Bringing Real World Experiences into the Industrial Engineering Classroom: From the Introductory Course to Senior Design

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Abstract

At the Mercer University School of Engineering (MUSE), an emphasis on real world content is spread throughout the industrial engineering curriculum. Beginning with the introduction to industrial engineering course (ISE 288), and continuing through to the senior design courses (ISE 487/488), students enrolled in Mercer's industrial engineering program are exposed to a variety of courses that emphasize real world content. The four authors are responsible for teaching courses in the industrial and systems engineering specialization. This paper includes an overview of the authors' efforts to include real world content in the following courses: ISE 288 (selected senior design presentations and plant visits), ISE 327 (company interviews and the Ford/Firestone case study), ISE 370 (hands-on manufacturing), ISE 424 (robot programming), ISE 402 (the use of commercially-available software tools) and ISE 412 (interface and work space design projects). The paper will conclude with a description of a successful senior design project that was conducted for an industrial client.

Introduction

The advancement in technology, computers, and automation demands continuous improvement in the quality of education both in theory in the classroom as well as hands-on practice in computer simulation, and manufacturing laboratories. There is a growing need for preparing the students both in theory and practice so that they are well prepared to meet the challenges in the job market especially in the manufacturing industries of the 21st century. A strong multi-disciplinary background is required from engineers due to increased automation in the shop floor and the globalization of industries. To improve U. S. technology transfer and address the problems in engineering education requires a program that links industry more tightly to engineering schools. Such a program has two objectives: to improve U. S. technological competitiveness by creating a substantive, people-based technology transfer relationship between industry and engineering colleges; and to improve the industrial relevance of the undergraduate engineering experience without compromising the teaching of fundamental science and mathematics. The above objectives are achieved by professors with a strong industrial background, expertise in technology transfer, some management experience, a good undergraduate and graduate academic record, and demonstrated teaching ability thereby bringing corporate know-how to the classroom [8].

Engineering design converts an idea into a technical system that can be produced. The process is usually described as a sequence of phases, beginning with a perceived need, and can be broken down into four steps: task clarification, which defines the problem, resulting in a design specification; conceptual design, which generates, selects, and evaluates solutions; embodiment design, which develops the concept, resulting in a final layout; and detail design, which defines the shape and form of every component, resulting in manufacturing information. Management involvement is crucial to the development of high-quality, competitive product in the shortest time. Design team activities must be directed and monitored for performance. The design output must be continually assessed against specification requirements [5].

Students can improve competence by practicing design. One experience at the end of a four-year program is not enough. The creation, implementation, and maintenance of a design curriculum are in fact a design

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problem. The faculty and industry partners of each school need to develop their own appropriate solution. Borrowing ideas and innovations is encouraged [11].

Manufacturing is strategic for United States global competitiveness, which directly relates to national health and wealth. American industry has awakened to the importance of the manufacturing enterprise and the need for engineering education. Although industry struggles to overcome tradition and organizational inertia in the product development enterprise, one must ask whether the same urgency has propagated to our educational systems that supply industry with engineers [12].

Transforming the engineering curriculum is "to influence the content of engineering education in ways that will better prepare tomorrow's graduates to the practice of engineering in a world-class industrial environment" [4]. There is a need for increasing emphasis on cost, communications and continuous learning, modifying faculty promotion guidelines to honor collaboration in teaching and research, and collaborating with industry. Eventually, industry could be better by becoming a partner in the educational process [4].

The industrial engineering students at MUSE are exposed to a variety of courses that emphasize real world content. The four authors are responsible for teaching courses in the industrial and systems engineering specialization. This paper provides an overview of the authors' efforts to include real world content in the following courses: ISE 288 (selected senior design presentations and plant visits), ISE 327 (company interviews and the Ford/Firestone case study), ISE 370 (hands-on manufacturing), ISE 424 (robot programming: a sample laboratory experiment), ISE 402 (the use of commercially-available software tools), ISE 412 (interface and work space design projects), and ISE 487/488 (a successful senior design project).

Real World Experiences into the Industrial Engineering Classroom

At Mercer University, design and manufacturing courses are integral parts of industrial engineering education. At the freshman level, students are introduced to problem identification, information gathering and development of alternative solutions, merit analysis, decision presentation, implementation, testing, and design. Also, the students learn engineering ethics, impact of engineering practice in the context of society, critical reading and thinking skills through extensive reading and discussion, preparing and presenting the results of teamwork both in written and oral format. During the summer semester, students are encouraged to participate in intern programs in the local manufacturing industries where they are exposed to hands-on real world design and manufacturing related projects. At the sophomore level, visualization and the interpretation of mechanical drawings in a manufacturing environment are emphasized. The ASME and ISO standards for geometric dimensioning and tolerancing, 2-D, and 3-D drawing of simple objects are also introduced to the students. Selected senior design presentations provide students insight on real world engineering applications. Industry visits organized by professional societies help the students to observe the state-of-the-art technologies in the manufacturing industries. At the junior level, students learn the basic concepts of manufacturing processes – casting, metal machining, plastics, electronic manufacturing, and introduction to automation and numerical control. In the manufacturing lab course, students are introduced to theory and application of metal working machinery, industrial safety, engineering and technological aspects of joining operation, interpretation of engineering drawings, design of simple jigs and fixtures, and hands-on experience. In the computer assisted manufacturing course, fixed and flexible automation, computer aided process planning, computer control of manufacturing systems, group technology and cellular manufacturing, CAD/CAM integration, and programming on CNC machining center and numerically controlled devices are emphasized. They also work on term projects illustrating computer aided design and manufacturing concepts. At the senior level, they are introduced to synthesis and integration of the common techniques and methods of engineering to solve "real" world or "quasi-real" world problems. Emphasis is also given on team solutions and communications. In the senior design exhibit, small groups of students design, build, and test realistic engineering system under faculty supervision.

These projects include safety, economic, environmental, and ethical considerations and require a written report and oral presentation.

A Sample Laboratory Experiment in Robotics

Automation and robotics are common in the modern manufacturing industries. Most of the time there is a need to interface robots with CNC machining centers and automation devices for loading/unloading operations, pick-and-palace operations, and packaging applications. To illustrate the concept of pick-and-place operations in the real world situations, a sample laboratory experiment in ISE 424 (computer assisted manufacturing systems) is to write a program using the Robcomm3 software for the CRS-A255 robot arm (Figure 1) and the teach pendant. The robot has to pick up 22 dice of two different colors (red and green) and arrange them on a square board with 9 bins/circles. The dice are placed on a marked board as shown in Figure 2. A typical sequence in which the robot arm will pickup the dice from the marked board is indicated by arrows from the start location. The robot arm will actually move each die once into a specified circle/bin in the square board with 9 bins/circles (Figure 3), located in front of the robot. This laboratory experiment is carried out using the following steps: 1. Determine the initial and the final layout for each individual die. 2. Determine the number each die will display initially. 3. Setup points into the Robcomm3 software. 4. Write the program. 5. Run the program.

Fig. 1. CRS-A255 Robot Arm.

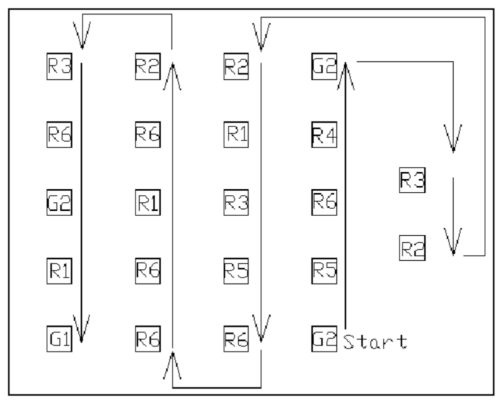


Fig. 2. The Board with Initial Locations Marked.

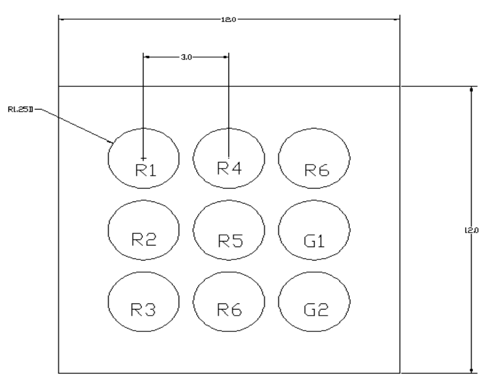


Fig. 3. The Square Board with Nine Circles/Bins

Quality Practices in Industry

All industrial engineering students are required to complete ISE 327, Statistical Process and Quality Control. The prerequisite for this course is EGR 252, Engineering Statistics. The course ISE 327 covers statistical process control methods for both products and services. While the course emphasizes the quantitative components of a quality assurance system, the students are exposed to issues related to the management of quality programs, including ISO 9000 and related standards. We discuss the history of quality, including the contributions of Deming and Taguchi. In order to introduce a real-world component into the course, we require the students to conduct a Company Interview. The students are instructed to contact a professional who deals with quality in some capacity in a manufacturing or service industry. The students are given the following set of interview questions as a guide.

Corporate Philosophy

- How important is quality to your organization?
- Do you have a quality mission statement? Does your company's mission statement mention quality?
- What methods do you use to ensure quality output?
- Do you have a quality department? Who heads the department? What is the educational background of this individual?
- In your organization, who is responsible for quality?
- How do you train your employees concerning quality issues?
- How do your customers influence your quality program?
- Has your company (or department) ever applied for a national quality award or international certification? (MBNQA, ISO 9000, Other?)

Quality Methodology

- Do you routinely collect data on the quality of your product or process? Do you use statistics to analyze the data collected?
- Do you use control charts?
- What kind of reporting techniques do you use? Who generates the reports? Who routinely sees the reports?
- What kind of quality control/process control software do you use? (Excel, generic SPC, customized or proprietary)
- How do you monitor incoming materials and/or your suppliers?
- Do you use acceptance sampling methods? If so, what standards are they based on? Who designs the sampling plan?
- What percentage of your product requires rework?

The students are instructed to add questions as needed. After the interview, each student submits a written report that includes the following:

1) Title page
2) Introduction (Background about the organization, Name and position of contact person, Date and method of interview)
3) Interview (Specific questions asked, Responses to questions)
4) Discussion (Personal evaluation of status of quality at the selected organization)
5) Appendix - (Supporting materials such as company brochures, on-site photos, award certificates, etc.)

The Company Interview assignment is more than just a list of questions and answers. Students are encouraged to pay special attention to the Discussion section and compose a response to the interview in their own words. The inclusion of an Appendix allows students to individualize their efforts. Some students include samples of the company's product; others include copies of the company Web site in the Appendix. Students often contact MUSE graduates for the quality interview. Other times they interview their employer from a previous co-op experience. After all students have completed their reports, results are discussed in class. Since many of our graduates are employed at the Warner Robins Air Force Base, Boeing, and Milliken, these companies are represented almost every year. More recently, students have conducted quality interviews at educational institutions and hospital settings. From the interview and reporting process, students are made aware that many companies are very serious about quality; both Boeing and Milliken are Baldrige Award winners. Other companies, especially the small family-owned ones, have a more modest commitment to quality. There have been unintended consequences of the company interview assignment. For example, one student obtained an offer for a future co-op experience from one employer after conducting the quality interview. The Company Interview has been a part of the ISE 327 course for five years and gives students an opportunity to relate textbook learning to workplace reality.

The Ford Explorer / Firestone Tire Controversy

The Ford Explorer/Firestone case has been used at Mercer University in the project management component of the engineering economy course that is a graduation requirement for all engineering specializations. It has also been used in the quality-related industrial engineering courses (ISE 327-statistical process and quality control and IDM 355-quality management) which are required of industrial engineering and industrial management graduates, respectively. The case study is adaptable to manufacturing courses taught by the industrial engineering faculty and design courses taught by mechanical engineering faculty.

Details of the controversy show how the case may be adapted to a variety of industrial engineering and manufacturing courses. Taguchi defines quality in terms of the way the product will be used in the field [2]. However an analysis of design failures in the past indicates that it is not always easy to anticipate how the manufacture or use of a device will influence its safety. Firestone reports [1] emphasize the company's belief that consumer use and repair were contributing factors in the deaths and injuries associated with tire separation. On the other hand, consumer watchdog groups [10] assert that both Ford and Firestone had access to data that showed that the design and manufacture of certain tires and Explorers was problematic. More than two and a half years after the initial recall, many questions remain. Have we really determined the root cause of the tire failure? Have we fully investigated the relationship between SUV rollovers and tire failure? More importantly, will the differing viewpoints of design engineers, manufacturers, and company executives be resolved before additional lives are lost? Or must victims and their families continue to resort to expensive lawsuits in order to assign fault? Finally, will the National Highway and Traffic Safety Administration do a better job in the future to uncover the existence of a life-threatening problem in a timely manner? The Ford/Firestone Controversy provides a rich case in which the complexity of problem identification, data collection, and data analysis is clearly shown.

The written case study materials include a summary of the events surrounding the August 2000 recall of certain models of Firestone tires as well as a list of related Web sites. Due to the tremendous public interest in the recall, numerous Web sites were constructed in response to Firestone's defense of the quality of their product. While some Web sites emphasize legal and ethical considerations, others emphasize details on the design and construction of automobile tires. The National Highway Traffic and Safety Administration's data on injuries and deaths associated with various SUV models brings up issues related to the interaction between automobile design and tire failures. In the past, students have been enthusiastic in their response to the case study materials. The in-class discussions have been very lively, perhaps because there have always been at least three students in each class who drive Explorers or own Firestone tires.

Exposure to Commercially-Used Software Tools

At MUSE, students are exposed to a variety of commercially available and commercially utilized software tools. A major topic in the ISE 402 deterministic Operations Research course is Linear Programming (LP). Students are first exposed to problem formulation, followed by solving LPs using the graphic method, the Simplex method, using commercial software, and the interior point method. Students also receive exposure to sensitivity analysis and a brief discussion on duality. While the students receive a good foundation in the aforementioned topics, emphasis is primarily on problem formulation and secondarily on use of commercial software to solve the LPs. The students begin by using Microsoft Excel's Solver add-in. Sample spreadsheets / templates are provided to the students as a framework for solving the LPs. Students are encouraged to experiment with and develop templates with which they are comfortable. Additionally, students are given examples and perform assignments that demonstrate the ease with which sensitivity analysis can be performed by merely cutting and pasting and altering values within the spreadsheet. The students also learn how to formulate and solve LPs using Lindo 6.1 and Lingo 7.0 from Lindo Systems, Inc. The web site www.lindo.com/cgi/frameset.cgi?leftabout.html;aboutf.html supports the claim that the Lindo systems are commercially used by citing numerous testimonials by real-world users. Exposing the students to three software packages allows them to formulate their own conclusions on the comparative strengths and weaknesses of each package.

In the ISE 403 stochastic Operations Research and Simulation course, students are once again exposed to commercial software tools. In this course, students rely extensively on the use of the Rockwell Software's Arena 5.0 simulation environment. The Arena simulation software is used extensively in industry, as noted through numerous testimonials found on the www.arenasimulation.com web site. The course is taught as a series of combined lecture and in-class lab assignments so that the student is gaining the theory and applying the theory at the same time. The course culminates with a simulation project, where teams of students use Arena to simulate a real world manufacturing or service process.

The above examples demonstrate just two of many instances where students are exposed to commercially used software to help solve and analyze real world problems.

Interface / Workspace Design

Senior industrial engineering students are exposed to interface and work space design in the ISE 412 Human Factors Engineering course. Students are exposed to the tools necessary for evaluating man-machine interfaces and designing workspaces. These skills are then applied by the students in two ways: an individual project and a team project.

For the individual project, students are required to evaluate an existing man-machine interface and analyze the strengths and weaknesses with particular emphasis on the cognitive engineering aspects of the interface. Students address the weaknesses by proposing possible solutions and present their analysis in a formal oral presentation. Typical individual projects have included evaluation of commercially available software such as ErgoMaster® and ErgoIntellegence®.

Workspace design encompasses the total environment in which the human operates in addition to physical constraints [9]. To assist students in applying these skills more effectively in a real environment, students design various types of work spaces while learning how to avoid static loads and fixed work postures on the body; to reduce cumulative trauma disorders for the hand/wrist, shoulder/neck/elbow, back and legs; and where the optimum work height should be located [7]. Students have also expressed that they learned including users in design decisions is critical in final user acceptance and ultimately the success of the workspace design. This is consistent with observations made by Kerk [6]. Students work in teams to develop two design alternatives for the workstation for which they perform merit, ergonomic, cost, and safety analysis to determine the best alternative. The results of their analysis are presented in the form of a written and oral presentation to the client(s). Typical projects have included design of graphical user interface for a ground reaction force generation program and interface for presenting measurements of the loading on the human foot.

A Typical Senior Design Project

Senior design projects are multidisciplinary in nature with duration of two semesters. During the first semester, teams consisting of two or more students are expected to work on a project proposed by the client and come up with a preliminary design acceptable to the client. They work closely with the client and the technical advisors to accomplish this task. Once the preliminary design is approved, during the second semester, the students' team builds, tests, and installs the design to the satisfaction of the client and the technical advisors. It is very common that three students from three engineering disciplines to work on a design project involving knowledge and skills from different engineering disciplines.

Industries from different countries manufacture machine tools, automation devices, and robots. Integrating machine tools with different kinds of automation devices, robots, and computers often requires additional hardware and software tools to make them functional in the real world situations. One such project, given to a design team consisting of three students from three different disciplines (ISE, IDM, and ECE) is to integrate a CRS-A255 robot arm with a Fadal VMC 15 CNC machining center [3]. The team must design an automatic clamping device to hold the part that is being machined. They also must design a control system to operate the automatic clamping device. They are expected to consider the safety issues while operating the system, as well as learn to program the robot arm and the CNC machining center. The summary of the work accomplished by the team is presented and discussed below.

A. The Clamping Device

Three different alternatives proposed for the clamping device were: 1. Use a pneumatic vise. 2. Use two air cylinders and a permanently mounted piece of L-shaped metal. 3. Use one air cylinder and a permanently mounted piece of V-shaped metal. The feasibility criteria considered for the clamping device were: to produce a clamping force from 10 to 150 psi; to fit onto a 16"x 29" CNC machining center table; capable of opening and closing automatically; and to hold a 3"x 3" part. The merit criteria considered for the clamping device were: cost, centering ability, and safety.

Based on the feasibility criteria, merit criteria, cycle time analysis, force analysis, robot work envelop, robot control program capability, and sensitivity analysis, the third design alternative was chosen. This included an air cylinder with a V-block attached to the end of the shaft, and a V-block that will be mounted on the CNC machining center table.

B. Control System Design

Three different alternatives proposed for the control system design were: 1. Write a computer program for the CRS-A255 robot arm to control the air solenoid. This will be accomplished through an integrated relay switch in the robot's general-purpose input/output port on the back of the C500C robot control unit. The relay switch will be normally open and supply the 120-volt AC to the solenoid so that it will stay closed thereby keeping the clamping device open. When the computer activates the relay switch, the switch will open removing the 120-volt AC from the solenoid so that the solenoid will open. This will allow the air pressure through to close the clamping device. 2. Use the manual approach, in which the human user will flip a switch and the clamping device will either open or close. Similar to the design alternative 1, when the switch is flipped, the current will flow through the solenoid and close it thereby opening the clamping device. When the current is cut off, the solenoid will open and allow the air pressure to close the clamping device. 3.

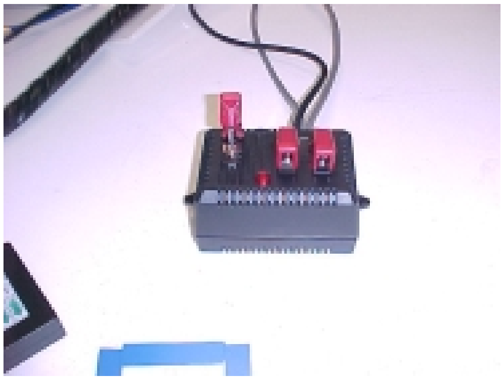
Use the combination of alternatives 1 and 2. In this, the user will select whether the clamping device should operate in automatic or manual control mode.

The feasibility criteria considered for the control system design were that it should fit on or around the table to which the robot arm is attached to, the table should fit securely inside the CNC machining center opening, and the robot arm should not make contact with the CNC machining center while loading or unloading a part. The merit criteria considered for the control system were: cost, easy use, safety, constructability, and client preference.

The third alternative with a dual control system in which the user may select either automatic (computer control) or manual (user control) mode was selected. The overall project cost was estimated to be $150 considering only the material cost for building the clamping device and the control system.

During the second semester, the students designed and built the selected clamping device with one air cylinder and a permanently mounted piece of V-shaped metal using the facilities available in the manufacturing laboratory. The clamping device when tested met all the feasibility and merit criteria that

Fig. 4. Clamping Device Mounted on the Machine Table.



Legend: From Left to Right:
1. Power on or off Switch
2. Automatic or Manual Mode
3. Open or Close Position (in ManualMode Only)

Fig. 5. Switch Box for Clamping Device.

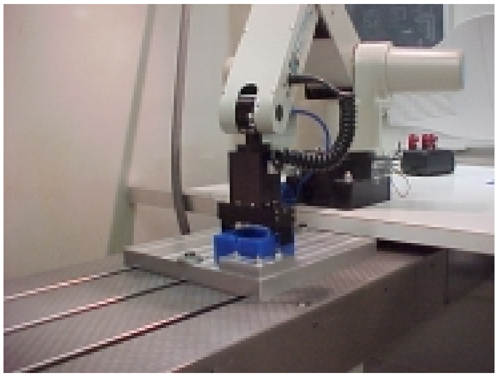


Fig. 6. Robot Preparing to Remove Part from Clamping Device.

were chosen by the students. The clamping device is mounted on the CNC machining center table and is shown in Figure 4. The switch box shown in Figure 5 has been made as part of the control system design to operate the clamping device automatically for opening and closing when the part is placed on the clamping device by the robot arm. When tested, the switch box also met the feasibility and merit criteria chosen by the students. The clamping device and the control system were installed and tested together with the CRS-A255 robot and the CNC machining center for automatic loading and unloading of parts, as well as automatic opening and closing of the clamping device when the part is loaded/unloaded. The CRS-A255 robot preparing to remove the part from the clamping device is shown in Figure 6. At present, this set up forms an integral part of the CNC machining cell with robot interface for loading, unloading, and automatic actuation of the clamping device in the manufacturing laboratory.

Conclusions

The industrial engineering curriculum based on hands-on experience, lab work in design and manufacturing, exposure to commercially-used software, industry co-op and summer internship experiences, open-ended design projects, industry visits, and participation in professional society activities provide opportunities to bring real world experiences into the industrial engineering classroom.

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