

# Integrated Curriculum to Improve Engineering Problem Solving

John K. Jackman, Sigurdur Olafsson, Frank E. Peters, Sarah M. Ryan  
Department of Industrial & Manufacturing Systems Engineering

Kevin Saunders  
Department of Educational Leadership and Policy Studies

Iowa State University  
Ames, IA 50011

## Abstract

A series of modules based on realistic problems are being developed for our industrial engineering curriculum. These modules require students to use a variety of information technology skills to access, screen and analyze the data available to them. The modules are also designed to help students build relationships among the courses, which they traditionally treat as isolated bodies of knowledge. Students' engineering problem solving will also be enhanced by the challenge presented by more realistic open-ended problems that are incorporated into the modules. This paper details the results of the latest module used in a Manufacturing Systems Engineering course.

## Keywords

Information technology, active learning, course content integration, problem solving.

## 1. Introduction

For programmatic needs, most engineering topics are packaged into courses that are of a discrete length. Students are therefore conditioned to concentrate on the topics that are part of the courses in which they are currently enrolled. While this situation is partially buffered by the fact that some courses are prerequisites for others, opportunities do not exist in the curriculum to reinforce many topics. While this situation is true in many engineering curricula, the traditional industrial engineering curriculum, in particular, is perceived to contain a loosely connected set of topics that pertain to different aspects of manufacturing and service enterprises. The senior capstone design class does integrate the knowledge gained in the curriculum; however, this is only one course and usually taken during a student's final semester.

The authors have been working to develop a series of modules, which will be utilized in most required industrial engineering courses. A module for a particular course will reinforce the topics of that course and integrate topics from other courses. To support these efforts, software is also being developed to deliver the modules to the students. One of the advantages of this format is that students are able to receive assistance from the software, such as a tutorial or review of a topic, for some of the ancillary topics that are required to complete the module.

The modules are designed with several goals in mind:

- Each module presents a *realistic engineering problem* that students must solve using the tools acquired during the course [1]. This helps the students apply discipline-specific knowledge to solve engineering problems, and also lends credibility to the problems. The problems are much broader than the narrowly defined questions traditionally offered by textbooks.
- The modules are *interconnected* so that the relationships between previously isolated parts of the curriculum are made apparent. Therefore, over a set of several courses, students will develop a better appreciation of the connections among courses. While this type of integration would be difficult to achieve without the use of information technology, in the IT-based module linkages are made via common interfaces and databases, which allows the students to focus on the content connections.

- The modules focus on helping students develop both their *cognitive ability* to structure schemas in industrial engineering knowledge domains and their *metacognitive ability* by reflecting on their solutions and justifying each action that is made..
- For each module, students must independently define goals, formulate problems, and develop solution strategies while mastering the course material. This environment, which encourages cooperation and communication with other students, is thus a fundamental shift from the existing emphasis on the traditional lecture format to *active and collaborative learning*.
- Another goal of this project is the increased *use of information technology skills by students* including querying databases, spreadsheets, cleaning and sorting data, and analyzing data.

The first module developed was for the Engineering Economic Analysis course. This module was deployed the fall 2002 semester, and has now been used four times. Details on the results of this module are available in another paper. [2] The latest module was deployed in a senior level Manufacturing Systems Engineering course. Both of the current modules and future modules will utilize a common software delivery system, called the Electronic Learning Portal, developed by the authors.

## 2. Electronic Learning Portal Software

The basic functions of the electronic learning portal (ELP) are to: (1) provide scenario specific information based on student-initiated requests, (2) structure the problem solving process, (3) collect information on cognitive processes, (4) collect work in multiple formats from each student team, and (5) provide feedback to teams

ELP is based on a client-server architecture that provides control mechanisms, information transfers, and administrative functions through the Internet. After connecting to ELP, students have access to specific information for a scenario. This information can take the form of reports, spreadsheets, design specifications, drawings, pictures, or streaming video. In addition, teams submit their work, self-evaluations, and the solution process to the portal. Student information is stored in a module repository consisting of a relational database that describes how they obtained their solution, as well as a set of files containing student work created using different software tools (such as spreadsheets, CAD, or optimization).

A project consists of the work students submit, evaluations, and information on cognitive processes they use. Any student on the team can make changes to a project. The client software provides a mechanism to create projects for a given module. Each project consists of the following stages:

- *Objective:* Students specify what they are trying to achieve before they begin the solution process. A justification of the objective is also required.
- *Plan:* Teams construct plans for solving the problem consisting of system actions and student actions. System actions are those tasks that can be performed by the ELP module. These actions can have cost and time parameters that would result in a cost incurred for the project or a delay in the scenario timeline. The team must provide justification for each action in the plan.
- *Solution:* After completing the plan, the solution is specified based on a list of possible alternatives. A justification of the solution must be provided in order to submit.
- *Performance:* A scenario specific simulation model provides a representation of the system under the solution parameters selected by the team. (The performance stage was part of the generic module format but was not utilized for the module used in the Manufacturing Systems Engineering course.)

Since this is a learning experience, the students are allowed to start as many projects as they want, and the instructor only evaluates the final project.

The software design also requires reflection. Along with each *objective*, *action* and *solution* element, students enter a reason for making that choice. In order to progress from each of the first three stages, students must also complete a self-evaluation, which will be discussed further in Section 3.2.

## 3. Module for Manufacturing Systems Engineering Course

The second module that was created under this program was for the senior level Manufacturing Systems Engineering course. The topics of this course include: geometric tolerancing, fixturing, process planning, make vs. buy decisions,

design for X, strategies for lean manufacturing, and plant layout. Most of these individual topics are reinforced through assignments and laboratory experiments. However, the course was lacking an assignment that truly addressed the ‘systems’ aspects that exist in many industrial problems.

### 3.1 Problem Description

The problem description was developed around a local manufacturer of concession equipment, Paragon International, whose major product is popcorn poppers. Sheet metal processing accounts for a major portion of their manufacturing operations, and near the beginning is the need to cut the sheet metal parts from the sheet steel. Currently they use a CNC turret punch press to cut the pieces according to the design specifications. This operation is frequently a bottleneck, and production quantities are increasing. The maximum sheet size that the machine can accept is 4 x 4 feet, requiring the incoming sheets be cut into blanks based on the size of the final parts. After punching, the operator needs to sand the edges of the parts to remove a burr. Some parts are outsourced because the turret punch press is not capable of cutting.

Figure 1 is a copy of the initial screen the students encounter. There are six tabs across the top; the last four of these are the project completion stages discussed above. In the first version of the previous module, much of the background information was given in a single ‘problem description’ document. In this module, the first tab introduces the student to the company, its products, and the various departments within the company. This is a significant improvement over the single document because by segregating the information into the appropriate departments, the students gain a sense of how different departments interact within an enterprise. Table 1 summarizes the departments and the data they provide.

As can be seen in Table 1, the information available from the departments took many different forms. Some were simple memos, which were written as staff updates on policies or recent studies of production problems. Other information was presented in spreadsheets, and the engineering drawings were provided as CAD files. To attain the sales history and BOM, the students needed to write SQL statements to query the database, which was part of the ELP. Some information was purposely extraneous to this problem, such as the spreadsheet on mall construction starts and suggested retail products.

Once reviewing the problem description and the other information available, the students needed to submit an *Objective* statement for their project through the ELP system. Along with the statement, they needed to include the measures used to evaluate compliance with the objective and a short reasoning. The instructor reviewed the objectives through the ELP system and either approved the statement or rejected it with some feedback. Most groups were able to develop an acceptable objective statement during the second or third attempt. Teams could not continue without instructor approval.

Figure 1: A screen print of the starting page for the module.

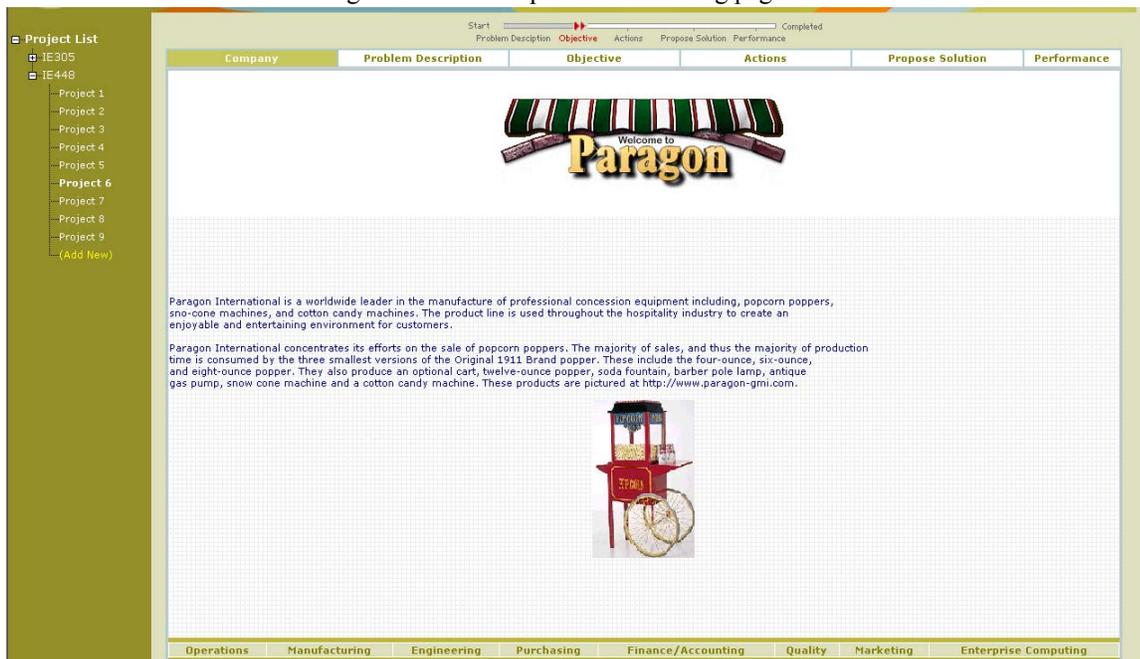


Table 1: A list of the data and information available from the different departments in the simulated enterprise.

Department	Information Available
Operations	Recent memo about reducing lot sizes and WIP Process flowchart
Manufacturing	Report on manufacturing Recent memo about reducing raw material costs Memo about problems with the press Memo about reducing scrap Memo about study of duty cycles for alternative cutting processes Spreadsheet with replacement machine part costs Spreadsheet with thickness and density of steel sheets Machine specification sheets for alternative cutting processes Results of current turret press operations study Current and Forecasted prices for sheet steel
Engineering	Database which can be queried to get BOM SolidWorks CAD drawings of many of the parts
Purchasing	General information about the department's function Memo on the acceptable MARR for justifications
Finance/Accounting	Spreadsheet for depreciation calculations Suggested retail prices of final products
Quality	Memo reminding staff of quality improvement memo
Marketing	Database which can be queried to attain sales history Spreadsheet of estimated shopping mall construction starts Spreadsheet of demographic data on current customers
Enterprise Computing	Tutorial on how to use SQL to access database

An important set of information that was available from the manufacturing department was the machine specification sheets for new equipment for a variety of sheet cutting processes. The students were also provided with a set of possible cutting processes to replace the current turret punch press that were said to have been created from a staff brainstorming session. The potential processes included die stamping, bandsaw, plasma, laser, waterjet, EDM and oxy-fuel. Some of these processes could be quickly eliminated by looking at the tolerance or processing speeds. Once they narrowed the potential processes down to one or two, they were to submit their conclusions to complete the *Analysis* stage of the project.

The final stage of the project was the *Solution* stage for which the students needed to conduct more in depth analysis. The laser cutting equipment can handle larger sheet sizes compared with the current turret punch press, which would eliminate the need for cutting rectangular blanks from the large sheets to feed the turret punch press. To calculate the savings resulting from the increased material yield, the project required the students to import the SolidWorks CAD files into SigmaNest nesting software. SigmaNest calculates the optimal sheet steel yield given the list of parts required per the BOM. The software also was used to calculate the machine time to cut the parts.

In addition to the increased material yield, the students needed to calculate and sometimes estimate the expected changes in the labor, outsourcing, WIP, machine downtime and maintenance costs based on the information about the company that was provided. Armed with these values, they then could proceed to conduct an economic analysis and propose a final solution. The solution was submitted by uploading a file through the ELP. The ELP once again prompted the students to provide reasoning for the solution steps, and a self-evaluation.

### 3.2 Evaluation Criteria

A rubric, or evaluation matrix, was developed to assess the performance of each student group. This assessment mechanism is discussed more fully in reference [3]. The rubric was divided into sections for the *Objective*, *Plan* and *Solution* stages. The *Solution* portion of the rubric is shown in Table 2. The students were able to review the rubric before submitting work at each stage, and after each submission the ELP prompted them to evaluate themselves using the rubric. The self-evaluation forced the students to consider their actions, and the research team will study correlation between these self-evaluation scores and the instructor scores to better understand students' learning strategies.

There was initially some apprehension of providing a rubric because the instructors felt that they were 'giving away' the solution. However, we recognize that this is a learning environment, and the rubric is effective in guiding students in developing better problem solving skills.

Table 2: Rubric to evaluation the *Solution* portion of the project.

Criteria	Exemplary	Satisfactory	Unacceptable	Score (0-6)
	6	4-5	0-1	
<b>Production System Improvements</b>	Solution correctly considers the impact on the production system (e.g. WIP, lead time, quality) of the option chosen.	Some considerations ignored or incorrectly taken into account.	A substantial portion of these factors are ignored or incorrectly taken into account.	
<b>Costs</b>	Solution correctly considers the operating costs (including labor and material) of the option chosen.	Some considerations ignored or incorrectly taken into account.	A substantial portion of these factors are ignored or incorrectly taken into account.	
<b>Justification</b>	Reason for selected option is clearly and concisely stated.	Some minor flaws in justification.	Reasons are unclear, missing, or unrelated to plan.	
<b>Presentation</b>	Justification is clearly presented and supporting data is properly presented.	Justification has more than a few minor grammatical errors, problems with sentence, paragraph structure, or presentation of data.	Justification has moderate or severe problems with grammar, sentence structure, paragraph structure, or presentation of data.	

### 3.3 Student Feedback

To evaluate the effectiveness of the modules and how the students valued the learning experience, a focus group was held. To minimize instructor bias, a researcher from the College of Education conducted the hour-long meeting. Fifteen students voluntarily attended, six were third year students and the remainder were fourth year students. There were five female students, which is representative of the overall percentage in the class. A series of questions were asked, and the pertinent highlights are discussed below.

Students offered various reactions to the open-ended nature of the module. At first, they felt like the directions were unclear and it was difficult to get started on the project. Since this was either the first or second time (if they had taken the Engineering Economic Analysis course in the previous year) that they seen the problem format, some experienced an initial shock because the problem was unlike others they have seen in their previous academic experience. They did note that as they progressed and were able to better comprehend the problem, they were more comfortable with the format. However, some uncomfortableness with the open-ended nature persisted given the large amount of data and that they were unsure on how far to extend the analysis.

Despite the challenges of adapting to an open-ended problem, overall the students were positive and enthusiastic regarding their experiences. Students appreciated that there was more than one way to approach the problem, and the opportunity to be creative. They indicated that they had many thought processes and explored a few tangents on their way to a solution.

Students offered some procedural issues with the software and noted places where better explanations were needed. Overall, they appreciated the user interface to the module. Many of the changes they suggested will be made for the next course offering, and incorporated into future modules. They also desired additional feedback, which will be addressed in future versions.

Some of the largest learning dividends realized were in the area of developing problem solving strategies. One student commented that the module helped students realize that problem solving is “more of an in depth process” than that which is required in other college courses. Several recognized the need to document more, particularly of assumptions made, as they progressed through the problem so they could better justify their answer at the end. The focus groups offered advice for future students based on the experience they gained, including: make logical assumptions before rushing to make calculations, decide what steps will add value to their solution, better organize their spreadsheets, make a decision chart to track progress, and be patient.

To assess how the module is affecting students’ thinking and problem solving processes, we are using a modified version of the Motivated Strategies for Learning Questionnaire [4]. The MSLQ is a self-report instrument that measures students’ motivation and self-regulated learning behaviors in classroom contexts. Specifically we

measured their self-efficacy related to the course material (i.e. capability in comprehending the subject matter), their self-efficacy related to their confidence (their confidence in their ability to do well in the course), teamwork and problem solving skills, and finally the learning strategies they utilized. These four items were quantified with 25 questions that comprised the modified MSLQ.

The MSLQ was conducted during the 5<sup>th</sup> and at the end of the 15<sup>th</sup> week of the semester. The students worked on the module between weeks 12 and 15. As a comparison, the MSLQ was also conducted at the same time of the semester in another required upper level industrial engineering class, Optimization. For each class, a paired t-test was conducted for those students who completed the MSLQ both times within a class. There were 22 and 39 such students in the Manufacturing Systems Engineering and Optimization courses, respectively.

For the Manufacturing Systems Engineering course, the students' self efficacy related to the material, their self efficacy related to their confidence, and their learning strategies all increased at the statistically significant level of 0.005. The problem solving and teamworking category, which initially had the highest value, also increased, but was not statistically significant. These results indicate that the students had more confidence in their abilities in this course, and they improved their problem solving skills during the ten weeks between completing the MSLQ instruments. In the Optimization course, for which a module has not been developed yet, the only statistically significant result was increase in those students problem-solving skills.

#### **4. Conclusions**

The module profiled here is a second in a planned series of modules to link the industrial engineering curriculum. This module was very different in format than the first one created for the Engineering Economic Analysis class, however we were able to utilize much of the standard problem format and software. This is encouraging as we develop modules for additional courses.

Student feedback was very favorable. While being a little frustrated at first, they accepted the challenge presented by the open-ended nature of the problem. They appreciated the realism of the problem, and the ability to develop a variety of problem solving skills and to be creative. We will work to incorporate additional feedback mechanisms, without limiting their freedom to think independently to develop a solution. One of the items that challenged students was that there was not a perfect solution that they could follow. In particular they were uncomfortable because there was not a clear point to end the analysis.

While they were provided the evaluation rubrics, the students still did not completely trust that their project was going to be graded solely on those factors, and not graded on achieving a perfect answer to the problem. The instructor found the rubrics to be a very valuable tool, and plans to use them for other evaluation applications.

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