An Integrated Systems Lab and Curriculum to Address IE Program Criteria

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Abstract

ABET program criteria for industrial engineering require programs to demonstrate that "graduates have the ability to design, develop, implement, and improve integrated systems that include people, materials, information, equipment, and energy" and to include "in-depth instruction to accomplish the integration of systems using appropriate analytical, computational, and experimental practices." Faculty in the industrial engineering program at Tennessee Technological University have developed an integrated junior-year curriculum supported by an Integrated Systems Laboratory and related projects. The projects provide opportunities for students to apply their newly acquired tools in an integrated setting prior to enrolling in the capstone course. Project requirements can include work measurement, work design and ergonomics, engineering economics, simulation, statistical analysis and experimental design, project management, and technical communication. In addition to a description of the laboratory and projects, the rationale and a description of the curriculum is presented. Also included is a preliminary analysis of the impact of this approach on student learning.

Introduction

ABET program criteria for industrial engineering require programs to demonstrate that "graduates have the ability to design, develop, implement, and improve integrated systems that include people, materials, information, equipment, and energy" and to include "in-depth instruction to accomplish the integration of systems using appropriate analytical, computational, and experimental practices."[1] Many industrial engineering programs use senior capstone design projects to achieve program outcomes that relate to integrated systems. In such an environment, courses preceding the capstone project focus on developing "tools" that will be applied to an integrated system in the capstone project. The tools are acquired through stand-alone topics with applications limited to textbook problems or projects that are limited in scope. The problem of developing a student's ability to engineer integrated systems is exacerbated by the typical, stand-alone laboratories that focus on individual topic areas within industrial engineering, e.g., ergonomics or manufacturing processes. As a result, students often struggle to apply the tools in an integrated setting, such as the capstone project, even though they may have excelled in courses where the tools are learned.

To develop the student's problem-solving capabilities within integrated systems, faculty in the industrial engineering program at Tennessee Technological University have developed an integrated junior-year curriculum that incorporates an Integrated Systems Laboratory and related projects. The projects enable students to apply their newly acquired tools in an integrated setting prior to the capstone course.

Rationale

As part of the ABET 2000 continuous improvement process, assessment data for the BSIE program at Tennessee Tech have identified the need to improve students' understanding of integrated systems prior to their enrolling in the senior capstone course. Senior exit interviews provided qualitative evidence that students did not know important relationships between some of the junior year courses. Senior project juries, composed of Industrial Advisory Board and faculty members, provided quantitative assessment data to support the conclusion that students were ineffectively using all of the tools that could be applied to the projects. In particular, simulation, process improvement, and design of experiments were topics that students struggled to properly apply in their senior projects.

In addition, curriculum and laboratory integration has been the focus of research and funding activity, which has provided encouraging results. The Foundation Coalition, an NSF-sponsored education coalition that focused on developing an integrated curriculum for the first two years, offers the following definitions of curriculum integration.[2]

> *Strong Version: In its stronger version, curriculum integration is a pedagogical approach to help students build a small set of powerful, broadly applicable concepts/abilities/skills instead of a large set of weak, narrowly applicable concepts/abilities/skills.*

> *Weak Version: In its weaker version, curriculum integration is a pedagogical approach to help students build connections across disciplines.*

The goals of curriculum integration in this paper refer to the strong version with respect to building powerful, broadly applicable concepts/abilities/skills and refer to the weak version with respect to building connections. However, the connections here are within the discipline of industrial engineering.

Integrated curricula and laboratories have also been developed within industrial engineering and related programs with positive results. For example, laboratory integration has been accomplished within an engineering management program at the University of Missouri-Rolla[3] and within an industrial engineering program at Rochester Institute of Technology[4]. An integrated curriculum has also been developed for the freshman year at Rochester Institute of Technology[5].

Integrated Curriculum

As Table 1 shows, the junior year curriculum is now almost entirely devoted to courses in the major. The only industrial engineering course taken prior to the junior year is Introduction to Industrial Engineering and Computers. A major reason for moving industrial engineering courses to the junior year is the articulation agreements with community colleges that enable most of the freshman and sophomore year coursework to be taken at almost any Tennessee institution of higher learning. Another reason is that most of the students who enroll in engineering do not enroll in the calculus sequence as articulated in the catalog. The distinct advantage of more than 80% of the junior-year coursework allocated to industrial engineering courses is that it created the opportunity to develop an integrated approach to the curriculum.

Table 1. Junior-year BSIE curriculum at Tennessee Tech.

Fall		Spring	
ACCT 2110 Principles of Financial Accounting	3	ACCT 2120 Principles of Managerial Accounting	3
ISE 3100 Engineering Economy	3	ISE 3220 Design of Experiments	3
ISE 3200 Engineering Statistics	3	ISE 3310 Process Improvement	4
ISE 3400 Operations Research	3	ISE 3410 Simulation of Industrial Systems	3
ISE 3800 Information Systems for IE	3	ISE 3900 Industrial Engineering Seminar	1
MATH 2120 Differential Equations	3	ISE 3910 Engineering Leadership and Project Management	3
Total	18	Total	17

The integrated curriculum continues to evolve because of recent changes to the junior year curriculum. In academic year 2004-05, the Information Systems for IE and Design of Experiments courses were moved to the junior year. The Design of Experiments course is expected to strengthen the integrated curriculum. The Information Systems for IE course will not contribute directly to the integrated curriculum. However, the information systems projects will reinforce concepts in Engineering Economy, Engineering Statistics, and Operations Research. Also, students will develop another tool that will be available in their senior year.

During academic year 2003-04, the curriculum integration occurred primarily in the spring semester. A Process Improvement project that was implemented in the Integrated Systems Laboratory was also the basis for related assignments in IE Seminar, Simulation of Industrial Systems, and Engineering Leadership and Project Management.

Integrated Systems Laboratory

Laboratory development is a work in progress with a long-term goal of providing a comprehensive environment for students to design and develop manual as well as automated integrated systems. Because manufacturing applications are important to IE and are readily available to offer for hands-on experience, the focus of this lab is on integrated systems in production environments. Equipment and furnishings were selected to demonstrate material processing, material handling, assembly, inspection, storage, and safety. In addition, data collection and information flow are an important feature of the Integrated Systems Laboratory. A list of the physical equipment available is shown in Table 2.

In other industrial engineering programs, this laboratory might be referred to as a Manufacturing Systems or a CIM Laboratory. However, it was decided that the name should reflect the importance of the laboratory in an integrated curriculum. All faculty are encouraged to reinforce curriculum topics in the laboratory. However, not everyone has elected to use these resources.

Table 2. Equipment in the Integrated Systems Laboratory

ProLight 1000 CNC mill with automated tool changer
Scorbot ER-IX robot on linear slide base
Automated conveyors (6' and 4' sections)
Automated turntable and vision system
Bar code reader and printer
AS/RS
Two industrial grade workstations (reconfigurable)
Balancers
Ergonomic sit/stand stools
Gravity conveyors
Palm PDAs for time study
Miscellaneous tools (manual and electric)
Ergonomic equipment to assess physical work, vibration, reaction time, grip strength, anthropometric data, and other characteristics
Computers

The Integrated Systems Laboratory is also used by freshmen engineering and sophomore industrial engineering students. For the freshman and sophomore courses, the focus is on individual laboratory components and discussions on the importance of system integration. For example, the sophomore Introduction to IE and Computers course provides an opportunity to focus on material processing or material handling as a laboratory activity. The material processing assignment can be further developed in the same course or a later course by focusing on setup and analysis using design of experiments for process improvement. A related exercise might involve product costing for the processed part. Another individual component exercise might involve programming the robot to complete a task, time study of the robot, and then a process improvement exercise for the robot task. An important advantage of sophomore students using the laboratory is that they become familiar with the equipment and look forward to using it in the junior year.

The laboratory is also used in the freshman year as a workshop for students enrolled in ENGR 1210 Introduction to Engineering. Many of these students are undeclared majors, so the laboratory workshops provide an excellent opportunity for recruiting students to the BSIE program.

Integrated Project Example

An example of an integrated project can be found in requirements from the Spring 2004 junior courses. The project spanned four courses and incorporated value analysis, process improvement, work measurement, methods analysis, ergonomic design, simulation, project management, and technical communication.

A student team was assigned a product prototype that was the focus of the study. The product, shown in Figure 1, was a switched outlet assembly that might be used in an industrial setting.

Table 3 presents a list of the assignments by course. At the end of the semester, a team operated the assembly line to produce fifty product assemblies, which required a little longer than thirty minutes. Figures 2 shows students on the assembly line. It was interesting that the students were quite animated at the beginning of production but were silent except for expressions of exhaustion near the end of production.

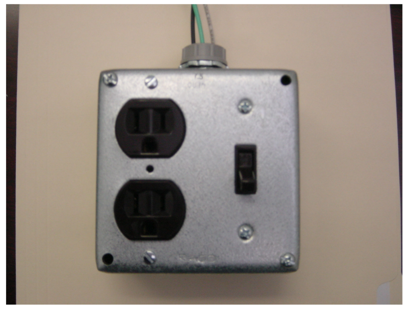

Figure 1. Product Prototype for Project.

Figure 2. Operators on the Assembly Line.

A survey in the Process Improvement course indicated that students were very positive about the opportunity to do the project. As expected, they expressed frustration with the ambiguity inherent in any project and offered some suggestions for improvement, which will be incorporated in the next iteration where feasible.

Impact

It was expected that student understanding of how to approach, and apply IE tools, in integrated systems would improve as a result of the junior-year experience. However, in the annual end-of-year survey of juniors and seniors, results for questions in key areas that should have improved, as shown in Table 4, did not with one exception. For the question about laboratories, the average student response moved from a "neutral" result to a "strongly agree" result for juniors. However, the lack of improvement in the other areas of the survey is not necessarily seen as a problem; the unusually small class size for juniors may have produced distorted results, and the junior class had a lower than average GPA. In addition, the survey questions reflect student perception. The faculty believe that the non-improvement is partially the result of a more accurate self-assessment of their ability by the juniors. Students in the industrial engineering program at Tennessee Tech often begin senior projects quite confident in their abilities and are

Table 3. Integrated Project Assignments.

Course	Focus	Assignment
Process Improvement	Reverse engineering, value engineering, and engineering economy	Identify component parts and find value engineering opportunities. Order parts if needed.
	Charting	Develop an operations process chart and plan for product assembly and inspection.
	Methods analysis	Establish a standard assembly method. Develop jigs and fixtures if needed. Order equipment if needed.
	Material handling	Develop a method for moving components between workstations and for replenishing supplies.
	Line balancing	Establish operator assignments and tasks to balance the assembly line.
	Time study	Develop a standard time for the standard method for each operator or task.
	Ergonomic evaluation	Consider physical and mental workloads. Identify and order aids to reduce physical and mental stress. Configure workstations using anthropometric data.
	Quality and ergonomics	Design a test station to incorporate inspection at the end of the line. Use ergonomics in test station design.
Project Management	Project plan	Develop project network, and use it for project scheduling and control.
Simulation	Modeling for process improvement	Using end-of-line failure data and time study data, investigate the feasibility of alternate rework stations to reduce end-of-line failures and study the need for buffering between workstations.
IE Seminar	Technical communication	Develop a group technical report of the project. Develop work instructions for each operator's tasks.

Table 4. Selected Questions from Annual Junior/Senior Enrolled Student Survey.

Problem Solving Skills: The BSIE program has provided me with the knowledge and skills needed to
Design systems, components, and processes to meet project requirements.
Identify and formulate industrial engineering problems embedded in projects.
Apply industrial engineering concepts and tools to improve processes in service and manufacturing systems.
Environment:
Laboratories are adequate to support instructional needs.

surprised by the difficulty in dealing with integrated systems. The juniors who experienced an integrated project may be more realistic in assessing their abilities to deal with complex projects. A more accurate assessment of the impact of the curriculum and laboratory will be available in another year when the current junior class completes their senior design projects.

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