Session 1657

A Conceptual Model for Integrating and Synthesizing the Industrial Engineering Curriculum

Bryan A. Norman, Mary Besterfield-Sacre, Bopaya Bidanda, Kim LaScola Needy, Jayant Rajgopal
University of Pittsburgh

Abstract

The Department of Industrial Engineering at the University of Pittsburgh is addressing an important issue in IE education – how to develop a comprehensive, integrated curriculum that (1) thoroughly prepares graduating engineering students for industrial practice and graduate school, (2) is pedagogically sound, and (3) trains students to readily recognize and apply their engineering background to solve unstructured problems, both locally and beyond US borders. We present an innovative and unique approach to curriculum reform that contains four overarching objectives: (1) the integration of fundamental concepts across the curriculum; (2) teaching students to synthesize different concepts to solve unstructured problems; (3) providing problem solving methods and strategies within a societal framework that allows for their application in a local as well as a global context; and (4) creating a portable development methodology that can be readily adapted to other engineering disciplines. Our broad objective is to develop a technically sound undergraduate IE curriculum that will (a) be tightly integrated and allow for enhanced learning, (b) ensure that our graduates will have the life-long engineering proficiencies to successfully apply what they learn, (c) allow our graduates to appreciate the societal role of engineering, both locally and globally, and (d) serve as a model for incorporating these same objectives into curricula for other industrial engineering programs and potentially other engineering disciplines. This paper presents a conceptual model for achieving this objective and reports upon the progress that has been made thus far on this ongoing effort.

1. Introduction

We address a pressing issue in engineering education – how to develop a comprehensive, integrated industrial engineering curriculum that thoroughly prepares graduates not only for industrial practice or graduate school, but also trains students to readily recognize and apply their engineering background to solve problems, both locally and internationally.

Beginning in the early 1990's, a series of reports emerged detailing serious deficiencies in engineering education and calling for major reforms. In short, these reports proclaimed that engineering education programs must teach not only the fundamentals of engineering theory, experimentation, and practice, but:

- "Prepare students for a broad range of careers and lifelong learning … feature multidisciplinary, collaborative, active learning and take into account students' varied learning styles," [1]
- "Include early exposure to 'real' engineering and more extensive exposure to interdisciplinary, hands-on, industrial practice aspects, team work, systems thinking and creative design" [2], and
- "Create an intellectual environment where students can develop an awareness of the impact of emerging technologies, an appreciation of engineering as an integral process of societal change, and an acceptance of responsibility for civilization's progress." [3]

More recently, Fromm [4] reemphasized the trend towards integration by stating: "We will see further integration of the important components that round out and complete the holistic experience of our educational programs…". The advent of the Accreditation Board for Engineering and Technology's (ABET) new accreditation criteria [5] with its ubiquitous eleven learning outcomes has also made engineering programs responsible for advising, monitoring and evaluating students so that they can successfully achieve a program's objectives. In addition, programs must have a system that is flexible enough to allow for the continuous identification of areas for improvement and the ability to measure resultant improvements.

As a result, pedagogical innovations over the past ten years have greatly changed how engineering education is delivered. One innovative feature has been the "integrated curriculum," which, by closely tying together coursework and faculty, aims to improve students' comprehension of the engineering fundamentals, teamwork and communication skills, and problem solving abilities 6 using a just-in-time delivery philosophy (akin to modern manufacturing systems). A number of engineering schools, including the University of Pittsburgh, have introduced integrated freshman engineering programs [6-12]; a few schools have attempted to move their programs into the sophomore year [13, 14]. In general, such programs have focused on delivering core science and engineering courses in a just-in-time manner, meaning that concepts or methods are taught in a particular course just prior to when they might be needed/applied in other related courses. Unfortunately, a number of these integrated programs, many supported by NSF, have not been sustained. This has not been the case at the University of Pittsburgh where we have learned to deliver an integrated curriculum to the large majority of our 400 freshmen.

However, there is a paucity of engineering programs that have successfully created *discipline specific* integrated curricula [15, 16]. All too often, the only "integration" students experience is through an individual course, often the culminating senior capstone design experience [17, 18]. Consequently, because students have not been systematically exposed to the linkages among the discipline's core areas, they are not adequately prepared to solve open-ended problems in their field of study. A plausible solution requires integrating the curricula by: (a) delivering discipline specific engineering science content in a just-in-time manner, (b) exposing students to complex, open-ended problems that require synthesis of the discipline's core knowledge, and (c) developing skills that graduates will utilize throughout their careers. Such life long engineering proficiencies have been identified as business practices and cost issues, data analysis and uncertainty, design and problem solving, information systems and programming, and communication and teamwork.

Coupled to this need is the fact that engineering is now, more than ever, a global profession. Because of the competitive advantage to corporations, many industrial operations have been globalized. This has had an impact not only locally, but internationally as well, as the US is becoming increasingly dependent upon overseas sources for its processed raw materials and engineering jobs (e.g., software design). Consequently, US engineering students need to be prepared to work for multinational companies where they may encounter non-US engineers defining and solving problems. Further, engineering students need to recognize that not only do cultural differences exist, but that the requirements of engineers are different in developing countries compared to developed countries. Thus, in considering the globalization of engineering education, the choice of humanities and social science electives requires careful consideration and incorporation into the integrated curriculum.

2. Problem Statement and Research Objectives

Industrial Engineering (IE) combines elements of several core engineering areas that vary widely in their nature from highly quantitative (e.g., operations research, probability and statistics) to more qualitative (e.g., engineering management, human factors engineering) or technical in nature (e.g., manufacturing systems, facilities design). While IE's diverse knowledge domains contribute to its uniqueness, they also highlight the need to effectively integrate material from these different domains into a compact curriculum. To succeed, students must learn how to integrate these different concepts and apply them to the complex problems that they will face in practice.

In response to the challenges facing engineering educators in general, and IE educators in particular, we are revising the undergraduate IE curriculum at the University of Pittsburgh with four primary objectives in mind:

1. **Integration**: Integrate concepts across the curriculum via
   - *Reinforcement* of course material throughout the curriculum.
   - "*Just-in-time"* concept integration.
2. **Synthesis**: Teach students how to synthesize different concepts to solve problems.
   - Industrial engineers often face ill-defined, complex problems in systems where there are significant interactions between different sub-system components.
   - Students often fail to see that solving a problem in practice requires the application of several *different* IE concepts and methods, and that the essence of IE lies in the ability to successfully integrate these methods within a system-level approach.
3. **Localization/Globalization**: Provide problem solving methods and strategies for problems within a local context and then extend them to a global context.
4. **Portability**: Create a framework for course integration, synthesis, and an appreciation for local and global issues that will be directly applicable to other IE programs, with the capability for adaptation by other fields of study.

Integration. IE courses tend to be poorly integrated with respect to the different concepts they address. While there seems to be a general consensus on what constitutes "core knowledge" for an IE undergraduate program, there appears to be no explicit attempt to *integrate* and continually *reinforce* these concepts across the curriculum. Courses tend to be delivered as separate "silos" of subject matter without any explicit attempt at integrating and timing the delivery of the contents in order to take advantage of mutual commonalities, relationships and synergies. This lack of integration leads to several undesirable outcomes. Students tend to forget material that they once learned but have not seen until it is needed again for another course later on in the curriculum. For example, in their senior level facility design course students often fail to recognize that certain facility design sub-problems can be solved using operations research and statistical tools acquired in their sophomore and junior years. There is also a need to integrate the *timing* of the teaching of material across courses to achieve just-in-time concept integration. For example, it is desirable to synchronize instruction so that just after the students learn the fundamentals of the normal distribution in a Probability and Statistics course they can immediately see an application of this material to signal detection theory in a Human Factors Engineering course. This type of course coordination can be difficult to achieve because the courses are not taught by the same faculty member. However, if it **can** be achieved the benefit to students is significant. In this example it will help students appreciate the importance of fundamental material such as the normal distribution by seeing its application in courses other than the one where it is first taught.

Synthesis. In Bloom's Taxonomy, synthesis involves taking many pieces and putting them together to make a new whole [19]. Traditional IE curricula do not give sufficient emphasis to the *synthesis* of concepts/methods in order to solve unstructured problems. This is an especially significant factor for industrial engineers who tend to face ill-defined problems. Moreover, Industrial Engineers typically work in cross-functional teams on *systems* that integrate machines and other physical entities with human beings. Almost invariably, there is also an economic element that they need to address. This in turn means that Industrial Engineers have a much more critical need for general skills related to (a) communication and teamwork, (b) uncertainty and costs, and (c) recognizing local and global implications of their decisions. More importantly, they need the ability to synthesize these with the technical skills taught in their curricula. Students also often fail to see that when one looks at a particular real-world problem, *different* IE concepts and methods could apply (albeit in varying degrees), and that the essence of IE lies in the synthesis of *all* these methods within a systems-level approach. While most programs have a senior design project of some sort there are very few curricula that go beyond this to explicitly address the issue of synthesis.

Localization/Globalization. As noted, students need to receive greater exposure to today's global business environment. Changes in communication and transportation have created both a global marketplace and supply chain; our students' education needs to prepare them for both global contexts. Many production planning problems that IE's encounter no longer focus on facilities in a single region or even in a single country but rather in multiple countries. Globalization has had a significant effect on companies' operations and many of these changes directly affect the work of industrial engineers such as: demand forecasting, logistics and delivery planning, inventory control, facility design, human factors, safety, manufacturing processes (including environmental concerns), information systems, costing systems, and engineering management. Students need to be better prepared to deal with these global challenges by learning systems engineering and integration concepts that are applicable on a global level and by incorporating globalization issues into the humanities and social science electives that they take.

Portability. In developing a model for a discipline specific integrated curriculum it is important that results be portable to other curriculum planning contexts. Our proposed framework for providing integration, synthesis, and localization/globalization is potentially applicable to 224 different IE programs (i.e. the 101 accredited IE, 10 engineering management, 24 manufacturing engineering, and 33 systems engineering programs as well as 15 accredited IE Technology and 41 manufacturing technology programs). However, the central issues of integration, synthesis, and localization/globalization are also applicable to other engineering disciplines as well as several other fields of study.

3. Conceptual Model, Approach, and Methodology

3.1 Overall Objectives

Based on the above discussion, our broad objective is to develop a technically sound undergraduate IE curriculum that will (a) be tightly integrated and allow for much better learning, (b) ensure that our graduates will have the life-long engineering proficiencies to successfully apply what they learn, (c) allow our graduates to appreciate the societal role of engineering, both locally and globally, and (d) serve as a model for incorporating these same objectives into curricula for other engineering disciplines.

3.2 Conceptual Model

While we present our discussions in the context of IE, the same approach could be followed for other engineering disciplines. We begin by identifying the core knowledge areas of IE and the expected life-long engineering proficiencies. We then develop a plan that builds on and continually reinforces these areas throughout the curriculum in support of our first objective of *integration*. Following this we detail a plan for combining the technical skills with life-long engineering proficiencies, in support of our second objective of *synthesis*. Finally, we discuss curricular implications of the changing role of science and technology in society. Discussions of pedagogical issues are woven into each of the above subsections. The conceptual model we propose is shown in Figure 1.

3.2.1 Industrial Engineering Science

Much as one uses the term "Engineering Science" to refer to the knowledge areas that are considered to be basic for all engineering disciplines (e.g., calculus, mechanics, electrical circuits, etc.), we use the term "Industrial Engineering Science" to refer to areas that would be considered basic to any IE program. (The term *Industrial Engineering Science* refers to core knowledge areas within IE and is not to be confused with the more general ABET engineering sciences.) To identify these areas the top 25 undergraduate IE programs in the country (as per the Gourman Rankings) were evaluated to identify those topics that most frequently comprised the curricula. The reader is also referred to Biles [20] for a related article. While the relative emphasis placed on each area could vary from one academic program to another, virtually every single program covers the following six broad areas:

1. Probability and Statistics
2. Operations Research
3. Engineering Management (including Engineering Economics)
4. Human Factors (including Work Methods)
5. Manufacturing and Facility Design
6. Production Operations Analysis

With very few exceptions, all reputable IE programs cover each of these subjects. Also note that in very broad terms, the first four areas are more conceptual/methodological in nature and tend to be covered relatively early in the curriculum, while the last two are more application driven and tend to be covered somewhat later in the curriculum.

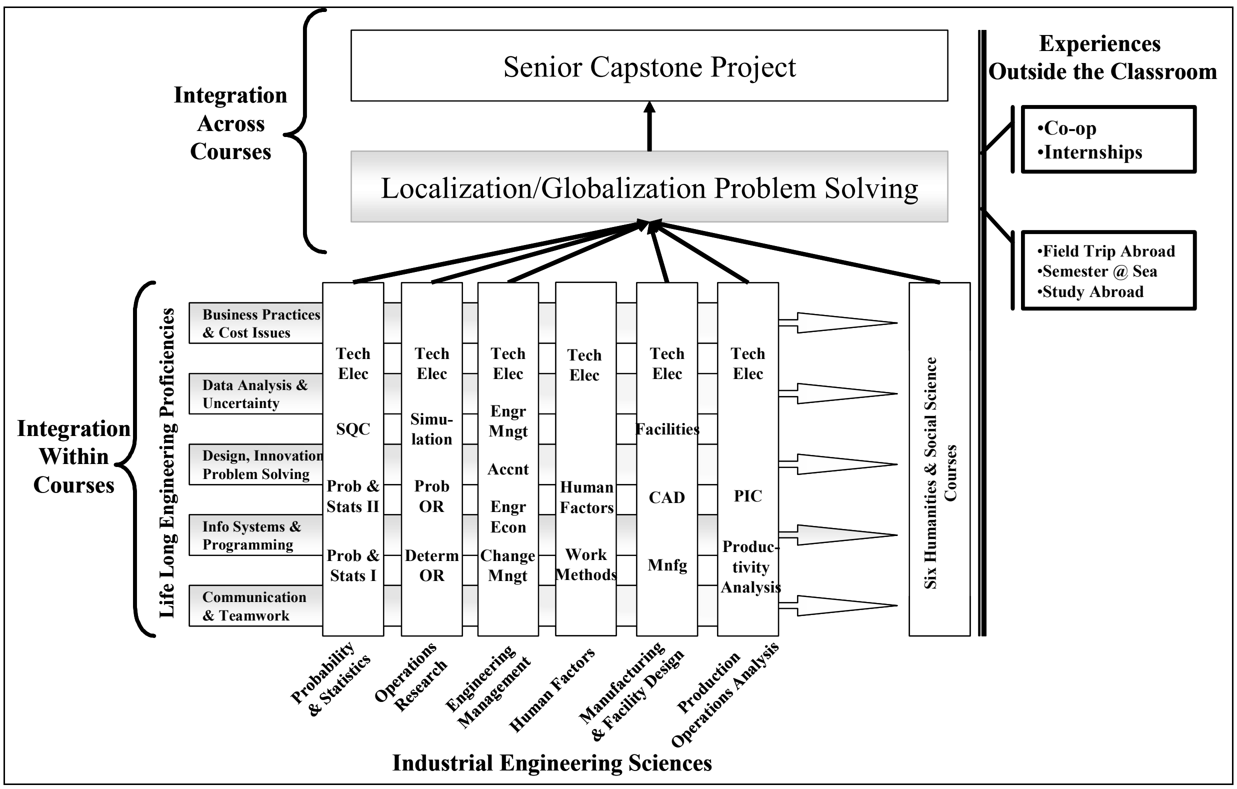

Figure 1. Conceptual Model for Curriculum Integration & Synthesis

3.2.2 Life-Long Engineering Proficiencies

We also identified those broad skills that cut across all technical areas and that every industrial engineer needs to possess in order to successfully apply the principles learned in an academic curriculum. These skills were identified based on ABET accreditation criteria, the FE and PE examinations, and extensive discussions with practicing industrial engineers including the departmental visiting committee (comprised of industrial colleagues in senior IE positions). We use the term "life-long engineering proficiency" to summarize these skills. It is worth noting that most of these are important for all engineers and not just IE's. These may be summarized as:

1. *Business practices and cost issues*: Refers to the ability to relate engineering skills to the larger business environment in order to address cost and economic issues, change management, management of innovation, ethics, etc.
2. *Data analysis and uncertainty*: Refers to the ability to specify information requirements and gather and analyze data in an uncertain environment.
3. *Design, innovation and problem solving*: Refers to the ability to define, develop specifications and design solutions to industrial problems.
4. *Information systems and programming*: Refers to the ability to use computers for extracting information from data, and for using and (where necessary) developing software for solving common engineering problems.
5. *Communication and teamwork*: Refers to the ability to work in multi-functional teams and to clearly communicate with managers and/or non-technical people, both orally and in writing.

As a pilot we are focusing on incorporating *business practices and cost issues* across a range of courses in our curriculum. The implementation approach is based on a web-based template created by Needy and Bursic [21]. For this particular proficiency, the template provides a "how to" for engineering economic analysis that allows students to answer questions such as "Which of the alternatives is more economically attractive?" "Is my solution fiscally feasible?" "What is the return on investment for my solution?" A question and answer discussion is also provided with the template. We are using this template as a foundation for creating modules (coupled to a particular content area or assignment) that expose students to experiential practice in each of their courses; thus cultivating their proficiency as well as synthesizing it across courses.

3.2.3 Integration

The model we propose for integrating technical skills and life-long proficiencies into the curriculum is based on two aspects of integration: reinforcement and just-in-time integration. By reinforcement we mean that once a subject has been introduced, at least one or two topics from this subject will be *explicitly* emphasized and used in each and every subsequent IE course within the program. Thus, basic concepts are continually reinforced. As the student moves further along in the program, more and more of these topics are integrated into the coursework. This allows students to more readily see the relevance of these topics and experience how they integrate together in the educational process, which should result in improved learning.

For example, IE students at the University of Pittsburgh typically take Engineering Economic Analysis (IE 1040) in the first term of their sophomore year. In order to apply this integration concept we would incorporate topics from IE 1040 in the second term of their sophomore year. The might include the following:

a) a module that uses expected payback time or expected present value when the concept of expectation is introduced in Probability and Statistics (ENGR 0020);

b) an explicit cost analysis using engineering economics methods when evaluating alternative ergonomic designs in Human Factors (IE 1061); and
c) a cost-benefit study for a workplace redesign exercise in Productivity Analysis (IE 1054).

The second aspect of our model is just-in-time concept integration. The idea here is to look at the different courses that a typical student would take in a particular term and to then synchronize the timing and delivery of topics in each of these courses to the maximum extent possible. As an illustrative example, again consider the second term of the sophomore year for a typical University of Pittsburgh IE student. Students would take three IE courses – Probability and Statistics (ENGR 0020), Productivity Analysis (IE 1054), and Human Factors (IE 1061). If certain topics were introduced in such a way that students simultaneously see their application in different areas, there would be better reinforcement as well as a much better appreciation for these principles. For instance, when the normal distribution is introduced in ENGR 0020, one might also do a work sampling study in IE 1054, and a signal detection theory laboratory in IE 1061 that require the use of normal tables. We are currently working on implementing both aspects of our model into the sophomore year curriculum.

3.2.4 Synthesis

Typically, most IE programs have a senior project course in the final term. The objective is to have students draw upon the skills that they have learned to solve an industry-based system design problem. The extent of emphasis placed on general skills and the degree to which the problem is structured tend to vary from one program to the other. At the University of Pittsburgh this course is listed as IE 1090. Three or four-person student teams work on an industrial problem, with their effort being guided by an industry mentor and supervised by a faculty member. The students submit a final written project report in addition to making oral presentations that are open to other students, faculty and the industrial "clients." While this course works reasonably well, it also has some shortcomings. First, students are often seeing a completely unstructured problem environment for the first time. This lack of structure leads to difficulty with issues such as defining the problem and its scope, identifying and collecting the correct set of data, and defining appropriate performance measures. Second, they also tend to have difficulty in drawing upon the technical skills they have learned in order to identify the appropriate tools to address the particular problem at hand. Often the students will focus on one particular tool when a much broader approach is in order. Third, there tends to be a lot of variability in terms of how well students can synthesize their technical abilities with the life-long engineering proficiencies. Based on analyzing projects over the last several years, it is our conclusion that these shortcomings could be attributed to the fact that students have never actually been *taught* how to integrate and synthesize their training and skills in order to solve unstructured problems. Homework or projects within courses cannot accomplish this task since they typically do not give students sufficient time to address an unstructured problem in depth.

We are addressing this issue by developing and delivering a separate course that actually teaches students the skills necessary to go out and execute a successful industry based team project in their final term. This course (offered in the junior year) will consist of two successive projects, each of which runs for half a term. Students will work in teams of three or four on each project. However, unlike senior project, students will work on the *same* project. The projects are being developed in the form of detailed case-studies and require the students to use a wide array of technical skills and to synthesize these with the life-long engineering proficiencies discussed earlier. Further, the first project will address the issue of *localization* and require the project to be addressed in the context of its impact on a local scale, while the second will address *globalization* and contain a global context. It is our belief that with a specific project-oriented course such as this, we will also be able to reduce some of the fragmented project work currently required in various courses across the curriculum. Students often see the latter as a very large demand on their time, especially towards the end of the term when they are often working simultaneously on numerous projects for several classes.

Pedagogically, problem-based learning (PBL) [22] will be employed as the instructional method as it is suitable in assisting students to solve the types of problems often confronted by practicing professionals. Using the PBL approach students further develop their ability to clearly define a problem, construct and alter hypotheses as needed, collect and evaluate data from many sources, and develop solutions that consider conditions inherent to the problem.

Since the projects being developed are adaptations of real problems, we have the option of introducing many different features. Ideally, we plan to develop a library of eight such projects so that we will not have to recycle a project for at least four years. We are in the process of developing the first two that will be piloted during the summer of 2004. Students who have been formally trained through this class will have a higher chance of successfully handling their final term project course as well as projects that they are assigned when they enter the workforce.

3.2.5 Localization/Globalization

As part of the synthesis process, we will make students much more aware of the societal implications of engineering at both local and global levels. To do this, we are better structuring the humanities and social science requirements so that they support this goal. Specifically, students will take three humanities and three social science courses as they currently do; however, at least one and possibly two courses will relate to the broad area of science, technology and society. The University of Pittsburgh has an excellent array of such courses through its History and Philosophy of Science (HPS) Department, as well as through Economics, Political Science and Sociology. We also plan to require that one of the electives explicitly deal with localization/globalization issues, or alternatively, require a study-abroad term where students would be exposed to such issues.

3.3 Portability

Our model is portable; i.e., easily adaptable to other IE programs and more broadly, to other engineering disciplines. Referring to Figure 1, each of the "IE science areas" rising vertically would be different for different engineering disciplines (and there could be fewer or more than six of them), but the rest of the model including the five horizontal layers cutting across these IE science areas and the two integration layers at the top would be similar. Similarly, the modules that we are developing for integration and synthesis will be unique to IE, but conceptually, the same idea can be readily extended to other disciplines by interested faculty. Our plan is to document and disseminate our procedures to facilitate adaptation with relative ease by faculty interested in porting our model and approach over to another area.

4. Summary

This paper addresses the development of a comprehensive integrated curriculum that enhances learning and thoroughly prepares graduates for industrial practice in a global context. It presents a realistic approach for developing an integrated curriculum by delivering discipline specific engineering science content in a just-in-time manner; exposing students to large open-ended problems that require synthesis of the discipline core with broader skills; and developing proficiencies that engineering will utilize throughout their careers.

5. Acknowledgements

This research is being supported through the National Science Foundation program for the Department-Level Reform of Undergraduate Engineering Education grant number EEC-0343080.

6. References

1. Augustine, N., and C. Vest, "Engineering Education for A Changing World", Joint Project by the Engineering Deans Council and the Corporate Roundtable of the American Society for Engineering Education, ASEE, 1994.
2. National Research Council, "Engineering Education: Designing an Adaptive System". National Academy Press: Washington, DC, 1995.
3. Bordogna, J., E. Fromm, and EW Ernst, "Engineering education: innovation through integration," *Journal of Engineering Education*, 82(1), January 1993, pp. 3-8.
4. Fromm, Eli. (April 2003). "The changing engineering educational paradigm," *Journal of Engineering Education*, 92(2), 113-121.
5. Accreditation Board for Engineering and Technology (ABET). Evaluation criteria can be found at the following URL address: http://www.abet.org/criteria.html.
6. Merton, P., C. Clark, J. Richardson, and J. Froyd. "Engineering curricula change across the foundation coalition: How they succeeded, what they learned," *Proceedings of the ASEE Annual Conference*, 2001.
7. Rogers, G. and B. J. Winkel. "Integrated first-year curriculum in science, engineering, and mathematics: Nature, evolution, and evaluation," *Proceedings of the ASEE Annual Conference*, pages 186–191, 1993.
8. Froyd, G. "Integrated, first-year curriculum in science, engineering, and mathematics - a ten-year process," *Proceedings of the Frontiers in Education Conference*, 1995.
9. Frair, K. "An integrated first year curriculum at the university of Alabama," *Proceedings of the Frontiers in Education Conference*, 1994.
10. Quinn, R.G. "Drexel's E4 program: A different professional experience for engineering students and faculty," *Journal of Engineering Education*, 82:196–202, 1993.
11. Morgan, J.R., and R.W. Bolton. "An integrated first-year engineering curricula," *Proceedings of the Frontiers in Education Conference*, 1998.
12. Hoit, M., and M. Ohland. "Integrating the first two years of engineering education," *Proceedings of the ASEE Annual Conference*, 1996.

13. Richards, D., and G. Rogers. "A new sophomore engineering curriculum – the first year experience," *Proceedings of the Frontiers in Education Conference*, 1996.
14. McLaughlan, W.H., and R.A. McLaughlan. "Development and implementation of an integrated engineering curriculum for the sophomore year," *Proceedings of the Frontiers in Education Conference*, 1997.
15. Grigg, N.S., M.E. Criswell, and T.J. Siller. "Integrated civil engineering curriculum: Implementation and management," *Journal of Professional Issues in Engineering Education and Practice*, October:151–155, 1996.
16. Farbrother, B.J. "A new approach to electrical and computer engineering programs at Rose-Hulman institute of technology," *Proceedings of the ASEE Annual Conference*, 1997.
17. Roedel, R.J., S. El-Ghazaly, and J.T. Aberle. "An integrated upper division course in electronic materials and electromagnetic engineering - wave phenomena for electrical engineers," *Proceedings of the Frontiers in Education Conference,* 1998.
18. McInerny, S.A., H.P. Stern, and T.A. Haskew. "A multidisciplinary junior level course in dynamic data acquisition," *Proceedings of the Frontiers in Education Conference*, 1996.
19. Wankat, Phillip .C. and Frank .S. Oreovicz, *Teaching Engineering*, McGraw Hill, 1993.
20. Biles, William E. (September 1991). "The engineering science of industrial engineering: A viewpoint of the industrial engineering curriculum," *IIE Transactions,* 23(3), 208-214.
21. Needy, K.L., and K.M. Bursic, *Integrating Engineering Economic Analysis into the Engineering Curriculum,* Innovation in Education Award, University of Pittsburgh, 2003.
22. Duch, B.J., S.E. Groh, and D.E. Allen, *The Power of Problem-Based Learning: A Practical "How To" for Teaching Undergraduate Courses in Any Discipline*, Stylus Publishing, 2001.

BRYAN A. NORMAN
Bryan A. Norman is an Associate Professor of Industrial Engineering at the University of Pittsburgh. He received his B.S. and M.S. degrees in Industrial Engineering from the University of Oklahoma, and his Ph.D. in Industrial and Operations Engineering from the University of Michigan. His research interests include the application of operations research methods to manufacturing and service operations. Particular application domains include: Facilities Design, Workforce Deployment and Scheduling, Machine Scheduling, and Power Systems. Dr. Norman is a member of IIE and INFORMS.

MARY BESTERFIELD-SACRE
Mary Besterfield-Sacre is an Assistant Professor in the Industrial Engineering Department at the University of Pittsburgh. Her principal research interests are in empirical modeling applications for quality improvement in manufacturing and service organizations, and in engineering education evaluation methodologies. She received her B.S. in Engineering Management from the University of Missouri - Rolla, her M.S. in Industrial Engineering from Purdue University, and a Ph.D. in Industrial Engineering at the University of Pittsburgh.

BOPAYA BIDANDA
Bopaya Bidanda is the Ernest Roth Professor & Chair at the Industrial Engineering Department at the University of Pittsburgh. He received his doctoral degree from Penn State and has industrial experience in aerospace and precision manufacturing. His research interests include manufacturing systems, manufacturing modernization, product realization, reverse engineering, and the globalization of engineering education. He has published over 100 journal and conference papers and has co-authored two books. He is a member of ASEE, SME, and a fellow of IIE.

KIM LaSCOLA NEEDY
Kim LaScola Needy is an Associate Professor of Industrial Engineering at the University of Pittsburgh. She received her B.S. and M.S. degrees in Industrial Engineering from the University of Pittsburgh, and her Ph.D. in Industrial Engineering from Wichita State University. Prior to her academic appointment, she accumulated nine years of industrial experience while working at PPG Industries and The Boeing Company. Her research interests include Activity Based Costing, Engineering Economic Analysis, Engineering Management and Integrated Resource

Management. Dr. Needy is a member of ASEE, ASEM, APICS, IEEE, IIE, and SWE. She is a licensed P.E. in Kansas.

JAYANT RAJGOPAL
Jayant Rajgopal joined the faculty of the Department of Industrial Engineering at the University of Pittsburgh after completing his doctoral studies in Industrial and Management Engineering at the University of Iowa. His primary interests are in production and operations analysis, optimization, and applied probability & statistics; he has taught, conducted research, and consulted in these areas. His publications have appeared in numerous scholarly journals including *IIE Transactions*, *Operations Research*, *Mathematical Programming*, *Naval Research Logistics*, *Technometrics*, and *European Journal of Operational Research*. Dr. Rajgopal is a senior member of IIE and INFORMS and a licensed professional engineer in the state of Pennsylvania.