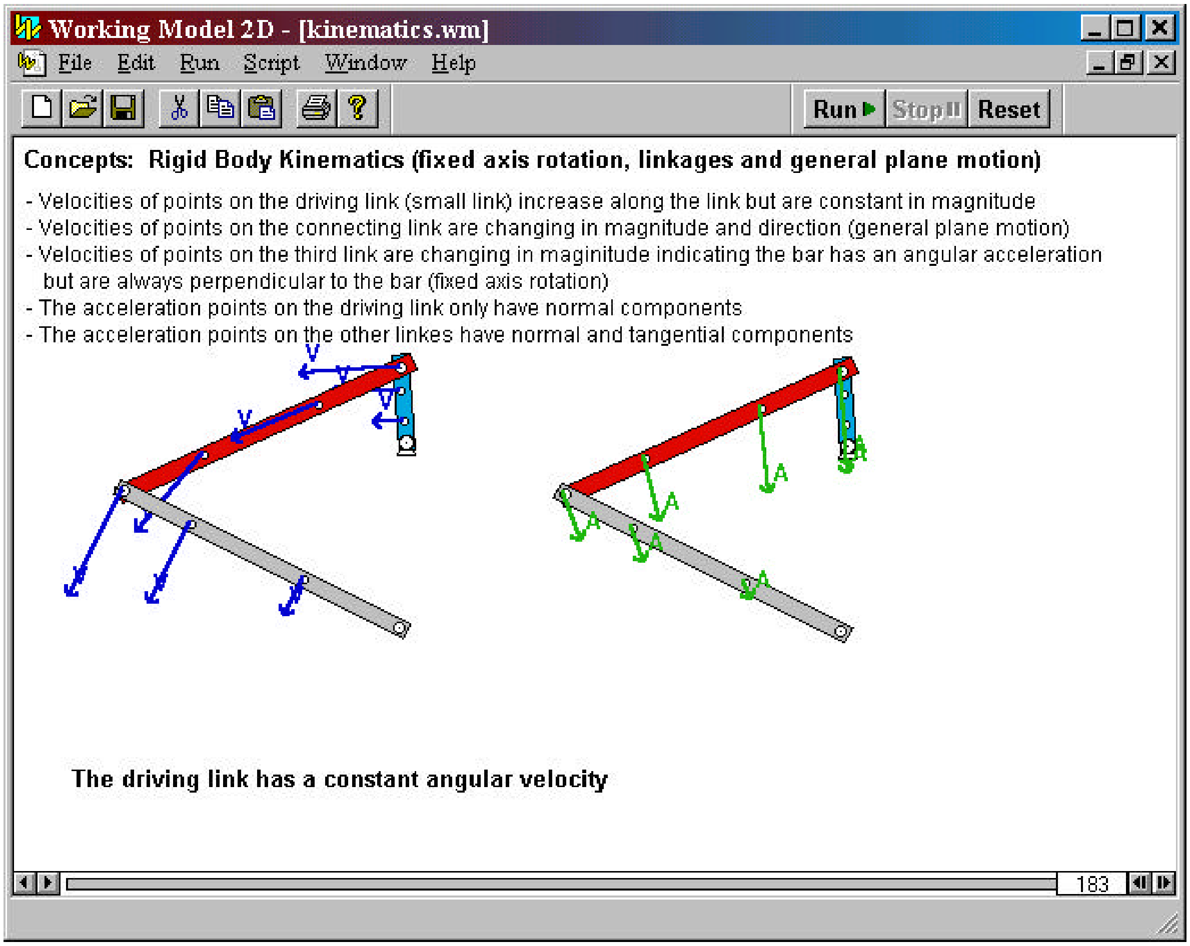

Figure 2 – Working Model demonstration illustrating concepts in rigid body kinematics

IV.C The WWW

During the 1998-1999 academic year, I made my first foray into utilizing the WWW in my engineering mechanics courses. Granted, others have been doing this for years, but to be perfectly honest I could not find any guidance (not that I looked very hard) as to what should be put on a website for a course. Therefore, material was placed on the website that was assumed to be of interest to the students. By the end of the course it became obvious to me that the first step should have been to engage the students in meaningful dialog. Students at Rose-Hulman are, in general, experienced web users and their thoughts and feelings of what sort of resources they would actually find useful are certainly valid. To begin this dialog, I asked the students to evaluate a number of proposed elements of a mechanics website on a scale from one to five where one indicated the student would never use this on a website and five indicated the student would use it frequently. The results of this survey are summarized in Table 1. It is important to note in Table 1 that even though some elements seemed to be more popular with students than others, everything proposed had some students who indicated that they believe they would use it frequently. It is likely that the students' responses were influenced by what I actually put on the web page and what they found helpful. The most popular component was a section where I posted the answers to the homework with some hints on the solution.

Table 1 – Results in order of preference of various proposed elements of a website for a dynamics course.						
Element that could be on website	1 (Would never use)	2	3	4	5 (Would use frequently)	Average
Answers to HW	0	0	0	0	50	5.00
Solutions posted after due date	0	0	5	13	31	4.53
Old exams	0	4	15	10	21	3.96
Administrative information (syllabus, etc.)	3	4	11	9	24	3.92
Working Model simulations	2	5	8	15	20	3.92
Concept maps	1	7	12	19	11	3.64
Maple worksheets (templates)	2	9	12	13	14	3.56
Example problems done in class (posted after class)	4	6	14	12	14	3.52
Interactive example problems (not just scanned in)	5	7	14	15	8	3.29
Copies of class notes	5	8	17	11	9	3.22
Additional notes (derivations etc.)	4	13	17	6	10	3.10
Drill and practice quizzes	6	13	15	10	6	2.94
Video of lecture	19	11	7	6	6	2.37
Bulletin board for posting questions	17	9	17	6	1	2.30

There is one other topics that I would like to discuss that did not conveniently fit into any of the categories discussed so far so I will just put it in its own catagory.

V. Concept Maps

I use concept maps, which are pictorial representations of course material, to try to help students understand the relationships between the various topics covered in Dynamics and to help them organize the material in their minds. A concept map illustrating the relationship of topics typically covered in the area of particle kinematics is shown in Figure 3. At the top of Fig. 3 are the basic kinematic relationships between position, velocity, and acceleration. The next level of the map illustrates that these relationships can be integrated to obtain algebraic relationships between these quantities and that they are vector quantities that can be represented in different coordinate systems. The last level shows the equations for position, velocity and acceleration in terms of rectangular components, normal-tangential components, and radial-transverse components. While covering this chapter in class, Fig. 3 is projected onto a corner of the

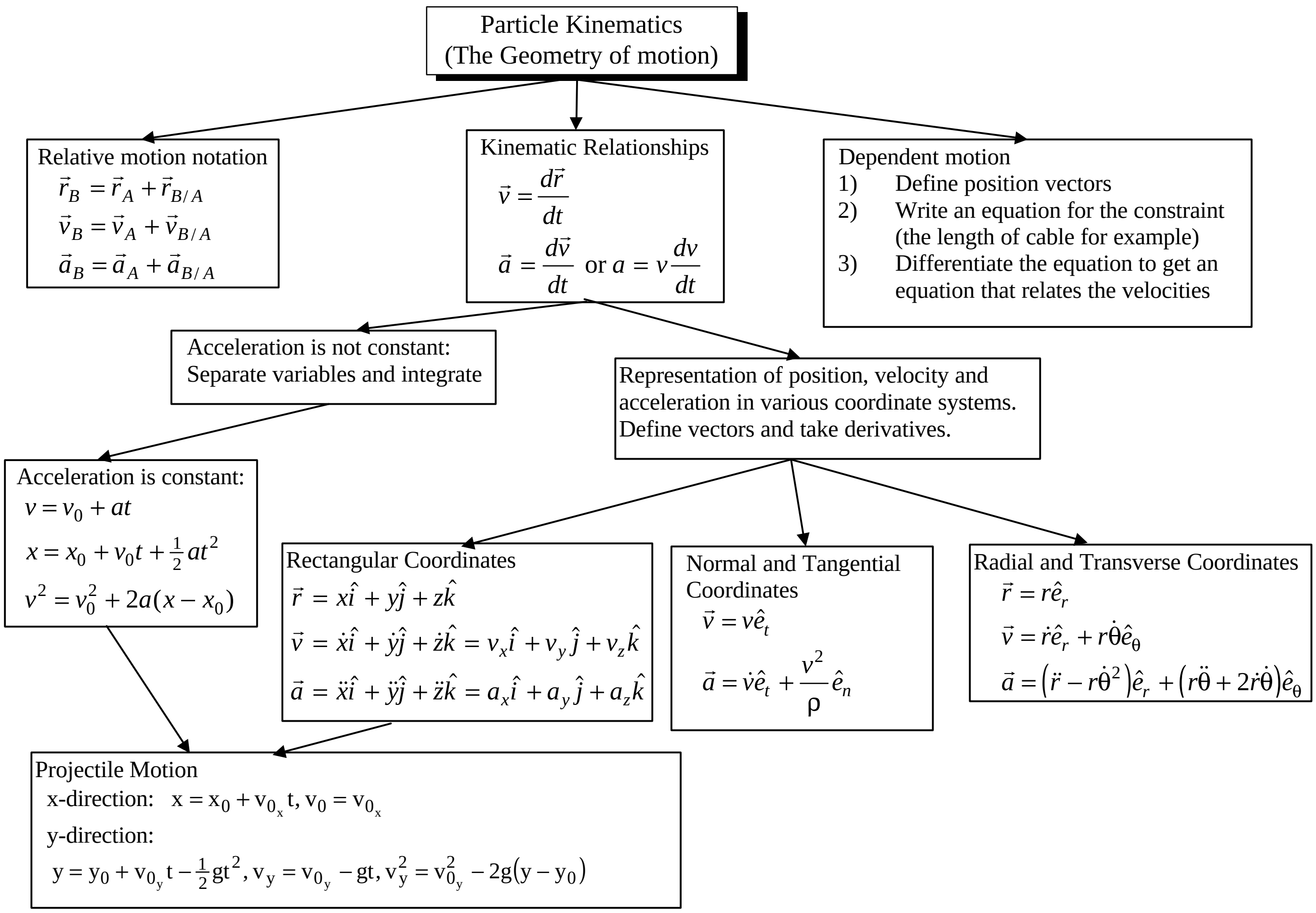

Figure 3 - Concept map for the topic of particle kinematics

classroom's front wall and whenever new material is presented, its location in the concept map is shown to the students so they can see how it is related to topics already covered. Other concept maps can be found in Reference 3.

VI. How do the students feel about all this?

In 1994 I first gave my students a survey and asked them to evaluate many of the things I was trying in my dynamics class. I repeated this survey in 1999 and the results are presented in Table 1. In 1994 I asked students to rate on a scale from one to five how lectures, in-class group work, homework, Working Model demonstrations, concept maps, and computer algebra helped the students in five areas. The five areas were 1) problem solving skills, 2) learning and comprehension of dynamics material, 3) motivation and interest in dynamics, 4) ability to visualize problems and develop intuition, and 5) enjoyment of dynamics. A rating of one indicated that the student did not feel that element of the class helped at all and a rating of five indicated that that element helped a great deal. In the 1999 survey I also asked the students to rate the daily quizzes.

From Table 1 it is clear that the highest rated element in almost every category both in 1994 and in 1999 was the “lectures”. This is of course because I am such a great lecturer! Ha! I feel a strong need to clarify what I believe students interpreted to be "lecture" lest someone use these results to say we should not do group work but rather should simply lecture. I give very few traditional lectures with me writing on the board and students transcribing. If I do a derivation in class I typically will pass it out to the students with some key steps missing and then go over the derivation on an overhead. I believe the students interpreted "lecture" to be the in-class experience where I was basically guiding the solution of example problems or giving mini-lecturettes on the material.

Table 2 - Results of the student survey of course elements in 1994 and 1999. The scale was 1 to 5 where a one indicated that that element of the class did not help at all and a five indicated that that element helped a great deal.

	Problem Solving		Learning/ Comprehension		Motivation/ Interest		Problem Visualization and Intuition		Enjoyment	
	1994	1999	1994	1999	1994	1999	1994	1999	1994	1999
Lectures	4.2	4.6	4.2	4.7	3.8	3.7	4.1	4.4	3.8	4.1
In-Class group work	3.6	4.0	3.9	4.0	3.3	3.1	3.9	3.7	3.2	3.5
Homework	4.0	4.3	3.7	4.4	2.2	2.7	3.6	3.9	1.7	2.1
Working Model Demonstrations	3.8	3.3	3.5	3.8	3.8	3.5	4.5	4.1	4.1	3.7
Concept Maps	4.2	2.9	4.2	2.9	3.3	2.4	3.6	2.6	3.4	2.5
Computer Algebra	2.1	3.4	2.2	2.7	1.8	2.1	2.0	2.4	1.9	2.5
Daily Quizzes	N/A	3.9	N/A	4.1	N/A	2.9	N/A	3.7	N/A	2.9

In-class group work went up in some categories and down in others whereas the homework went up in every category. Working Model was still seen to help primarily in the area of developing students' intuition although its overall ratings went down. The daily quizzes generally fell somewhere in the middle of the other elements. It is also interesting to note the significant improvement in students' attitudes towards the use of Maple in the class. 1994 was the first year we made a deliberate attempt to require students to use Maple and, to be perfectly honest, it was not well received. I do not know if students are simply more adept at using Maple and the computer in general or if I have become better at emphasizing the setting up of problems so that the usefulness of Maple is really seen. It is important to note that only the averages are presented in Table 2 and that every single one of the elements listed has some students who rated them as a five.

The final topic I would like to discuss is the most significant change in the teaching of dynamics at Rose-Hulman as well as the only change that has been demonstrated to improve student learning. This change occured when we distributed dynamics throughout the sophomore year in a new sophomore curriculum. I believe that everything I have discussed so far has helped students in learning dynamics. Unfortunately the only evidence I have to support this is really anecdotal and through informal conversations with students. I do have, however, data that supports my contention that the new sophomore curriculum at Rose-Hulman has indeed improved learning of dynamics.

VII. Integrating Dynamics with Other Courses

Even though basic principles such as conservation of energy and conservation of linear and angular momentum are encountered in engineering science courses such as Thermodynamics, Fluids and Dynamics, the terminology, notation and methodology is often such that the principles look different in different classes. Therefore, subsequent courses do not reinforce the material taught in previous courses. Rose-Hulman, as part of the NSF sponsored Foundation Coalition, implemented a new sophomore curriculum starting in the 1995-96 academic year that repackaged the material in the courses listed above into a new sequence of courses called the Sophomore Engineering Curriculum (SEC). One purpose of the curriculum is to teach engineering science in a more cohesive manner. A number of papers have been written that discuss the major thrusts of the Foundation Coalition and how these have been incorporated into the curriculum at Rose-Hulman[4,5].

A comparison of the old and new curriculums is shown in Figure 4. Parallel to the engineering science courses are three math courses: Applied Math I (linear algebra and some linear ordinary differential equations), Applied Math II (statistics) and Applied Math III (systems of differential equations). In Fig. 4, the dashed lines are intended to illustrate a weak coupling between courses and a solid line is a strong coupling between courses.

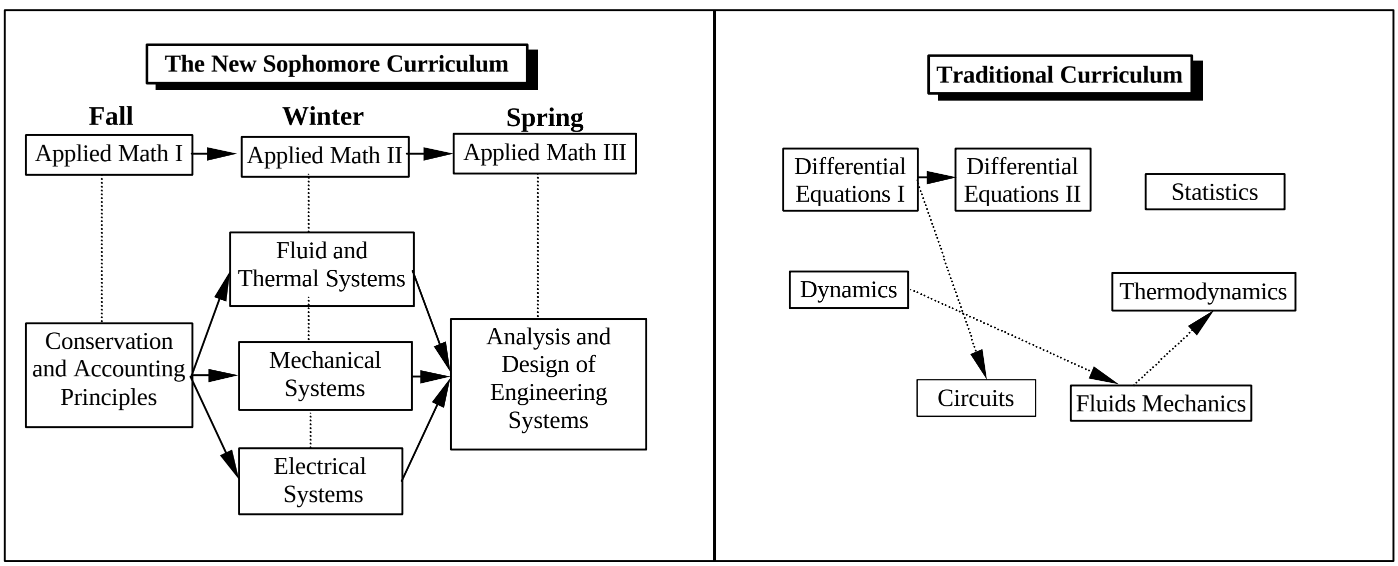

Figure 4 - Comparison of the traditional curriculum and the new sophomore curriculum at Rose-Hulman. A sequence of three courses can be used since Rose-Hulman is on the quarter system.

The engineering science courses are, what I affectionately call, the 1-3-1 sequence. In the first course in the fall, 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. The rate forms of these equations, as presented in the class, are shown in Table 3. We also teach a problem solving methodology and homework format that is used in all subsequent courses. In the winter quarter the students take three courses that build on the first course. These courses are Electrical Systems, Mechanical Systems, and Fluid and Thermal Systems. In these courses the more detailed applications of the conservation principles are discussed as well as some of the additional topics required to solve problems such as Kirchhoff's voltage law and active devices in Electrical Systems, properties in Fluid and Thermal Systems, and kinematics in Mechanical Systems. Finally in the spring quarter the material is brought back into a single course Analysis and Design of Engineering Systems where multi-disciplinary problems are studied and students are introduced to product design specifications. Since material is distributed over a sequence of three courses, it is frequently revisited and continually being reinforced at a higher level of learning. A complete description of how dynamics has been distributed throughout the sophomore year can be found in Reference 6.

Table 3 – Conservation and accounting principles as presented in ES201

Property	Conservation (or accounting) equation
Mass	$\frac{dm_{sys}}{dt} = \sum_{in} \dot{m}_i - \sum_{out} \dot{m}_o$
Charge	$\frac{dq_{sys}}{dt} = \sum_{in} i_i - \sum_{out} i_o$
Linear Momentum	$\frac{d\vec{P}_{sys}}{dt} = \sum \vec{F} + \sum_{in} \dot{m}_i \vec{v}_i - \sum_{out} \dot{m}_o \vec{v}_o$
Angular Momentum	$\frac{d\vec{L}_{sys_0}}{dt} = \sum \vec{M}_o + \sum_{in} \vec{r} \times \dot{m}_i \vec{v}_i - \sum_{out} \vec{r} \times \dot{m}_o \vec{v}_o$
Energy	$\frac{dE_{sys}}{dt} = \dot{Q} + \dot{W} + \sum_{in} \dot{m}_i \left(h + \frac{v^2}{2} + gz \right)_i - \sum_{out} \dot{m}_o \left(h + \frac{v^2}{2} + gz \right)_o$
Entropy	$\frac{dS_{sys}}{dt} = \sum \frac{\dot{Q}}{T} + \sum_{in} \dot{m}_i s - \sum_{out} \dot{m}_o s + \dot{S}_{GEN}$

A consequence of all the kinetics principles being taught in ES201 is that in ES204 the material can be reordered 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[1]. Of all the changes and modifications to dynamics through the years the only time I saw a significant improvement in student performance was when we implemented this new curriculum.

An important part of any new curriculum development effort is to assess the results to determine if the new curriculum is an improvement over the old, or, at the very least, produces roughly comparable results to the old curriculum. In order to assess the mechanics portion of the SEC, during the second and third years of the new curriculum a similar final was given to students taking ES204 and students taking the traditional dynamics course. There were approximately 125 Dynamics students and 90 SEC students. Both finals consisted of 20 multiple-choice problems (40% of the total points) and 3 workout problems (60% of the total points). This format for the final has been used for many years because it is felt that this is the best way to make the final very comprehensive. The first year the assessment was performed, sixteen of the multiple-choice problems and one of the workout problems were identical for the two finals. It was not possible to give identical finals since some of the faculty had strong objections. The second year of the assessment, the two finals were identical. A more complete discussion of the assessment can be found in Reference 7. As shown in this reference improvements were seen in both the multiple choice problems as well as the workout problems with the most profound difference being in the workout problems as shown in Table 4. For the purpose of Table 4 I assumed that a student who got a perfect score or only missed one point on the workout problem essentially got the problem correct. To reduce the influence of a particular professor the numbers for Table 4 were obtained by averaging the results from five Dynamics sections (three professors) and from four mechanical systems (ES204) sections (three professors).

Table 4 Percentage of students with correct answers for the work-out problems

Prob. #	**First Assessment**			**Second Assessment**		
	SEC - ES204	**Dynamics**	**Difference**	**SEC - ES204**	**Dynamics**	**Difference**
21	33.3	23.3	10	36.8	17.0	19.8
22	NA	NA	NA	70.1	22.0	48.1
23	NA	NA	NA	46.0	6.0	40.0

The workout problems were designed to be longer, more difficult and required multiple steps and concepts. The students in the new curriculum did significantly better than those taking the traditional dynamics course. From this assessment it is clear that the new curriculum does not hurt the students and in fact it appears to help them in mastering the mechanics material.

For this assessment, the majority of students in the SEC were majors in electrical engineering and computer engineering and the students in the traditional dynamics course were mechanical engineering majors. Therefore, the question remained as to whether the students in the new curriculum performed better because the EE/CO students were academically superior to the ME students or because of the new curriculum. Since this curriculum was required for all mechanical engineering students beginning in the 1998-1999 academic year it has been possible to compare the performance of EE/CO and ME students taking identical courses. A summary of the distribution of final grades for ES201 is shown in Table 5. On average the mechanical engineering students actually performed better although it is not clear if the difference is statistically significant. Therefore, I feel confident that the improved performance of students as indicated in Table 4 can be attributed to the new curriculum rather than the students' majors.

Table 5 Grade distribution for ES201 by major

Grade	Major	
	EE/CO	ME
A	8	9
B+	10	10
B	24	25
C+	21	19
C	22	8
D+	7	6
D	10	7
F	2	5
Average GPA	2.46	2.53

VIII. Conclusions

In this paper I have discussed how a traditional dynamics course has evolved from being primarily lecture to using cooperative learning and technology, and finally, how the course was integrated with other courses using a common conservation and accounting framework. I recognize I have discussed a great many topics and to the new engineering educator it could seem overwhelming. I would be more than happy to share any of the resources I have developed with anyone interested. In terms of the value added to my dynamics class I would rank the elements I have discussed in this paper as follows:

1. Rearranging the topics and revising the curriculum. This kind of dramatic change requires significant time and cooperation between members of a department, but it also has the potential of making the largest difference.
2. Daily quizzes/informal group work. I have found these to be very useful in engaging the students and in allowing me to reinforce individual topics and to correct poor intuition before a major exam.
3. Make copies of the problem statements for example problems and pass out to students. This may sound like a waste of money and I am sure some faculty (and administrators) will thus say "Bah Humbug! We didn't have any handouts when I was a student and the textbook didn't have any figures and the professor never did an example in class! We're just coddling students these days. Bah!"

4. Learn names and call on students by name in class. This makes a huge difference in the general atmosphere of the class and makes it more enjoyable for both the students and the professor.
5. Working Model. In a sophomore dynamics class I think this should be used primarily in a demonstration mode, using a projection system in class, for discussing dynamics concepts, problem visualization and developing student intuition.
6. Maple. In order for Maple or any computer algebra system to enhance the learning of dynamics students need to see how it makes their lives easier. This is done when there is a real emphasis on problem formulation and students are required to write down the principles they are using and to keep track of their unknowns and their equations. Computer algebra systems do enable students to solve a whole new class of problems, but it is important not to overwhelm them. Since students coming into my class already know how to use Maple I do not spend any time on how to use the code. If they did not I think it would be essential to spend at least some class time on the code and to pass out some templates, such as how to solve N equations and N unknowns.
7. The WWW. I have the least amount of experience in using the WWW in my classes and it is not clear how it can best be used to enhance student learning of dynamics. I believe a lot of time and energy is being spent to develop web resources, but it is not at all clear to me that much thought is going into what should actually be done. Perhaps this is as it should be since we do not really know what will work best and therefore we need to try a lot of things.
8. Plus/Deltas. I am not sure if these improve the learning of dynamics, but I do feel that plus/deltas can improve the student evaluations of the course. They enable the instructor to make midcourse corrections as well as to respond to student concerns.

Being an engineering educator is one of the most enjoyable jobs that I can imagine. Have fun.

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PHILLIP J. CORNWELL

Phillip Cornwell is an Associate Professor of Mechanical Engineering at Rose-Hulman Institute of Technology. He received his B.S. from Texas Tech University in 1985 and his M.A. and Ph.D. from Princeton University in 1987 and 1989 respectively. His present interests include structural dynamics, structural health monitoring, and undergraduate engineering education. Dr. Cornwell has received several awards including the 1990 ASME Aerospace Division Award, an SAE Ralph R. Teetor Educational Award in 1992 and Teacher of the Year from a Rose-Hulman student group in 1994.