Using Concepts from Statics and Mechanics of Materials to Teach Engineering Economy

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Abstract

The spectrum of topical knowledge ranges from an awareness of a lack of knowledge to application of the knowledge without thought about the implied knowledge. The acquisition of knowledge can be facilitated when previous knowledge or experience can be applied to the learning process.

In Engineering Economy, the toolbox calculations are based on algebraic expressions for the relationship between present worth, future worth, or annual payments as a function of interest rate and number of compounding periods. For a basic toolbox equation with four parameters (e.g., P, A, F, *i*, or *n*), it is intuitive for engineering students that three of these parameters must be specified in order to solve for an unknown (i.e., one equation and one unknown). These problems may be solved without much thought about the implied knowledge.

After students become familiar with the basic toolbox calculations, the concept of Equivalence is introduced. This topic is based on a definition and is therefore not as intuitive. It is apparent that there is a different rate of learning and therefore ability to apply the concept. As students become familiar with the concept, errors as well as the time needed to solve an Equivalence problem decrease. The generally accepted approach is to teach the concept by presenting numerous applications of the definition. This paper presents an alternative by integrating the previously learned concept of moments from Statics and Mechanics of Materials. In this approach, students are able to perform the calculations with little understanding and then learn the concepts. The result is that much less time is allocated to learning these topics.

Introduction

In order to reduce the cost of higher education, engineering faculty are under pressure to reduce credit-hour requirements for their degree programs. For example, engineering programs in Tennessee recently were mandated to reduce engineering degree requirements to 128 credit hours. Faculty must carefully design degree programs that reflect these directives and at the same time minimize the potential effects of such directives on the public's health and safety.

Elizandro and Matson[1] have presented a systematic methodology for administering degree programs in this type of environment. That approach extends the ABET Criteria for Accrediting Engineering Programs[2] by defining curriculum effectiveness and efficiency. Effectiveness refers to the achievement level of ABET Program Outcomes and Program Objectives, and efficiency measures the portion of the curriculum devoted to each Program Outcome and Program Objective.

An educational environment should be designed to move students from an awareness of a lack of knowledge to the application of the knowledge without thought about the implied knowledge.

Laptop and desktop computers have leveraged student productivity in achieving this result. With these tools the elapsed time for students to learn new course concepts and reinforce these concepts has been significantly reduced. Audiovisual technology has also increased classroom productivity because material can be organized and presented in a much more efficient manner. For the last twenty years these have been the most common approaches to increasing curriculum efficiency. Recent extensions of audiovisual technology have been in the area of distance education. Distance education facilitates the learning process by providing the educational environment at times that are convenient to the student. With the exception of distance education, these approaches are mature and therefore recent productivity improvements are not as dramatic.

Because the acquisition of knowledge can be facilitated when previous knowledge or experience can be applied to the learning process, another approach to facilitate the learning process is to identify concepts that are familiar to the students as the basis for teaching new concepts. Using the learning strategies exemplified in concept mapping, this approach focuses on adding links in the concept map. Additional links make it easier for students to learn and retain information[3]. Although different in scope to traditional interdisciplinary research efforts, this could be used as the basis for organizing interdisciplinary faculty teams for pedagogical research.

Within the engineering curriculum, engineering economy educators have noted a lack of significant change in engineering economy courses and textbooks over many decades[4], the need to decrease emphasis on rote calculations[4,5], and the corresponding need to increase the attention devoted to design and/or decision-making[4,5,6]. Instructional methods that decrease the time required for students to master the rote calculations can provide additional time for focusing on design and decision-making. As in other engineering courses, technologies such as spreadsheets and computers have provided productivity improvements in the past. Surveys[7] have shown a variety of traditional instructional methods are in current use. The focus of this paper, however, is on an instructional approach that builds on the student's experience and knowledge, adding links to speed and improve learning.

The remaining sections describe an alternative approach to teaching Engineering Economy based on the concept of moments from Statics and Mechanics of Materials. Preliminary results indicate that this may provide for a more efficient utilization of credit hours.

Environment

The Department of Industrial Engineering at Tennessee Technological University offers two courses in Engineering Economy. Course Outcomes for the three-credit-hour course, IME 3100, are presented below. Course Outcomes for the two-credit-hour course, IME 3110, are outcomes a through d.

a. **Summarize concepts of time value of money**. Cash flow diagrams; compound, nominal, and effective interest rates; and equivalence.
b. **Perform interest formula calculations for cash flow diagrams.** Present worth, annual equivalence, future worth, and internal rate of return for single, uniform, and gradient series payments.

c. **Develop the cash flow diagram for a project.** Sunk cost; nonrecurring cost; salvage value; revenues and expenses.
d. **Perform an economic analysis**. Sensitivity analysis of alternative projects using cost of capital/minimum annual rate of return. Alternatives with equal and unequal project lives as well as with and without project replacement; additional techniques including benefit/cost analysis, incremental internal rate of return, and payback period.
e. **Determine the effect of taxes and inflation on profitability of projects**. Straight line, sum of years digits, percentage completion, and MACRS depreciation methods.
f. **Perform replacement analysis for existing assets.** "Initial" cost and economic life before and after taxes.
g. **Perform basic capital budgeting.** Cutoff rate of return and present worth method.

Most Civil Engineering majors enroll in the two-credit IME 3110 course. The three-credit IME 3100 is required for industrial engineering and mechanical engineering students and is an elective for electrical engineering students. All students are in the same class but the IME 3110 course meets for approximately two thirds of the semester. With the exception of industrial engineering students, most of the students in both courses are seniors. All students have completed the Statics course.

The current text is *Engineering Economic Analysis*, 8th edition, by Newnan, Lavelle, and Eschenbach[8]. Chapters 3 and 4 of the text present calculations based on algebraic expressions for the relationships between present worth, future worth, or annual payments as a function of interest rate and number of compounding periods. For a basic equation with four parameters (e.g., P, A, F, *i*, or *n*), it is intuitive for engineering students that three of these parameters must be specified in order to solve for an unknown (i.e., one equation and one unknown). These problems may be solved without much thought about the implied knowledge.

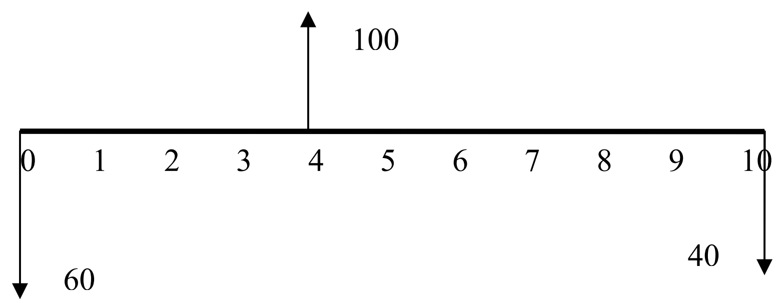
After students are familiar with the basic calculations, Equivalence is introduced. This topic is based on a definition. The concept is taught by presenting numerous applications of the definition. It is apparent that there is a different rate of learning and therefore ability to apply the concept. As students become familiar with the concept, errors as well as the time needed to solve an Equivalence problem decrease. Chapters 5 and 6 address the Present Worth and the Annual Uniform Payment Analysis, respectively. Chapters 7, 8, and 9 address other before-tax alternative selection methods.

During the fall 2003 semester, chapters 3 through 9 were presented using concepts of moment equations from statics and Chapters 5 and 6 were covered simultaneously and presented as extensions to the moment equations concept. The following sections detail the approach.

Concepts of Mechanics

Basic moment equations may be developed by assuming clockwise as positive and recalling that a moment about a point is defined as the sum of the products of each force and the length of its moment arm, or distance from that point. Each moment term acts in a clockwise or counter clockwise direction. Moment equations are used to determine equilibrium of a body acted upon by forces. For example, in the following problem, there are 60, 100, and 40 lb. forces at locations 0, 4, and 10, respectively. This body is in equilibrium because the moment at any point is 0; however, points 0, 4, and 10 simplify the calculations. Moments about each of these points are:

At 0: (-100)*4 + 40*10 = 0
At 4: (-60)*4 + 40*6 = 0
At 10: (-60)*10 + 100*6 = 0



Because of linearity, we assume that the length of the moment arm is positive. We can modify the definition such that an upward force is positive and downward force is negative, and when the force is to the left of the point where moment is taken, the length of the moment arm is positive. In a similar fashion, when the force is to the right of that point, the moment arm is negative. Using this definition, the above moment equations may be written as:

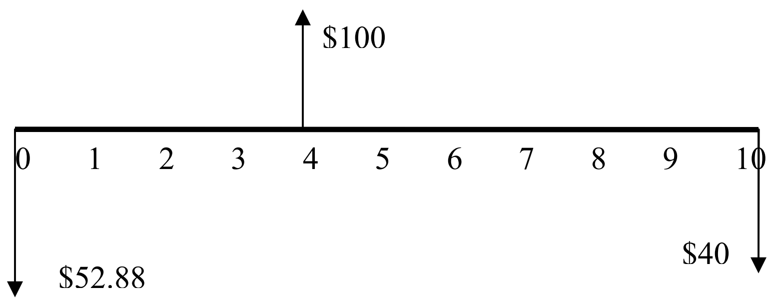
At 0: (100)*(-4) + (-40)*(-10) = 0
At 4: (-60)*(4) + (-40)*(-6) = 0
At 10: (-60)*(10) + 100*(6) = 0

In mechanics, either definition may be used to solve moment equations. The following section describes how the second definition is applied to Engineering Economy cash flow diagrams.

Concepts of Engineering Economy

The concept of moment equations may be applied to complex cash flow diagrams; however, rather than a moment arm linear in length x, the moment arm is $(1+i)^x$, where x is the distance in time units from the point where the moment is being determined. Because the moment arm is not linear, the direction of the cash flow and its relative position to the point where the moment is taken becomes the basis for these calculations. Therefore, the range of x is ($-n <= x <= n$) where n is the number of periods in the analysis and i is the compound interest rate.

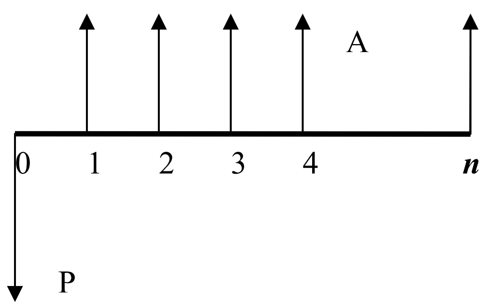
The following cash flow diagram represents an analysis period of 10 years; cash flows in the amount of -$52.88, $100, and -$40 occur at the end of periods 0 4, and 10, respectively.



Because the cash flow diagram is in equilibrium, the summation of moments about any other time period is $0. Applying the moment equation definition to this cash flow diagram with a compound interest rate of 10% at periods 0, 4, and 10 indicates that this cash flow diagram is in equilibrium at these points.

$$\text{At 0: } (-52.88)*(1.1)^{0} + 100*(1.1)^{-4} + (-40)*(1.1)^{-10} = 0$$
$$\text{At 4: } (-52.88)*(1.1)^{4} + 100*(1.1)^{0} + (-40)*(1.1)^{-6} = 0$$
$$\text{At 10: } (-52.88)*(1.1)^{10} + 100*(1.1)^{6} + (-40)*(1.1)^{0} = 0$$

Equivalence is developed based on the mechanics concept of equilibrium. For example, the present worth of a series of uniform payments may be viewed as the moment equation about time period 0.



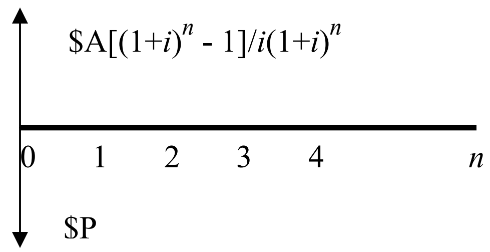
The moment equation at time period 0

$$-P(1+i)^{0} + A(1+i)^{-1} + A(1+i)^{-2} + A(1+i)^{-3} + \quad + A(1+i)^{-n} = 0$$

has the solution:

$$P = A[(1+i)^{n} - 1]/i(1+i)^{n}$$

As shown below, the resultant single payment at time period 0 of magnitude $A[(1+i)^{n} - 1]/i(1+i)^{n}$ has the opposite direction of P. There is a similar development for each of the commonly used engineering economy equations. The algebraic equations for P/F(i,n) and F/P(i,n), which are $(1+i)^{-n}$ and $(1+i)^{n}$, are moment arm expressions.



As described in the following section, the moment equations analogy seemed to enable students from both courses to quickly use the toolbox equations to solve for unknowns in cash flow diagrams.

Each of the alternative selection techniques was developed in a similar fashion. Present Worth and Annual Uniform Payments analysis techniques were presented simultaneously using the moment equations analogy and described as follows:

> Present and Future Worth are calculated using a moment equation at time 0 and n respectively.
>
> Annual Cash Flow Analysis of an alternative is the moment at time 0 or n multiplied by A/P(i,n) or A/F(i,n) respectively.

Internal Rate of Return and Benefit-Cost analysis are presented in a similar fashion but most of the discussion focuses on nuances of the best alternative selection criteria. The techniques are briefly described as follows:

> Internal Rate of Return for an alternative is based on the concept of moment equilibrium. The cash flow diagram and n are known; the unknown is the Internal Rate of Return. The cash flow diagram is by definition in equilibrium; therefore the moment may be taken anywhere along the time line and is always equal to 0.
>
> The Benefit-Cost of an alternative is viewed as two cash flow diagrams, one for benefits and the other for costs. The n and i are also known values. The Benefit Cost Ratio is the benefit moment divided by the absolute value of the cost moment; moments may be taken anywhere along the time line but it must be the same location for both cash flow diagrams.

In order to correctly apply alternative comparison techniques, the appropriate time for the analysis must be established. The student must determine whether the comparison involves alternatives with equal versus unequal lives as well as with or without replacement. These relationships are presented in table 1.

Table 1. Approaches for Replacement and Life Conditions

Condition	Equal Life	Unequal Life
With Replacement	For Annual Equivalence use life of the alternatives. Present Worth is Annual Equivalence * P/A(i,N*n) where N is the number of replacements and n is the alternative life.	For Annual Equivalence use respective alternative lives. For Present Worth use common multiple of alternative lives.
Without Replacement	For Annual Equivalence or Present Worth use life of the alternatives.	For Annual Equivalence use longest alternative life. For Present Worth use respective alternative life.

In the course material on effects of taxes and inflation as well as replacement analysis and capital budgeting, concepts of alternative evaluation techniques are used without any discussion on mechanics of the methods. The next section compares results of offering the Engineering Economy courses in consecutive semesters, one using the traditional approach and the other using the mechanics analogy as the basis for the course.

Analysis

The comparisons are not based on a complete statistical analysis; however, these preliminary results indicate that there is merit in further investigation of the mechanics-based approach. The fall 2003 sections were conducted using mechanics concepts as the basis for the introductory course concepts described in the previous section. Exam scores and times between exams are compared with spring 2003 courses, which were taught using the traditional approach. In the spring semester the IME 3100 and IME 3110 courses had five and three class examinations respectively. During the fall semester the IME 3110 students were required to complete the fourth exam. Fall and spring semester exams are sufficiently similar that any differences in corresponding exams between semesters are independent of the approach to the course.

In table 2, elapsed time is the number of class days between exams; t_1- t_0 and t_n - t_5 represent the elapsed number of class days between the first day of class and day of the first exam and the elapsed number of class days between the last exam and last scheduled class day in the semester. As indicated in the table, the number of class days to the third exam was reduced from 19 to 15. Additional compression of days between the first three exams in the fall was problematic because students had conflicts with exams in other classes. The fourth and fifth exams cover taxes, inflation, replacement analysis, and capital budgeting. The approach to presenting this material was essentially the same for both semesters; therefore, the time allocated to these topics was essentially the same.

Table 2. Elapsed Time to Exams (in Days)

Elapsed Time	Traditional: Spring 2003	Mechanics-Based: Fall 2003
$t_1 - t_0$	6	6
$t_2 - t_1$	6	5
$t_3 - t_2$	7	4
$t_4 - t_3$	5	4
$t_5 - t_4$	4	5
$t_n - t_5$	1	5

The number of students enrolled in the fall IME 3110 courses is small. However, averages and standard deviations of exam scores illustrated in figure 1 and table 3 indicate that exam scores in the fall semester were at least as good as those in the spring. As mentioned in a previous section, the IME 3110 course is for Civil Engineering students. As one may expect, there is some indication that these students grasp the application of mechanics concepts to engineering economy very quickly. The standard deviation of the second exam for the fall IME 3110 course is the result of only one student who did very poorly on the second exam; otherwise the second exam average for both fall semester courses would be much better that those in the spring. There was no significant difference in the presentation of material for exams 4 and 5 between semesters. However, there is insufficient data to attribute differences between average scores for these exams to different approaches to the first part of the course.

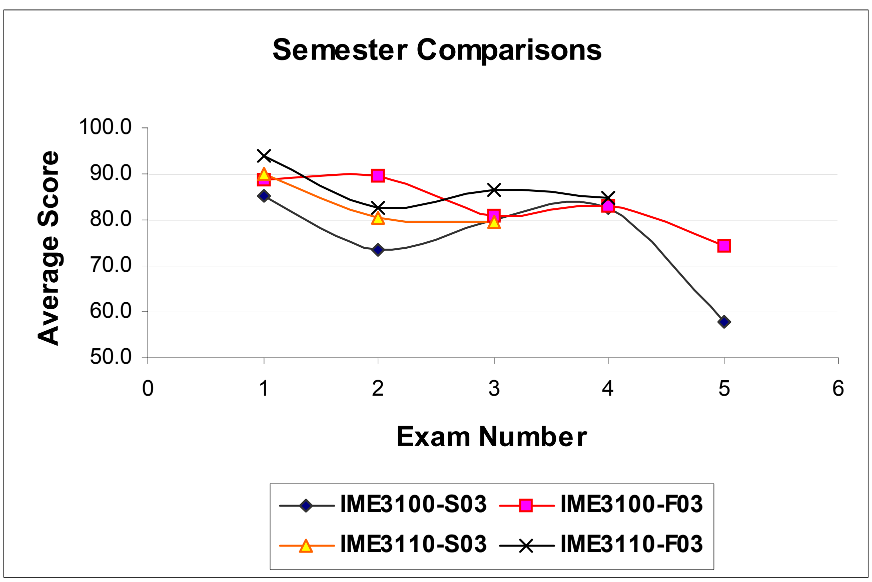


Figure 1. Average Exam Scores by Semester and Course

Table 3. Standard Deviation of Exam Scores by Semester and Course

Section and Semester	Examination 1	2	3	4	5	Class Size
IME 3100 – S03	13.9	19.0	10.0	12.4	13.8	20
IME 3100 – F03	11.7	7.9	11.7	9.9	14.0	21
IME 3110 – S03	12.4	10.9	13.0	N/A	N/A	10
IME 3110 – F03	5.1	17.9	11.5	10.1	N/A	7

To determine whether there were significant differences in student ability that might affect results, a comparison was made of the cumulative grade point averages (GPAs) of students enrolled in the spring and fall sections. Table 4 shows the means and standard deviations of the cumulative GPAs for students in the combined (IME 3100 and 3110) sections for spring and fall.

Table 4. Averages and Standard Deviations of Student Cumulative GPA

Cumulative GPA	Traditional: Spring 2003	Mechanics-Based: Fall 2003
Mean	2.743	2.983
Standard deviation	0.463	0.579

A two-tailed, two-sample means test at the 0.05 level of significance resulted in the conclusion that there is no difference in the mean GPAs of enrolled students from spring to fall. However, a one-tailed test at the same level of significance resulted in the conclusion that the GPAs of students enrolled in fall semester were higher than for spring semester. Since the equivalence of enrolled students was uncertain, further comparisons were needed. The objective of this analysis was to ensure that student grades were not adversely affected by the mechanics-based approach.

The average course grades for the two groups were compared to ensure that actual course grades were at least as high using the mechanics-based approach in fall semester. Table 5 provides a summary of the average and standard deviation of course grades by semester.

Table 5. Averages and Standard Deviations of Course Grade

Course Grades	Traditional: Spring 2003	Mechanics-Based: Fall 2003
Mean	2.548	3.000
Standard deviation	0.961	0.926

A two-tailed, two-sample means test at the 0.05 level of significance resulted in the conclusion that there is no difference in the mean grades for the two semesters. Again, however, a one-tailed test at the same level of significance resulted in the conclusion that the grades are higher for the mechanics-based approach. Because there appeared to be higher course grades in fall as well as higher GPAs of enrolled students, a comparison was made between the cumulative GPA and the grade in the course for each student. Table 6 shows a summary of the average and standard deviation of the differences between the cumulative GPA and course grade by semester.

Table 6. Statistics for Differences Between Cumulative GPA and Course Grade.

Difference: Cumulative GPA Minus Course Grade	Traditional: Spring 2003	Mechanics-Based: Fall 2003
Mean	0.195	-0.017
Standard deviation	0.783	0.609

A two-sample means test at the 0.05 level of significance resulted in the conclusion that there were no significant differences in cumulative GPAs and course grades from one semester to the next. Thus, the results of the mechanics-based approach were as good as for the traditional approach. Further analysis with additional sections of students in future semesters is warranted to determine if the mechanics-based approach can actually improve efficiency and improve performance on early examinations, thus improving course retention, course grades, and student satisfaction.

Conclusions

To reduce the cost of engineering education, faculty are being directed to reduce credit-hour requirements for degree programs. Therefore, instructional techniques must continue to become more efficient to reflect these directives and at the same time minimize the potential effects of such directives on the public's health and safety.

Laptop and desktop computers have reduced the time for students to learn and reinforce new concepts. Audiovisual technologies, including distance education, have also increased learning productivity.

Because the acquisition of knowledge can be facilitated when previous knowledge or experience can be applied to the learning process, another approach to facilitating the learning process is to utilize concepts that are familiar to the students as the basis for teaching new concepts. Although different in scope from traditional interdisciplinary research efforts, this could be the basis for organizing interdisciplinary faculty teams for pedagogical research.

The generally accepted approach to teaching introductory concepts of Engineering Economy is by presenting numerous applications of abstract definitions. This paper presents the results of using the concept of moments from Statics and Mechanics of Materials as the basis for introducing Engineering Economy. Preliminary results indicate that there is merit in further investigation of this approach.

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