Int. J. Engng Ed. Vol. 16, No. 5, pp. 441–446, 2000
Printed in Great Britain.

0949-149X/91 $3.00+0.00

Mechanics in the Rose-Hulman Foundation Coalition Sophomore Curriculum*

PHILLIP J. CORNWELL and JERRY M. FINE
Rose-Hulman Institute of Technology, Terre Haute, IN 47803, USA.
E-mail: phillip.cornwell@rose-hulman.edu

Rose-Hulman Institute of Technology implemented a new sophomore curriculum starting in the 1995–96 academic year. 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. At Rose-Hulman this material has been repackaged into a new sequence of courses where the concepts of conservation and accounting permeate the courses. The purpose of this paper is to discuss how the mechanics material has been distributed throughout the curriculum and how it is taught in the framework of conservation and accounting. Assessment results will also be presented.

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 Institute of Technology, as part of the NSF-sponsored Foundation Coalition, implemented a new sophomore curriculum starting in the 1995–96 academic year in an attempt 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 [1, 2] and how these thrusts have been incorporated into the curriculum at Rose-Hulman [3].

At Rose-Hulman the engineering science material usually covered in Dynamics, Thermodynamics I, Circuits I and Fluid Mechanics has been repackaged 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. This curriculum has its pedagogical roots in a sophomore curriculum at Texas A&M University [4] and there is at least one textbook that utilizes this methodology [5]. This curriculum was initially required for all electrical engineering majors and starting in 1998 was required for all mechanical engineering students.

The purpose of this paper is to discuss how the mechanics material traditionally taught in a dynamics course has been distributed throughout the curriculum and how it is taught in the framework of conservation and accounting. Assessment results comparing students taking a traditional dynamics class and students taking the new sophomore curriculum will also be presented.

DESCRIPTION OF THE SOPHOMORE ENGINEERING CURRICULUM (SEC)

A comparison between the old and new curriculum is illustrated in Fig. 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.

One purpose 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 evaluate,' and 'I can demonstrate my cleverness by solving problems while showing as little of the actual work as possible.' To cause the

---

* Accepted 15 October 1999.

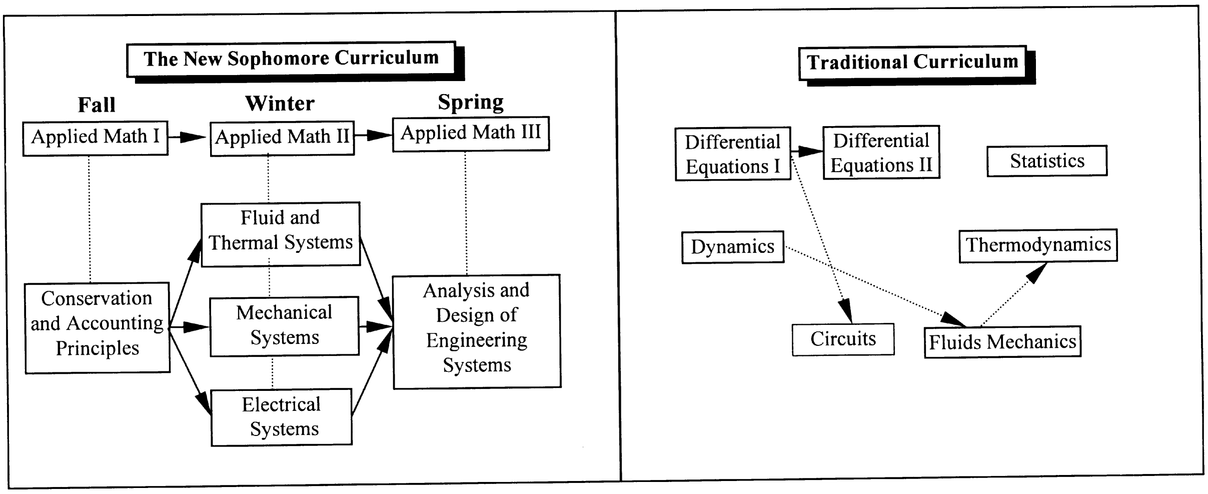

Fig. 1. Comparison of the traditional and the new sophomore curriculum at Rose-Hulman. A sequence of three courses can be used since Rose-Hulman is on the quarter system.

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 quarter, 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 problem:

1. What is the system? In fluid mechanics and thermodynamics 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.

All of the conservation principles can be put in the general form:

$$\frac{dB_{sys}}{dt} = \sum \dot{B}_{in} - \sum \dot{B}_{out} \qquad (1)$$

where B is the extensive property being conserved. For the cases of conservation of linear and angular momentum, B is a vector. Before applying this equation, one must ask how the change of the property in the system is calculated and how the property can be transported across the system boundary. Using this methodology, all of the conservation principles are presented in a common framework. A common homework format in addition to the common problem-solving methodology is also required for all the courses in the curriculum.

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 multidisciplinary problems are tackled.

MECHANICS IN THE SEC

Conservation and accounting 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. The topics not covered in the first course are 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 equations for conservation of linear momentum, angular momentum and energy used in the course are presented below.

Conservation of linear momentum (rate form):

$$\frac{d\vec{P}_{sys}}{dt} = \sum \vec{F} + \sum_{in} \dot{m}_i \vec{v}_i - \sum_{out} \dot{m}_0 \vec{v}_0 \qquad (2)$$

where

$\vec{P}_{sys}$ = linear momentum of the system
$\vec{F}$ = external forces
$\dot{m}_i$ = mass flow entering the system
$\vec{v}_i$ = velocity of mass entering the system
$\dot{m}_0$ = mass flow exiting the system
$\vec{v}_0$ = velocity of mass exiting the system.

Conservation of angular momentum (rate form):

$$\frac{d\vec{L}_{sys_0}}{dt} = \sum \vec{M}_0 + \sum_{in} \vec{r}_i \times \dot{m}_i \vec{v}_i - \sum_{out} \vec{r}_0 \times \dot{m}_0 \vec{v}_0 \qquad (3)$$

where

$\vec{L}_{sys_0}$ = angular momentum of the system about point O (if the system is a single rigid body undergoing plane motion)
$\vec{L}_{sys_0} = I_G \vec{\omega} + \vec{r}_{G/O} \times m \vec{v}_G$
$\vec{M}_0$ = external moments about point O

Conservation of energy (rate form):

$$\frac{dE_{sys}}{dt} = \dot{Q} + \dot{W} + \sum_{in} \dot{m}_i \left(h + \frac{v^2}{2} + gz \right)_i - \sum_{out} \dot{m}_0 \left(h + \frac{v^2}{2} + gz \right)_0 \qquad (4)$$

where

$E_{sys} = E_k + E_G + E_e + U + \ldots$ (that is, system energy = kinetic energy + gravitational energy + elastic energy + internal energy + ...)
$\dot{Q}$ = rate of heat transfer into the system
$\dot{W}$ = power into the system
h = specific enthalpy
v_i = average speed of the mass flow at the inlet
v_0 = average speed of the mass flow at the outlet
z_i = vertical distance of the inlet from an arbitrary datum
z_0 = vertical distance of the outlet from an arbitrary datum

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. These finite time versions are shown below.

Conservation of linear momentum (finite time/closed system):

$$\Delta \vec{P}_{sys} = \int_{t_1}^{t_2} \sum \vec{F} dt \qquad (5)$$

Conservation of energy (finite time/closed system):

$$\Delta E_{sys} = W \qquad (6)$$

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 classes (rate or finite time form for open and closed systems) and how it is applied in most dynamics classes (finite time form for closed systems). 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, 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. As did our traditional dynamics course, ES204 makes extensive use of a computer algebra program, Maple, and a dynamic simulation program, Working Model [6]. 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 dynamics the primary kinetics principles used to solve problems are usually presented as:

- direct application of Newton's Second Law,
- work-energy methods, and
- impulse-momentum methods.

In this curriculum these are presented as conservation of linear and angular momentum (rate and

Table 1. A comparison between the nomenclature used in dynamics and the one used in mechanical systems

Principle	ES201 Name	Dynamics Name	Comments
$\frac{d\vec{P}_{sys}}{dt} = \sum \vec{F}$ $\frac{d\vec{L}_{sys_0}}{dt} = \sum \vec{M}_0$	Rate form for conservation of linear and angular momentum for a closed system.	Direct application of Newton's Laws	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.
$\Delta\vec{P}_{sys} = \int_{t_1}^{t_2} \vec{F}dt$, $\Delta\vec{L}_{sys_0} = \int_{t_1}^{t_2} \vec{M}_0 dt$ 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.	Finite time form of conservation of linear and angular momentum for a closed system.	Impulse-momentum methods	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.
$\Delta E_{sys} = W$	Finite time form of conservation of energy for an adiabatic closed system.	Work-energy methods.	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

finite time forms) and conservation of energy (finite time form). A comparison of the terminology is shown in Table 1. 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.

One advantage of this approach is that as the 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 conservation of energy and/or direct application of Newton's Second Law, that is, the rate form of conservation of linear momentum in our framework.

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 arrangement of the material, students need to decide which conservation principle is most applicable. Similarly, after the kinematics associated with fixed axis rotation is introduced, it is natural to extend the range of problems to include those involving energy, as well as linear and angular momentum for rigid bodies.

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

Table 2. Percentage of students with correct answers for the workout problems

Prob. #	First Assessment SEC - ES204	Dynamics	Difference	Second Assessment 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

course does not discuss the topic of vibrations at all.

Since the mechanics material covered in a traditional dynamics course is extended and distributed over a sequence of three courses the material is frequently revisited at a higher level of learning. This reinforces the material and gives the students some experience with the higher levels of learning in Bloom's Taxonomy of cognitive learning [7].

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 year of the 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). 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. In Table 2 is a comparison of the multiple-choice problems and in Table 3 is a comparison for the workout problems. For the purpose of Table 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).

As can be seen from Table 2, the students in the SEC did, in general, 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 as shown in Table 3. The students in the new curriculum did significantly better than those taking the traditional dynamics course. It is clear from this assessment that the new curriculum certainly does not hurt the students and in fact appears to help students in mastering the mechanics material.

Table 3. Percentage of students with correct answers for the multiple-choice problems

Prob. #	First Assessment SEC - ES204	Dynamics	Difference	Second Assessment 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

CONCLUSIONS

A new sophomore curriculum has been implemented at Rose-Hulman in which the mechanics material traditionally taught in a dynamics course has been expanded and distributed throughout a sequence of three courses and taught within a framework of conservation and accounting. One significant difference between the sequencing of mechanics material in the new curriculum is that the kinetics principles are introduced prior to any significant discussion of kinematics. Assessment results indicate an improved performance by students in the new curriculum over students taking the traditional dynamics course.

REFERENCES

1. K. Frair, J. Froyd, G. Rogers and K. Watson, The Foundation Coalition: past, present and future, *Proc. 1996 Frontiers in Education Conf.,* November 6–9, 1996, Salt Lake City, Utah.
2. K. Frair, D. Cordes, M. Cronan, D. Evans and J. Froyd, The NSF Foundation Coalition – looking towards the future, *Proc. 1997 Frontiers in Education Conf.*, November 5–8, 1997, Pittsburgh, Pennsylvania.
3. D. E. Richards and G. Rogers, A new sophomore engineering curriculum – The Rose-Hulman Experience, *Proc. 1996 ASEE Annual Conf.*, (1996).
4. R. B. Griffin, L. J. Everett, P. Keating, D. Lagoudas, E. Tebeaux, D. Parker, W. Bassichis and D. Barrow, Planning the Texas A&M University College of Engineering Sophomore Year Integrated Curriculum, *Fourth World Conf. Engineering Education*, St Paul, MN, **1** (1995).
5. C. Glover, *Conservation Principles and the Structure of Engineering*, McGraw-Hill, New York, NY (1996) pp. 228–232.
6. P. J. Cornwell, Teaching dynamics using modern tools, *Computers in Education J.,* (Oct–Dec. 1996).
7. B. S. Bloom, (Ed.), *A Taxonomy of Educational Objectives: The Classification of Educational Goals. Handbook 1: The Cognitive Domain,* New York: McKay (1956).

Phillip J. Cornwell is an Associate Professor of Mechanical Engineering at Rose-Hulman Institute of Technology. He received his BS from Texas Tech University in 1985 and his MA and Ph.D. from Princeton University in 1987 and 1989 respectively. His present interests include structural dynamics, health monitoring of structures using changes in their vibration characteristics, and improving undergraduate engineering education. Dr Cornwell has received several awards including the 1990 ASME Aerospace Division Award for a paper he presented at the AIAA/ASME/ASCE/AHS/ACS 30th Structures, Structural Dynamics and Materials Conference, a Ralph R. Teetor Educational Award from SAE in 1992 and Teacher of the Year from a Rose-Hulman student group in 1994.

Jerry M. Fine graduated from Rice University with BA and MME degrees in 1971. After serving as an aviator with the US Navy until 1978, he began graduate studies in the Texas Institute for Computational Mechanics at the University of Texas at Austin. He was awarded the Ph.D. in 1984, specializing in numerical methods for solving systems of ordinary differential equations. He came to Rose-Hulman Institute of Technology in 1986. Since coming to Rose-Hulman, he has been involved with a number of innovations in engineering education, including the development of the Integrated First Year Curriculum in Science, Engineering and Mathematics, and the Foundation Coalition Sophomore Engineering Curriculum.