AC 2010-1477: INTEGRATION OF ENGINEERING ECONOMICS, STATISTICS, AND PROJECT MANAGEMENT: REINFORCING KEY CONCEPTS

Paul Kauffmann, East Carolina University

Paul J. Kauffmann is Professor and Chair in the Department of Engineering at East Carolina University. His industry career included positions as Plant Manager and Engineering Director. Dr. Kauffmann received a BS degree in Electrical Engineering and MENG in Mechanical Engineering from Virginia Tech. He received his Ph.D. in Industrial Engineering from Penn State and is a registered Professional Engineer in Virginia and North Carolina.

Stephanie Sullivan, East Carolina University

Stephanie Sullivan is a visiting instructor in the Department of Engineering at East Carolina University. She received a MS in Chemical Engineering from NC State University. Her research interests focus on biomaterials and bioprocessing. Educational efforts include the development of a bioprocess engineering laboratory, engineering program outreach, as well as curriculum development.

Gene Dixon, East Carolina University

Gene Dixon is an assistant professor in the Department of Engineering at East Carolina University. He received a BS in Material Engineering from Auburn University, an MBA from Nova Southeastern and a PhD in Industrial and System Engineering and Engineering Management from the University of Alabama – Huntsville. His professional experience includes positions with Chicago Bridge and Westinghouse. General research interests focus on engineering management and related processes. Specific interests include the role of leaders and followers in the leadership process.

B.J. Kim, East Carolina University

BJ Kim is an assistant professor in the Department of Engineering at East Carolina University. He received a PhD in Industrial, Management Systems, and Manufacturing Engineering from the University of Nebraska – Lincoln. General research interests focus on decision support systems, information systems management, and human-machine interactions. Educational research interests include computer-aided interactive program development and web-based distance learning.

Integration of Engineering Economics, Statistics, and Project Management: Reinforcing Key Concepts

Abstract

Engineering economics, statistics, and project management are courses which have significant workplace application. Consequently, it is important that they prepare graduates with essential skills which complement the technical engineering content of engineering programs and make new engineers more effective in applying technology and solving problems. These courses are often offered independently and the concepts contained in each are not linked to clearly illustrate how these courses together represent an essential, integrated, and complementary body of knowledge. This presents a lost opportunity in reinforcing concepts in areas such as project valuation, variation in estimates, statistical risk, expected value and similar real world topics which are essential in a project engineering workplace. This paper presents a curricular plan to accomplish integration of key topics in these courses in a focused and effective manner. It begins with examining general concepts in engineering curriculum integration. Next it examines key curricular topics in engineering economics, statistics, and project management courses and maps specific areas which can be reinforced and integrated. Finally, it maps course concepts to the Fundamentals of Engineering (FE) exam and segments FE topics based on those which apply to the Industrial Engineering exam (afternoon segment) and those which are more broadly applicable to the general portion of the exam (morning segment) and other engineering disciplines. The paper contributes to the literature on curricular integration, work place skills, and pass rate for the FE exam.

Introduction

The concept of an integrated engineering curriculum is based on the foundation of how engineering is defined and how engineering is practiced. Most commonly accepted definitions of engineering involve the concept of the application of mathematics and science to solve real world or applied problems. Closely aligned to this definition is the question of how engineering problems are solved, often called the engineering design process or the engineering approach. Koen[1] described this engineering approach as "the strategy for causing the best change in a poorly understood situation within available resources." Another similar definition indicates the engineering approach "links concepts and resources together to create what has never been."[2] Based on the definition of engineering and the concept of the engineering approach to problem solving, engineering educators have continually examined approaches to equip graduates with the needed skills through the program curriculum.

As a vehicle for curricular improvement, the goal of an integrated curriculum has been a frequent and consistent topic of study and analysis. Froyd and Ohland[3] trace the initiation of the study of and focus on an integrated engineering curriculum to 1988. Their comprehensive paper summarized a number of key areas based on the literature at the time of publication (2005) and contains references to over 170 papers, books, and conference proceedings.

A fundamental skill set targeted by the integrated curriculum and identified by individual authors and national studies involves development of integrated and system based thinking coupled with the ability to analyze and reduce information. This is a challenging educational objective since it goes beyond the ability to learn individual bodies of knowledge contained in individual courses. Many of these papers have focused on the integration of mathematics and science with engineering in the first two years of typical BS programs. Typical of these writings are Everett, Imbrie, and Morgan[4] who examine efforts to integrate science and mathematics into problem solving and design in a foundations curriculum. Other papers address the integration of specific topics such as mathematics, physics, and chemistry in the first two years.[5, 6] Often, as in Olds and Miller,[7] the focus of these efforts is not only to build a curricular foundation but also to improve retention.

A smaller body of literature examines methods to employ an integrated curriculum to develop skills in nontechnical (softer skill) outcomes in areas covered in ABET a-k criteria[8] including the ability to function on multidisciplinary teams, an understanding of professional and ethical responsibility, an ability to communicate effectively, the broad education necessary to understand the impact of engineering solutions in a global and societal context, a recognition of the need for and an ability to engage in life-long learning, and a knowledge of contemporary issues.[9,10,11] Our paper contributes to this literature and addresses a more focused area of integrated curricular planning than has been commonly examined; specifically that of integrating key, high level concepts in a degree program. This element of curricular integration is essential since research indicates that information gained through learning which is based on one time feedback (i.e. test or quiz) without repetition and context is lost within a few months.[12] This indicates that students often do not retain knowledge of key concepts after completion of a course and this has very negative implications for degree programs. However, if a topic can be presented to students multiple times and in an increasingly richer context, learning is substantially enhanced.

As noted, the literature on developing an integrated curriculum with an overall program focus is limited and the following examples are provided as context for the general directions which have been published. Several examples involve the use of concept maps[13] as a tool to trace ideas through the learning process and for assessment.[14, 15] Another approach involves the use of a concept called “academic threads” in which specific topics are considered for integration at a number of different points within the curriculum.[16] Finally several papers use decision analysis tools such as quality function deployment.[17]

This paper extends this literature involving curricular integration at a program level and proposes an approach which is similar in concept to the academic thread paradigm. The basis of our application is that certain courses in a program can be viewed, based on the chain of prerequisites, as “capstone” or concept integration courses for a sub set of specific skills developed in previous courses. Using this focus, concepts can be mapped from one course to the next, can be reinforced, and can be developed in a richer and more applied context. The paper addresses integration of a natural and related group of three topical areas found in many engineering programs and identified as high priority skills by industry: statistics, engineering economics and project management.

Curriculum Context

The basic course plan of the curricular integration implementation rests on the sequence of courses described in Figure 1. Although it is not always possible to predict the requirements of the capstone project, the curriculum in statistics, engineering economics, and project management is laid out to provide a foundation for possible analytical tools in the senior capstone project sequence. Building on Calculus I and II in freshman year, students take mathematical statistics in sophomore year followed by applied engineering statistics. These are followed by engineering economics and project management in junior year. This builds to the capstone project sequence in senior year. The next section provides examples of topics which are integrated in this sequence.

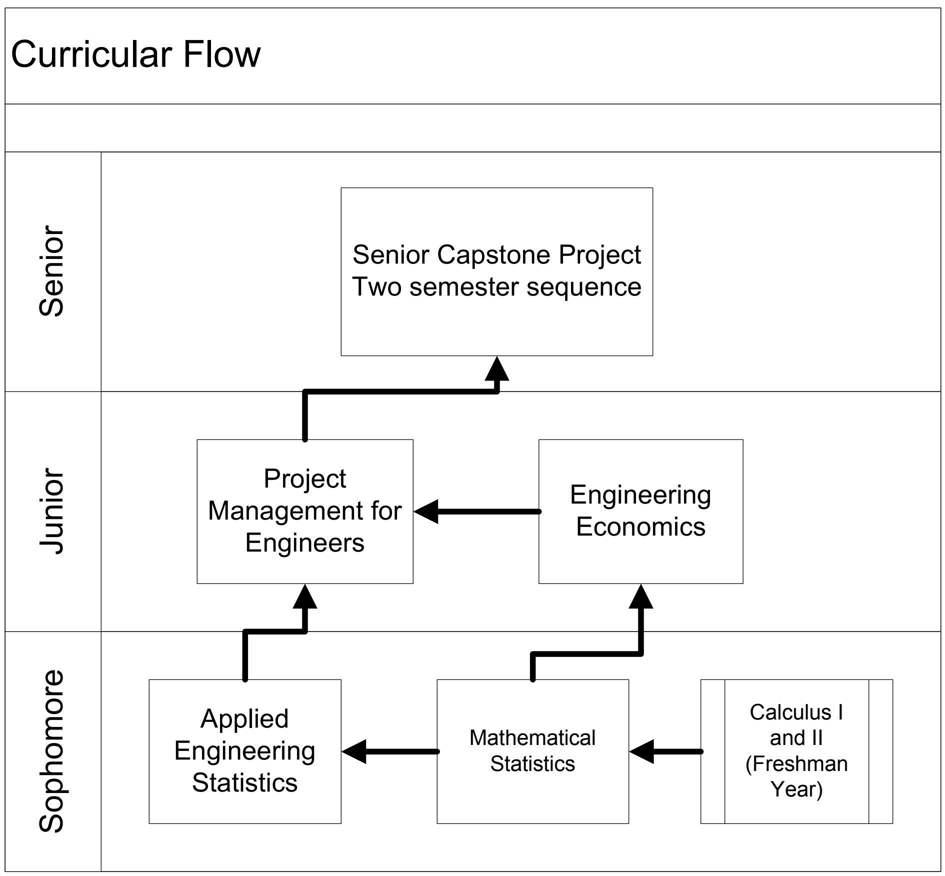

Figure 1 Course Plan and Sequence

Topical Integration

Table 1 provides an example of possible areas targeted for multiple applications across the courses in the integrated curriculum thread concept. By careful application of lectures, homework, and other assignments, the topics noted in Table 1 can be covered multiple times and in an increasingly rich context. Using embedded questions or other assessment means, student progress in these topics can be measured from a foundation skill level to more advanced levels.

As an example, consider the curricular thread involving risk management. Engineering decisions are often made in an uncertain environment and involve risk factors. Integrating uncertainty and risk with a core curriculum is a significant advantage. Risk-analytic methods are often taught in engineering courses. However, it is important to build depth and skills in creativity and realism in developing estimates of uncertainty and risk associated with alternatives and potential outcomes. The table below describes the topic areas across the courses in the integrated curriculum.

Table 1 Application of Topics in Integrated Curriculum Plan

Topic	**Mathematical statistics**	**Applied Engineering Statistics**	**Engineering Economics**	**Project Management**
Probability laws and conditional probability	Introduce foundation concepts and reliability block diagrams.	Apply to decision trees and Bayesian decisions	Apply using decision trees and payoff tables	Apply using reliability block diagrams
Discrete distributions, histograms, and expected value	Introduce foundation concepts	Apply uncertainty analysis using deterministic values	Apply expected value and variation in risk analysis	Apply risk analysis using crystal ball and discrete event models.
Continuous distributions: normal, exponential, lognormal, beta	Introduce foundation concepts	Goodness of fit	Examine in cost estimating	Apply in PERT / CPM context
Point estimate and confidence intervals for a single mean	Foundation concept	Review and apply to multiple populations	Apply to estimating	Apply in project context
Uncertainty and expected value	Foundation concept	Expand concepts in uncertainty analysis	Apply to cash flow risk	Apply to project risk
Sums of random variables	Introduce concepts		Review in a cost estimating context	Apply to project cost estimating
Linear regression and curve fitting.		Introduce foundation concepts	Apply in cost estimating context	Apply to estimating project elements
Present worth and rate of return methods			Introduce foundation concepts	Apply in a project comparison context
Fixed and variable cost			Introduction of concepts	Apply in a project comparison context
Monte Carlo Simulations	Introduction of basic concepts	Apply in a computational context	Apply in a risk of estimate context	Apply in a project completion context
Software applications	Excel	Excel and statistical software (minitab)	Excel	Excel, Crystal Ball, MS Project

Fundamentals of Engineering Impact

The concept of an integrated curriculum in the areas noted in Table 2 can also provide a foundation for topical preparation for the Fundamentals of Engineering (FE) exam. The topics selected in integrating the curriculum across statistics, engineering economics and project management provide an excellent opportunity to assure adequate and repetitive coverage of topics included in the FE exam. However program faculty decide to employ the FE exam in the program assessment plan, it cannot be denied that there is great potential in its use as an assessment tool when integrated into a comprehensive plan which includes multiple data sets and analytical perspectives. Table 3 provides one possible scheme of mapping topics in the FE exam based on the coverage topics and weights specified in the exam literature.[18]

The first part of Table 2 examines the topics in the morning portion of the FE exam and these are common to all engineering disciplines. The afternoon exam is discipline specific and a number of areas are also presented in Table 2. There are two points evident in examining this table. First, integrating these courses (which are often service courses) can positively impact FE performance across a range of engineering disciplines. The concept of identifying curricular threads is a powerful method to provide comprehensive topical impact across a number of engineering topics and disciplines. Second, the percentage of the exam questions impacted by these four courses is about 15% in the morning portion and as high as 20% (general afternoon exam) to 30% (industrial engineering afternoon exam).

Table 2 FE Exam Topics

FE Exam Area	Mathematical Statistics	Engineering Statistics	Engineering Economics	Project Management
Morning Exam Engineering Probability and Statistics 7%				
A. Measures of central tendencies and dispersions (e.g., mean, mode, standard deviation)	X	X	X	X
B. Probability distributions (e.g., discrete, continuous, normal, binomial)	X	X	X	
C. Probability and conditional probabilities	X		X	X
D. Estimation (e.g., point, confidence intervals) for a single mean	X	X		
E. Regression and curve fitting		X	X	X
F. Expected value (weighted average) in decision-making	X		X	
G. Hypothesis testing		X		
Morning exam Engineering Economics 8%				
A. Discounted cash flow (e.g., equivalence, PW, equivalent annual FW, rate of return)			X	X
B. Cost (e.g., incremental, average, sunk, estimating)			X	X
C. Analyses (e.g., breakeven, benefit-cost)			X	X
D. Uncertainty (e.g., expected value and risk)	X		X	X
Afternoon- Chemical: Process Design and Economic Optimization 10%				
A. Process flow diagrams (PFD)				
B. Piping and instrumentation diagrams (P&ID)				
C. Scale-up			X	X
D. Comparison of economic alternatives (e.g., NPV, discounted cash flow, rate of return)			X	X
E. Cost estimation			X	X
Afternoon- Civil: Construction Management 10%				
A. Procurement methods (e.g., design-build, design-bid-build, qualifications based)				
B. Allocation of resources (e.g., labor, equipment, materials, money, time)				
C. Contracts/contract law				
D. Project scheduling (e.g., CPM, PERT)		X		X
E. Engineering economics			X	X
F. Project management (e.g., owner/contractor/client relations, safety)				X
G. Construction estimating		X	X	X
Afternoon –Industrial: Engineering Economics 15%				
A. Discounted cash flows (equivalence, PW, EAC, FW, IRR, loan amortization)			X	X
B. Types and breakdown of costs (e.g., fixed, variable, direct and indirect labor, material, capitalized)			X	X
C. Analyses (e.g., benefit-cost, breakeven, minimum cost, overhead, risk, incremental, life cycle)			X	X
D. Accounting (financial statements and overhead cost allocation)			X	
E. Cost estimating		X	X	X
F. Depreciation and taxes			X	
G. Capital budgeting			X	X

FE Exam Area	Mathematical Statistics	Engineering Statistics	Engineering Economics	Project Management
Afternoon- Industrial: Probability and Statistics 15%				
A. Combinatorics (e.g., combinations, permutations)	X			
B. Probability distributions (e.g., normal, binomial, empirical)	X	X	X	X
C. Conditional probabilities	X		X	X
D. Sampling distributions, sample sizes, and statistics (e.g., central tendency, dispersion)	X	X	X	X
E. Estimation (point estimates, confidence intervals)	X	X	X	X
F. Hypothesis testing	X	X	X	
G. Regression (linear, multiple)	X	X	X	X
H. System reliability (single components, parallel and series systems)	X	X	X	X
I. Design of experiments (e.g., ANOVA, factorial designs)	X	X		
Afternoon-General: Engineering Probability and Statistics 9%				
A. Sample distributions and sizes	X	X		
B. Design of experiments	X	X		
C. Hypothesis testing		X		
D. Goodness of fit (coefficient of correlation, chi square)		X		
E. Estimation (e.g., point, confidence intervals) for two means		X	X	X
Afternoon- General: Engineering Economics 10%				
A. Cost estimating	X	X	X	X
B. Project selection			X	X
C. Lease/buy/make			X	X
D. Replacement analysis (e.g., optimal economic life)			X	X

Summary

This paper examined the concept of curricular integration for upper division topics contained in undergraduate courses such as statistics, engineering economics, and project management. This curricular approach of considering academic threads, which continue across multiple courses, presents significant opportunities to reinforce concepts, demonstrate them in an increasingly rich and realistic context, and better equip students for improved performance in the work place. Additional benefits include the potential to improve performance on the FE exam and to enhance faculty collaboration on assessment. Finally, an important issue is to provide additional skills which may be important on the senior capstone project.

As we progress with the plan to accomplish this curricular improvement, it is important to develop an assessment plan which monitors success in advancing and measuring student skills in integrating concepts and solving more complex problems by employing appropriate tools. This is in fact the goal of the twenty plus years of efforts by engineering educators to pursue approaches to integrate the engineering curriculum and we hope this paper contributes an important example and conceptual approach to achieving this goal.

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