Integrating Mechanics throughout the Sophomore Year

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Abstract

At Rose-Hulman Institute of Technology, the sophomore year curriculum primarily concentrates on engineering science material that is traditionally covered in courses such as Dynamics, Thermodynamics I, Fluid Mechanics and Circuits I. In the 1995-96 academic year, as part of the NSF sponsored Foundation Coalition, this material was repackaged for several majors into a new sequence of courses called the Sophomore Engineering Curriculum (SEC) where the concepts of conservation and accounting permeate the courses and are used to tie the subjects together. The mechanics material, traditionally taught in a dynamics course, has been distributed throughout the curriculum and is taught in a unified framework with the other engineering science material. From its inception, this curriculum has been required for all electrical engineering majors and computer engineering majors, but in the 1998-1999 academic year this curriculum was required for all mechanical engineering majors as well. Previous assessment results indicated student taking the new curriculum performed better on a standardized test compared to students who took a traditional dynamics course. In this paper we will discuss how the mechanics material is distributed throughout the year and what difference, if any, there is in the performance of electrical, computer, and mechanical engineering students.

Introduction

Mastery of the engineering science material typically covered in courses such as Dynamics, Thermodynamics, Fluid Mechanics and Circuits in the sophomore or early junior year is crucial for advanced courses in these topics and for design courses. Even though basic principles such as conservation of energy and conservation of linear and angular momentum are encountered in many of these courses, 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 repackages 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 [1-2].

Preliminary assessment results indicated an improvement in students' problem solving abilities and understanding of dynamics principles from when students took a traditional dynamics class [3]. For this assessment, students taking the curriculum, primarily EE/CO students were compared to students taking a traditional dynamics course, primarily ME students. Therefore, there was some question as to whether the students performed better because the EE/CO students were academically superior to the ME students or because of the new curriculum. Beginning in the 1998-1999 academic year this curriculum is required for all mechanical engineering majors as well, so it will be possible to compare the ME and EE/CO students. In this paper we will discuss how the mechanics material is distributed throughout the year and what, if any, difference is there in the performance of electrical, computer, and mechanical engineering students.

Description of the Sophomore Engineering Curriculum

A comparison between the old and new curriculums is illustrated in Figure 1. 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. 1, the dashed lines are intended to illustrate a weak coupling between courses and a solid line is a strong coupling between courses.

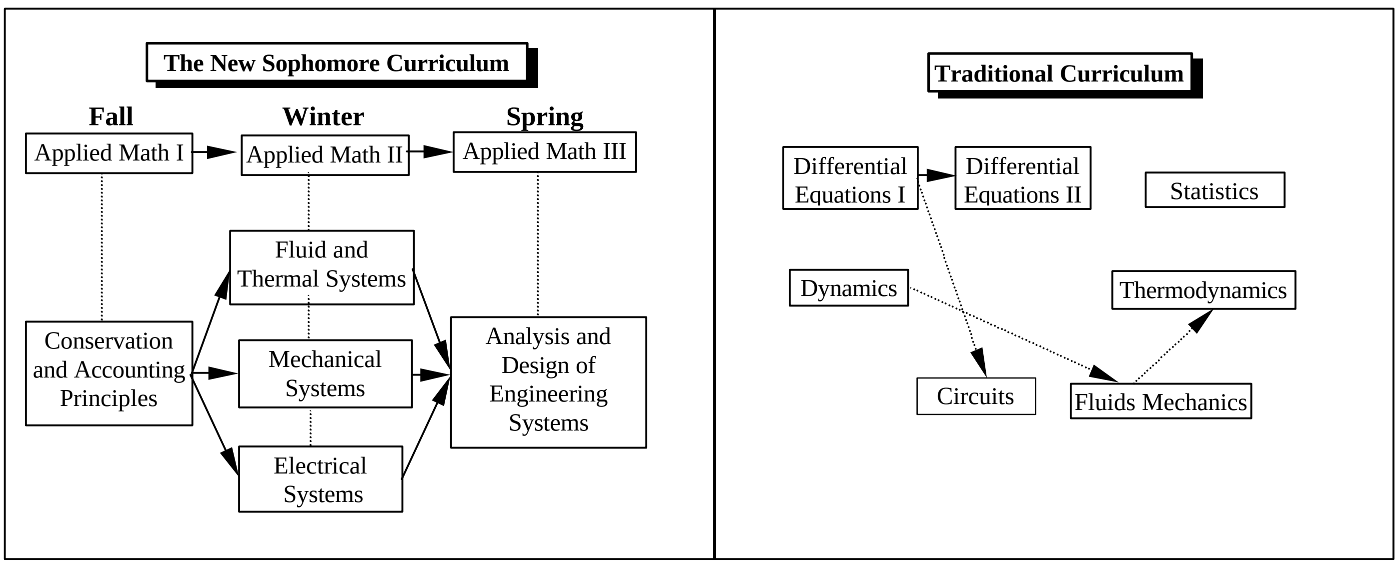

Figure 1 - Comparison of the traditional curriculum and the new sophomore curriculum at Rose-Hulman. A sequence of three courses can be used since Rose-Hulman is on the quarter system.

One overall intent of the Sophomore Curriculum is to enhance the students' abilities in solving problems in engineering analysis. We believe that the incoming students have some misconceptions about the problem solving process that need to be corrected before they can progress to the more difficult problems that they will face later in their undergraduate careers. These misconceptions include the ideas that, "solving problems means finding a formula to apply," and "I can demonstrate my cleverness by solving problems while showing as little of the actual work as possible." To cause the students to change some of their notions of problem solving, we require a far more formalized and complete approach to problem solving than they have yet experienced.

In the first course in the fall, Conservation and Accounting Principles, students are taught a problem solving methodology and format that is used in all subsequent courses. In addition to the traditional problem solving format the students are required to identify three things when solving any new problems:

1) What is the system? In traditional fluid mechanics and thermodynamics courses this is usually accomplished when students are asked to sketch the control volume and in dynamics when students are asked to sketch the free-body diagram. It is important for the students to learn that more than one system may be required for the solution of a particular problem.
2) What is the time frame? This question is basically asking the students to identify whether the rate form of the basic principles or the finite time form is most appropriate.
3) What is the property being counted? In this class we discuss extensive properties that are conserved such as mass, charge, linear momentum, angular momentum and energy and also the accounting of entropy. Again, for a particular problem it may be necessary to consider more than one property. For example, a problem may require conservation of mass, conservation of energy, and conservation of linear momentum.

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.

Mechanics in the SEC

The Conservation and Accounting Principles Course

Topics typically covered in a traditional dynamics class are spread throughout the new sophomore curriculum. 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 are used to discuss linear and angular momentum and three for the application of conservation of energy to mechanical systems. Topics not covered in the first course include inelastic impacts requiring introduction of the coefficient of restitution and most kinematics other than the basic relationships between position, velocity and acceleration. One significant difference, however, is that in ES201 the principles are applied to both open and closed systems whereas 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) as presented in ES201

Principle	Equation
Conservation of Linear Momentum (rate form)	$\frac{d\vec{P}_{sys}}{dt} = \sum \vec{F} + \sum_{in} \dot{m}_i \vec{v}_i - \sum_{out} \dot{m}_o \vec{v}_o$
Conservation of Angular Momentum (rate form)	$\frac{d\vec{L}_{sys_0}}{dt} = \sum \vec{M}_o + \sum_{in} \vec{r}_i \times \dot{m}_i \vec{v}_i - \sum_{out} \vec{r}_o \times \dot{m}_o \vec{v}_o$
Conservation of Energy (rate form)	$\frac{dE_{sys}}{dt} = \dot{Q} + \dot{W} + \sum_{in} \dot{m}_i \left(h + \frac{v^2}{2} + gz \right)_i - \sum_{out} \dot{m}_o \left(h + \frac{v^2}{2} + gz \right)_o$

To be consistent with all the conservation principles presented in the course it is assumed that any energy coming into the system is positive (i.e. makes the energy in the system increase) and 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 of the nice features 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 then the work the spring force does needs to be calculated.

Mechanical Systems Course

In the Mechanical Systems course (ES204) taken in the winter quarter, students learn the kinematics necessary to apply the conservation principles to more difficult problems. A traditional dynamics textbook is used in the course and the relationship between how the principles are presented in the dynamics book and how they were introduced the previous quarter is shown. The students also perform three labs as a part of this course. The first lab involves using Working Model, the second, angular momentum and the third general plane motion.

In sophomore Dynamics the primary kinetics principles used to solve problems are usually presented as 1) direct application of Newton's Second Law, 2) work-energy methods, and 3) impulse-momentum methods. In this curriculum these are presented as conservation of linear and angular momentum (rate and finite time forms) and conservation of energy (finite time form). A comparison of the terminology is shown in Figure 2. This figure is given to the students at the beginning of the course to help them relate the material in the text to the material learned in the previous course.

<table>
<tr><th>Principle</th><th>ES201 Name</th><th>Dynamics Name</th><th>Comments</th></tr>
<tr><td>$$\frac{d\vec{P}_{sys}}{dt} = \sum \vec{F}$$
$$\frac{d\vec{L}_{sys_0}}{dt} = \sum \vec{M}_o$$</td><td>Rate form for conservation of linear and angular momentum for a closed system.</td><td>Direct application of Newton's Laws</td><td>When to use:
• want to find forces and/or accelerations
• want to find velocities and/or distance traveled (which can be found by separating variables and integrating the basic kinematic relationships)
Other:
• Be careful! These are vector equations.
• The book uses H_0 for angular momentum instead of L_0.</td></tr>
<tr><td>$$\Delta\vec{P}_{sys} = \int_{t_1}^{t_2} \vec{F}dt\ , \quad \Delta\vec{L}_{sys_0} = \int_{t_1}^{t_2} \vec{M}_0 dt$$
or if there are impulsive loads acting on the system
$$\Delta\vec{P}_{sys} = \sum \vec{F}_i \Delta t\ ,$$
$$\Delta\vec{L}_{sys_0} = \sum (\vec{M}_0)_i \Delta t$$
where F_i and M_i are the external impulsive forces and moments acting on the system.</td><td>Finite time form of conservation of linear and angular momentum for a closed system.</td><td>Impulse-momentum methods</td><td>When to use:
• have an impact or impulsive forces
• the system consists of several objects
• given a force as a function of time
• want to find velocities, times, or forces (especially impulsive forces)
Other:
• Be careful! These are vector equations.
• The book uses H_0 for angular momentum instead of L_0.</td></tr>
<tr><td>$$\Delta E_{sys} = W$$</td><td>Finite time form of conservation of energy for an adiabatic closed system.</td><td>Work-energy methods.</td><td>When to use:
• have two locations in space
• given a force as a function of position
• want to find velocities, distances, or forces (sometimes)
Other:
• This is a scalar equation</td></tr>
</table>

Figure 2 - A comparison between the nomenclature used in Dynamics and the one used in Mechanical Systems

One major advantage of this curriculum and the ordering of the material is that as kinematics is taught it 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 [4]. As did our old dynamics course, ES204 makes extensive use of a computer algebra program, Maple, a dynamic simulation program, Working Model, and Concept Maps [5].

Analysis and Design of Engineering Systems

The mechanics material covered in the spring course, Analysis and Design of Engineering Systems (ES205) is similar to that covered in a traditional systems class. Equations of motion are obtained for mechanical systems (and electromechanical systems) involving 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 of free response, step response and response due to harmonic excitation and general periodic forcing, frequency response plots (Bode plots), transfer functions, and Fourier Series are discussed. The concepts of natural frequency and damping ratio are discussed for mechanical as well as electrical and thermal problems. Clearly, the mechanics material in the area of vibrations is significantly more than what is covered in most sophomore dynamics texts. In fact, at Rose-Hulman, the traditional dynamics course did not discuss the topic of vibrations at all.

ASSESSMENT

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. Table 2 is a comparison for the multiple-choice problems and in Table 3 is a comparison for the workout problems. For the purpose of Tables 2 and 3 it was 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 Tables 2 and 3 were obtained by averaging the results from five dynamics sections (three professors) and from four mechanical systems sections (three professors).

Table 2 Percentage of students with correct answers for the multiple choice problems						
Prob. #	**First Assessment**			**Second Assessment**		
	SEC - ES204	**Dynamics**	**Difference**	**SEC - ES204**	**Dynamics**	**Difference**
1	45.7	43.0	2.7	40.2	32.0	8.2
2	24.7	48.6	-23.9	56.3	61.0	-4.7
3	88.9	90.8	-2.0	94.3	94.0	0.3
4				87.4	81.0	6.4
5	80.2	45.8	34.5	71.3	56.0	15.3
6	72.8	66.9	5.9	82.8	79.0	3.8
7	91.4	62.7	28.7	82.8	76.0	6.8
8	59.3	47.2	12.1	57.5	55.0	2.5
9	87.7	85.2	2.4	87.4	94.0	-6.6
10	74.1	28.9	45.2	78.2	49.0	29.2
11	95.1	95.8	-0.7	90.8	93.0	-2.2
12	48.1	33.8	14.3	46.0	57.0	-11.0
13				96.6	98.0	-1.4
14	92.6	88.0	4.6	90.8	95.0	-4.2
15	90.1	80.3	9.8	66.7	63.0	3.7
16				62.1	54.0	8.1
17	61.7	52.1	9.6	50.6	79.0	-28.4
18	45.7	39.4	6.2	41.4	47.0	-5.6
19				9.2	47.0	-37.8
20	71.6	44.4	27.2	63.2	56.0	7.2

Table 3 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				70.1	22.0	48.1
23				46.0	6.0	40.0

As can be seen from Table 2, the students in the SEC did better than the students taking the traditional dynamics course on a majority of the multiple-choice problems. It is important to note, however, that the percentage difference is quite minor for a number of problems. The difference is more dramatic when looking at the three workout problems. 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 remains 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 4. On average the mechanical engineering students actually performed better although it is not clear if the difference is statistically significant. Therefore, the authors feel confident that the improved performance of students as indicated in Tables 2 and 3 can be attributed to the new curriculum.

Table 4 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

CONCLUSIONS

A new curriculum has been implemented at Rose-Hulman that covers the basic engineering science material. In this curriculum mechanics has been integrated throughout the sophomore year and assessment results indicate students are better in mechanics after taking the new curriculum than are students taking a traditional dynamics course. This difference in performance cannot be attributed to students being in different majors.

References

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