Department-Level Reform of Undergraduate Industrial Engineering Education: A New Paradigm for Engineering Curriculum Renewal

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Abstract
The Roy Report serves as the basis for today's typical industrial engineering curriculum. That report documents a 1966-1967 study led by Robert Roy, Dean of Engineering Science at Johns Hopkins University, supported by NSF and sponsored by ASEE. Unfortunately, few major changes have been made to the core baccalaureate-level industrial engineering curriculum shared by most American universities since the dissemination of the Roy Report and initial implementations based on its findings.

This paper describes the work of a project team from the Department of Industrial Engineering at Clemson University, sponsored by NSF. The team has been working since September 2002 to develop a new scalable and deployable industrial engineering baccalaureate-degree model. This model is designed to permit scaling up from an information technology kernel of coursework to a fully integrated industrial engineering undergraduate curriculum. Three aspects of the new curriculum plan are described in this paper.

Overview
During the mid 1960s, a study group sponsored by NSF and ASEE developed the prototype for today's typical industrial engineering curriculum, with its emphasis on operations research tools of analysis. Industrial engineering academic professionals from across the United States participated in the study led by Robert Roy, Dean of Engineering Science at Johns Hopkins University. The rapid and almost universal adoption of the Roy model for the industrial engineering curriculum speaks to the willingness of industrial engineers to implement sound academic models.

The study led by Roy was based on the following mutually agreed upon definition of industrial engineering, as officially adopted by the American Institute of Industrial Engineers (AIIE) in 1955:

> Industrial Engineering is concerned with the design, improvement, and installation of integrated systems of men, materials, and equipment. It draws upon specialized knowledge and skill in the mathematical, physical, and social sciences together with the principles and methods of engineering analysis and design, to specify, predict, and evaluate the results to be obtained from such systems.

Roy observed, "We have interpreted the primary objective of this study as consonant with that [AIIE] definition."

Given the emphasis on uniformity of academic programs induced by the process-oriented accreditation standards of the Engineers' Council for Professional Development (the predecessor of the ABET, Inc.), the approach to curriculum model development that Roy and his colleagues used was especially effective. Roy's efforts led to the development of a curriculum model based on carefully considered input from a wide variety of recognized leaders in industrial engineering education and professional practice. At the time of the distribution of the report, and in the decade that followed, the results of the study were widely respected and generally agreed to by the industrial engineering academic and professional practice communities.

Nearly a decade and a half later, John Buzacott, a professor in the Department of Management Sciences at the University of Waterloo, expressed the frustrations he believed to be shared by many industrial engineering academicians. In a 1984 article (Buzacott 1984), Buzacott stated that the AIIE definition of industrial engineering was too broad. He commented that the complement of faculty that must be assembled to teach the Roy report curriculum is certain to be poorly integrated. This, Buzacott stated, insures discord because the research methods, techniques and skills of the assembled faculty do not match, and faculty have no common forum for scientific communications.

Buzacott also claimed that the focus of industrial engineering was outdated in terms of the current needs of innovative industries. He expressed the opinion that students enrolled in Roy report curricula did not acquire significant engineering training. Buzacott suggested some possible avenues of reform/reconstruction of industrial engineering academic programs, including (1) reduction in theoretical research and focus on applications, (2) rapid response to innovation, and (3) faculties consisting of more smaller cohesive groups of specialists.

Even with the soul-searching discussions precipitated by the Buzacott article, and many subsequent years of rapid technological advance in the design of production and service delivery systems and engineering pedagogy, the industrial engineering academic community continues to structure almost all of the bachelor's degree industrial engineering curricula consistent with the Roy report recommendations. But now, after more than thirty-five years, it is certainly appropriate to revisit the structure and the content of the industrial engineering curriculum, at least at the level of the academic department in a particular university.

An article by Way Kuo and Bryan Deuermeyer provides an excellent summary of important issues to be considered in IE curriculum redesign (Kuo and Deuermeyer 1998). Specifically, Kuo and Deuermeyer observe that the traditional industrial engineering curriculum (1) is characterized by an emphasis on tools rather than on engineering problems, (2) is characterized by poor vertical integration of fundamental concepts, i.e., that tools courses typically fail to support upper-level coursework, (3) is focused on the sub-disciplines of industrial engineering rather than on the problems that industrial engineers are expected to solve, (4) fails to address the needs of today's industry, and (5) places a gap between undergraduate education and graduate programs.

The Kuo and Deuermeyer list of limitations for the traditional industrial engineering curriculum is remarkably similar to the set of issues given as limitations of almost all current engineering curricula taught in the United States, as described by NSF in its Program Solicitation NSF-02-091, the program which is funding the curriculum model being developed by the authors. Thus, the authors believe that a planning process for reform of a traditional IE curriculum can be expected to address current concerns about the appropriateness of curricula for many other engineering disciplines.

Curriculum Model
What has been missing for over thirty years is the opportunity to go back to the drawing board with a clean sheet of paper and carefully review all phases of industrial engineering education. This paper examines three aspects of the authors' efforts to develop a planning model to reform industrial engineering education: a focus on problems solved by industrial engineers, the identification of appropriate educational-delivery methods for industrial engineering tools, and a master-teacher course-offering paradigm.

Focus on Problems: Traditionally, a curriculum is built up from the knowledge and skills areas, and the tools used, in the practice of the discipline. As Buzacott observed, industrial engineering academic programs have typically included topical coverage from a wide variety of relatively diverse areas in the physical, biological, and social sciences. Rather than building the curriculum from an initial choice of knowledge, skills, and tools, the authors' curriculum planning model begins with a choice of problems that the curriculum will prepare program graduates to solve. Currently, the curriculum renewal project team is working with the following set of industrial engineering problems:

- *Production and Service Systems Operations Problems* are concerned with the development and application of deterministic and stochastic tools for modeling and optimization of production and service systems operations (e.g., logistics, supply chain management, facilities design and material handling, production planning and control, scheduling, health care delivery).

- *Human Factors Problems* are defined as the problems associated with the application and use of information on human behavior, abilities, limitations and other characteristics in the design of systems, equipment, processes and environment for efficient, effective, safe and comfortable human use (e.g., human –machine systems design, human computer systems, ergonomics, macro ergonomics, safety).

- *Engineering Design Problems* are broadly defined to include problems related to the conception and description of engineered products, systems, processes and services, including comparative analysis of alternatives and selection of a preferred alternative (e.g., design methodologies, systems design, concurrent engineering, rapid prototyping, information systems design, collaborative design).

- *Cost Problems* are broadly defined as class of problems related to the development and application of costing techniques to engineering domains (e.g., engineering economic analysis, financial engineering, retailing, cost accounting).

- *Manufacturing Processes PSroblems* are broadly defined to include problems related to manufacturing process technology and systems development (e.g., cutting tool design, process planning, equipment design, computer integrated manufacturing, robotics).

- *Quality Problems* are concerned with the development and application of tools for evaluating system performance and improving quality and reliability of components, products, and systems (e.g., quality control, quality engineering, quality and reliability testing, software reliability, risk assessment).

Thus, with the new curriculum-planning model, curriculum renewal for a particular academic program begins with the faculty's choice of problems from a problem set like the one above. Of course, ABET Engineering 2000 accreditation criteria require that this choice be consistent with the mission of the university and the needs of program constituents.

Associated with each industrial engineering problem is a set of problem-solving knowledge, skills, and tools. Taxonomies of these knowledge, skills, and tools elements; and mappings of industrial engineering problems into these elements are available on request from the authors. Once a choice of problems has been made, knowledge, skills, and tool elements needed by program graduates can also be identified. With this information at hand, a program faculty can determine where changes will need to be made to their existing curriculum.

Appropriate Educational Delivery Methods: The tools that industrial engineers, and indeed all engineers, use in the practice of their disciplines can be classified by form ranging from concepts, to standards, to models. Tools can also be categorized in a two-dimensional taxonomy, keyed by type of problem being examined and by knowledge base used in analysis and/or design. In addition, tools may be made accessible to the engineer from printed text; by use of formulas, charts and nomograms; and by use of enabling software. The choice of instructional delivery methods used to teach engineering students how to use a particular tool is a function of nature of the tool, the problem being examined and the knowledge bases employed, and the format used to access the tool. In addition, the instructional delivery methods that might be used in teaching are clearly related to the level of learning that is desired. If Bloom's taxonomy (Bloom 1956) were used as a framework for describing learning outcomes, the industrial engineering faculty member might be satisfied with knowledge, comprehension, application, analysis, synthesis, evaluation, or valuation as the outcome of a particular tool-teaching process. Certainly, most appropriate choices of instructional method vary by learning outcome desired.

Our NSF Department Level Reform of Undergraduate Industrial Engineering Education Project Team believes that it would be particularly useful to build a classification scheme for industrial engineering tools and a process for creating a list of such tools and keeping it up to date. Similarly, our team believes that it would be helpful to conduct a careful study to determine the most appropriate instructional delivery methods to teach industrial engineering students how to use elements of the tool set while insuring that (1) the focus of instruction is on the problems that industrial engineers are expected to solve rather than on using tools, (2) there is good vertical integration of fundamental concepts, i.e., that tools courses support upper-level coursework, (3) the instruction is consistent with practice in industry, and (4) teaching methods do not put an unbridgeable gap between undergraduate education and graduate study. Plans to develop the tool classification scheme, and to conduct the educational delivery methods study, are currently being made. Interested readers should contact the authors for an update on the status of these efforts.

Master Teacher Paradigm: Our project team believes that a package of instructional materials, a text and CDROM with cases, projects, and examples could provide the basis for a very useful new paradigm for course offerings. A master teacher, or set of master teachers, would take responsibility for assembling and periodically updating course materials. Other academic programs could gain access to the course materials by way of student purchases of the text and CDROM, and a subscription fee paid by the academic program to the master teacher(s). Each academic program using the course materials would identify a subscribing course instructor. Through use of the video modules and an extensive set of examples and projects, it is anticipated that a subscribing course instructor's course-preparation time would be approximately one-third that typically required of a three-semester-hour course. Rather than prepare and deliver the semester's lectures, the subscribing instructor would select topics, examples and projects from the video library and CDROM, and organize and sequence them according to local requirements. Delivery of course topics could be direct to students on demand, or to a classroom supervised by a teaching assistant. The subscribing instructor and teaching assistants would supervise and serve as mentors in student engagement in course projects selected from the CDROM. In essence, the master teacher(s) would develop a superset of topics, examples and projects, with each subscribing instructor selecting those that matched local requirements. The local instructor would be free to deliver as much or as little as deemed appropriate, and to focus more on interactions with students.

Revisions to course materials in this scenario would be coupled with major changes resulting from the adoption of new technology, such as a new software release. In a course revision, the master teacher(s) would update the CDROM and video content as well as textbooks. The master teacher's(s') release of new course materials would lead to new-course-materials selection decisions on the part of each subscribing instructor, rather than a duplication of course redesign efforts on every campus. This approach seems especially useful in software-based courses, but it could also prove useful in any course where content is relatively stable between revisions and subject material is presented at a basic skills level.

While many programs have courses in programming or engineering economy, for example, few programs recruit faculty with primary responsibility to teach or develop those courses. In many institutions these courses, over time, become the domain of teaching assistants, adjuncts, or faculty near retirement. At best, they are the secondary interest of a faculty member whose time is more likely devoted elsewhere. Thus, these courses are least likely to be well maintained and taught by the most proficient and interested faculty members. At the same time, they are regarded as fundamental and necessary.

Two key questions arise for the further development of this new paradigm of course delivery by master teacher. First, can a combination of text and electronic media be developed with sufficient variety in materials and with adequate quality to support instruction by a non-expert subscribing instructor or, with minimal time requirement, by a faculty member in his/her secondary area of interest? Second, how can agreement be reached on course content so that master teacher(s) could reasonable expect the wide-spread adoption needed to pay for materials development and revision efforts? While some disciplines may provide topical guidance (through ABET program criteria, for example) for subject material selection, no common mechanism presently exists across engineering disciplines to achieve this agreement. Development of this new course paradigm and a process to support it should be a valuable contribution to education in all disciplines, particularly those in engineering and the sciences.

The authors will begin to test this master-teacher paradigm at Clemson University during the second summer session of 2003. Dr. Ravindra K. Ahuja, Professor of Industrial and Systems Engineering at the University of Florida, is in the process of developing textbooks and accompanying resource materials for two information technology courses. Our NSF Department-Level Reform of Undergraduate Industrial Engineering Education Project Team has been in contact with Dr. Ahuja because our curriculum-renewal focus is on an information technology kernel for the baccalaureate industrial engineering curriculum, a thrust that is compatible with Dr. Ahuja's work in developing and teaching information technology courses. Dr. Ahuja, who is internationally known for his work in combinatorial optimization, is attempting to reduce the course revision consequences of periodic software updates with the approach his is taking to course, text, and instructional material development. He is developing a CDROM companion to his texts to provide cases, projects, and examples. Further, he expects to develop a set of video modules presenting basic concepts; these videos would feature faculty from the University of Florida and elsewhere, instructing students in key concepts and principles. Rather than create a set of presentations in the conventional model of a series of one-hour lectures, his modules would be sized to fit the topic and provided on demand, perhaps by subscription to a web server or coupled with text adoption. The Department of Industrial Engineering at Clemson will test a portion of Dr. Ahuja's material in the course IE 220: Design of Information Systems in Industrial Engineering.

Next Steps

All of the elements of the new curriculum-planning model will need to be applied and carefully evaluated by faculty members at work in actual academic environments. The authors hope to conduct a significant portion of the curriculum model evaluation and validation in industrial engineering departments within the structure of the SUCCEED NSF Engineering Education Coalition. Working within the SUCCEED Coalition has provided opportunities to develop excellent collaborative relationships among industrial engineering colleagues in some of the nation's best industrial engineering departments, which by good fortune are in the contiguous states of Virginia, North and South Carolina, Georgia, and Florida. SUCCEED engineering schools represent a remarkable slice of our country's engineering student population. Engineering enrollments in SUCCEED universities include 1/13 of all engineering students, 1/12 of all women engineering students, and 1/5 of all African American engineering students in the United States. Moreover, this region of the country includes North American headquarters of many of the world's major industrial firms, including BMW and Michelin. Our NSF Department Level Reform of Undergraduate Industrial Engineering Education Project Team believes that it would be particularly beneficial to evaluate the curriculum renewal planning process on several SUCCEED campuses.

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