Implementation and Assessment of Industrial Engineering Curriculum Reform

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Abstract

We describe a curriculum reform project that aims to improve the industrial engineering curriculum through a web-based learning environment that engages students in active and collaborative learning. This environment focuses on engineering problems solving, increased information technology content, and the higher order cognitive skills that are needed to be a successful engineering problem solver. We describe the status of this project, which has been implemented in two courses: an engineering economy course and a manufacturing systems engineering course. One of the objectives of this new environment is integration of the curriculum, and we discuss how links were created between these two courses to highlight connections between the course contents, and how this results in rethinking and improvements of the existing curriculum. We also show how the environment encourages development of engineering problem solving skills, as well as the basic cognitive skills needed. Finally, we discuss our assessment of the new learning environment, how it has been received by students, and how it is improving learning for industrial engineering students.

1. Introduction

Using information technology (IT) to improve engineering education offers much promise for curriculum reform\(^7,16,20\). However, this also requires careful consideration of both the technical content and of the learning objectives. In this paper, we describe our work in designing and developing an IT-based learning environment for industrial engineering that both effectively delivers the desired engineering content and promotes learning that we value by improving students’ cognitive skills.

A key motivation for introducing technology into the classroom is its ability to address challenges that may be difficult to solve without the enabling technology. One clear potential for using information technology to improve upon traditional lecture classes is to use it to promote collaborative learning\(^19\) and active learning\(^12,13\). Specifically, using information technology, simulated environments can be created that allow students to address realistic problem scenarios in a hands-on fashion using domain knowledge mastered in the relevant courses\(^4\).

There are also many other challenges in education where information technology can be used as an enabler. For example, the traditional industrial engineering curriculum includes what may seem like loosely connected courses that address different elements of manufacturing and service
enterprises. A common IT-based environment can be used to integrate these courses. As another example, such an environment can also be used to encourage the development of specific learning skills. In traditional educational environments, it is difficult to monitor and encourage students’ higher-order cognitive activities, such as planning how to learn a given task, monitoring comprehension of the task, and evaluate the progress towards completing the task. On the other hand, such metacognition has been found to be important to learning and we believe an IT-based environment can enable monitoring and development of those skills.

Following the above motivation, we have identified several elements that we believe are important in an IT-based learning environment and we have incorporated these elements into the development of a new learning environment for industrial engineering. In particular, we believe that the learning environment should: (a) Make connections between the course material and real-world problems by presenting realistic problem scenarios; (b) Emphasize relationships between previously isolated parts of the curriculum; (c) Help develop both students’ cognitive ability to structure schemas in industrial engineering knowledge domains and their metacognition; (d) Increase active learning and collaborative learning.

The remainder of this paper is organized as follows. In Section 2, we describe the learning environment that we are currently in the process of implementing for our industrial engineering curriculum. In Section 3, we describe the software modules that have been implemented so far as part of this new environment. In Section 4, we describe the assessment of the environment and report on student experiences, and finally, Section 5 contains some concluding remarks.

2. Industrial Engineering Curriculum Reform

As was pointed out above, although it is widely accepted that information technology may be used as a vehicle to improve industrial engineering education, doing so will require a careful consideration of both technical content and of learning objectives so that the technology environment promotes learning that we value and effectively delivers the technical content. To increase its usefulness it should also be used to address challenges in the existing curriculum that may be difficult to solve without the enabling technology. Some of these challenges were identified in the introduction, and those will be expanded on in this section.

In an effort to rethinking the entire industrial engineering curriculum, we are in the process of designing a new active learning environment where for each course students complete one or more software modules that relate to the course content. These modules are designed to accomplish numerous goals identified as being desirable:

- Each module will present a realistic engineering problem that students must solve using the tools acquired during the course. This helps the students to not only make a connection between the course material and a real-world problem, but also develop their ability to apply discipline-specific knowledge to solve engineering problems and monitor their problem solving strategies.

- The modules will be interconnected so that the relationships between previously isolated parts of the curriculum are made apparent. Over a set of several courses students will therefore develop a better appreciation of the connections among courses.
The modules will focus on helping students develop both their cognitive ability to structure schemas in industrial engineering knowledge domains and develop 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 is thus a fundamental shift from the existing emphasis on the traditional lecture format to active learning\cite{12,13}. This is also an ideal tool to encourage cooperation and communication with other students through collaborative learning\cite{19}.

One of the means by which information technology (IT) can support learning is to present real-world problems as part of the curriculum and to create an active environment where students formulate and solve difficult problems using the tools learned in class\cite{4}. Our new learning environment is heavily centered on such realistic problems developed in cooperation with industry partners.

Currently two modules have been implemented, but as the development of additional modules in the new learning environment continues, one of the key focus areas will be the integration of the industrial engineering curriculum. The motivation behind this is that the traditional industrial engineering curriculum encompasses what may seem like loosely connected courses that address different elements of manufacturing and service enterprises. The engineering economy module is the first piece in a common IT-based environment that will be used to integrate these courses, and at the same time encourage the development of specific learning skills. Thus, modules will deliberately highlight connections between the content of multiple courses. This will be achieved by such mechanisms as solving two closely related problems using material from two different courses and using the output of a module from one class as an input to a different module. This type of integration would be difficult to achieve without the use of information technology. In the IT-based modules, linkages will also be made via common interfaces and databases, which allows the students to focus on the content connections among the courses.

The fact that we are using IT to achieve this integration of the curriculum also enhances a student's ability to solve engineering problems. In the past, and continuing to some extent for traditional engineering disciplines, foundational knowledge in mathematics and engineering sciences helped to integrate curricula as the concepts and tools introduced in the first two years were reinforced and expanded by their application in subsequent, discipline-specific courses. For industrial engineering, we see information technology increasingly taking over this integrative function. However, the typical curriculum has not been revised sufficiently to allow the IT we teach our freshmen to permeate the subsequent coursework. The key concept of this approach is a common learning environment based on new and emerging information technology tools and ideas that integrate isolated course content.

Another effective use of IT to enhance learning is increased capacity for providing students with timely feedback, and to encourage reflection and revision on the part of the students. Using formative assessment for feedback and to encourage learning from mistakes is an integral part of this environment but has not yet been implemented as part of the engineering economy prototype module. However, special effort has been made to incorporate student reflection into the
environment via student self-evaluations and explanations of actions. This is again something that is difficult to achieve without the enabling technology, and will be discussed next.

2.2 Higher-Order Cognitive Processes

Educational psychology has recently had significant focus on metacognition as a key enabler to being a successful learner\textsuperscript{1,2,5,9,10,18}. Sometimes referred to simply as “thinking about thinking,” metacognition differs from just cognition in that it refers to higher order thinking that involves active control over the cognitive processes engaged in learning. This may involve numerous activities, such as planning how to learn a given task, monitoring one’s comprehension of the task, and evaluating the progress that is made towards the task.

Several researchers have recently focused on the application of metacognitive theory in education\textsuperscript{3,6,14,17,21}. It has been observed that as students become aware of their own thinking and problem solving process their learning can be enhanced. One of the key innovative elements of the new learning environment is a focus on the development of metacognitive skills. Thus, the several elements are incorporated into the modules that explicitly encourage students to reflect critically on their work, monitor their progress towards understanding the problem, planning the problem solving process, and evaluating their progress.

Throughout the project, students are required to provide a self-evaluation of their work based on the same rubrics that are used by the instructors to evaluate the final project. For example, before leaving the objective phase, where the students specify an objective function and the goal of their project, the students are prompted to evaluate the completeness, clarity, and justification of the objective. Thus, the IT is used to encourage student reflection and possibly revision based on this reflection. The standard for measuring the evaluation factors is made available to the students and they can be previewed at any time while the students are solving the problem. The purpose of the self-evaluation is to encourage students to reflect on their work and make revisions as necessary if it does not meet the set criteria.

In addition to the self-evaluations, students are required to explain and justify their actions throughout the module. For example, students must explain why they select their objective and why a specific task is included on the action plan. This is again intended to encourage students to be reflective and understand their own thought and problem solving processes.

Our experience from our pilot studies indicates that students are not accustomed to these types of reflections and in many cases gave either non-specific explanations or tried to go beyond what would be required for an explanation. We take this as an indication for the need to incorporate metacognitive skill development into the entire curriculum and expect as students move through such modules in a series of courses they will enhance their ability to reflect on their actions.

3. The Engineering Learning Portal

As described above, the thrust of this project focuses on how information technology could be used to improve the engineering problem-solving process based on real world industrial engineering problems. To support this effort, a software prototype called the Engineering Learning Portal (ELP) was developed and implemented. The ELP contains the modules and
infrastructure used (1) to provide scenario specific information based on student-initiated requests, (2) to structure the problem-solving process, (3) to collect information on cognitive processes, (4) to collect work in multiple formats from each student team, and (5) to provide feedback to teams on their progress. After connecting to the 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. The problem-solving process is structured by the ELP into four stages.

- **Objective**: Students specify what they are trying to achieve before they begin the solution process and what measures they will use to evaluate their achievement of the objective. A justification of the objective is also required.

- **Plan**: Teams construct plans for solving the problem consisting of system actions (performed by the ELP) and student actions, which require the students to apply their knowledge of the domain implemented in the module. The team must justify each action in the plan.

- **Solution**: After completing the plan, students specify a solution based on a list of possible alternatives. A justification of the solution must be provided in order to submit the solution.

- **Performance**: A scenario-specific simulation model provides a representation of the system under the solution parameters selected by the team. Performance measures for the system are provided at pre-defined time periods. Students can use the results to modify their solution.

The ELP was designed to encourage the metacognitive processes of planning, reflecting, and evaluating one’s own progress (see Section 2.2). Along with each choice of 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 complete a self-evaluation based on rubrics. The evaluation criteria can be viewed prior to completing the stage. An example of the rubric to evaluate the objective phase is shown in Figure 1.

![Figure 1. An example rubric](image-url)

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The problems in the ELP are deliberately kept open-ended as to better replicate real-world scenarios. Likewise, information is not simply given to students, but rather students can click on “Company” and then select from various departments, such as Operations, Manufacturing, and Purchasing. Figure 2 shows the view for the Engineering department. For each department, students can download relevant memos and other files, and when appropriate query relevant databases.

The first module of the ELP was developed for a course in engineering economic analysis. Engineering economy was determined to be good choice for the first module for numerous reasons, but in particular because it has numerous connections to other courses in the industrial engineering curriculum. The problem scenario for the engineering economy module, developed in consultation with a local manufacturer, centered on the selection of a manufacturing strategy from three possible alternatives to implement in each of the next five years. In the Objective stage, students formulated and justified a numerical measure of performance they would later use to compare alternatives. The system actions available in the Plan stage consisted of gathering various types of information, along with optional studies that would result in costs and delays. The student actions were various types of computations and analysis relevant to the knowledge domain (see Figure 3 for an example).
In the *Solution* stage, students specified a decision for each year. Completion of this step also required uploading an Excel spreadsheet with a net income and cash flow statement for the five-year horizon. Students could then progress to the *Performance* stage and view the results of a simulation of the first year, including realizations of variables such as demand, production volume, costs and net income. After the first year, they could view the results of the market research study (if applicable) and modify the alternatives chosen for years 2 - 5. The simulation would run at this point, after which the students completed the final submission of their project.

The first module was pilot tested extensively in our junior-level Engineering Economic Analysis course (IE 305), first as an extra credit option during the Fall 2002 semester and then as a project worth 20% of the final grade in Spring 2003 semester. It was also used in the summer semester offering of the course and for the fourth time in a new web-based format during Fall 2003. The Engineering Economic Analysis course is a 3-credit course required for industrial and electrical engineering majors, and a popular elective for mechanical and chemical engineers. Feedback from students was obtained through project self-evaluations, surveys, and focus groups. In addition, groups of students were hired during both semesters to evaluate the module. This feedback proved invaluable to revise module details, validate the learning environment, identify challenges and research issues, and to gain experience that will be leveraged for future module development. This assessment will be discussed in more detail in Section 4 below.
During the Fall 2003 semester, a second module was also offered for the first time in IE 448 Manufacturing Systems. This is an upper-level course consisting primarily of IE majors. This module uses the same general setting as the IE 305 module, but has a different problem. In particular, the students are given the following problem statement:

With the explosion in demand since the reorganization of the company, Paragon has found the need to re-evaluate their original process of metal stamping of the sheet metal parts. They believe that current buying trends will continue at the same rate and thus exceed their ability to meet demand in their market niche. Their current inefficiencies with some of their processes need to be reviewed in light of their projected inability to meet this demand.

In response to the inability to meet demand, management has begun to investigate the feasibility and profitability of a number of alternative options. Possible metal cutting operations for sheet metal include:

- A new CNC turret punch press
- Die stamping operations
- Abrasive water jet
- Laser cutting
- Plasma cutting
- Oxy-fuel torch
- Wire electro-discharge machining
- Band saw

As before, the students must go through an objective, action, and solution phases. This new module allowed for the first effort to integrate course material. In particular, to select between the different cutting operations, students need to perform and economic analysis of each option. Thus, the output of the engineering economy module becomes an input to the manufacturing systems module and students more clearly see the connections between the two different courses.

4. Assessment

The course assessment during Fall 2003 semester consisted of both surveys and focus groups. First, both pre- and post-module surveys were administered to students. Second, students in both classes gave their feedback through focus groups.

4.1 Survey Results

To help assess students problem solving skills, learning strategies, and self-efficacy with respect to both the material and general confidence, a survey was conducted both before and after the students experienced the module. This was done in both courses, and as a control group the survey was also administered to students in our optimization course (IE 312), which consists mostly of junior and senior IE students.
The survey questions are reported in Appendix A. As of the writing of this paper, the post-project survey results are not yet available. We are therefore not able to report any results regarding the affect of the module (that is, pre- and post-module difference) at this time.

4.2 Focus Groups

For an immediate feedback on the affect of the module, focus groups were conducted for students in both courses. The focus group for IE 305 included individuals who majored in mechanical engineering (n = 2), computer engineering (n = 4), electrical engineering (n = 1) and industrial engineering (n = 1). The participants included seven seniors and one junior. Six males and two female students participated. To start the session, students were informed of the purpose of the focus group, basic demographic information gathered, informed consent to participate secured, and the confidential nature of the process explained.

The format of the focus group session was a general discussion, guided by the following set of questions:

1. Give one or two examples of specific things from the project that really helped you learn.
2. What technology did you apply to achieve the solution?
3. How has the project influenced your thinking about solving engineering problems?
4. Describe your problem-solving strategies and processes throughout the project. Describe the times you thought about your approach to the problem (e.g., completing rubrics, restarting module, discussion with partner).
5. What did you learn through the project?
6. How did you use information from other courses to solve the problem?
7. How do the lecture course and the project relate to each other?
8. Describe what you learned about teamwork through this project.
9. Suggest one or two specific, practical changes to the project that would help you improve your learning in this class.
10. What would you not change about the project?
11. How much time did you spend on the project?
12. Were the templates useful?
13. Did you follow the suggested timeline (objective, action, solution)?
14. Did you like having a set of actions to choose from?
15. Would you like the ability to select alternative actions?
16. What was confusing about the module?

The amount of details provided by the students varied greatly from one question to the next, and for the remainder of this section we report on some of the actual comments made by students.

When asked what they thought of the module, two students explained that they did not like the system because they found it confusing. They stated that when they asked questions about the module, they did not get direct answers. For example, when asking where to start, the instructor explained to students that they could start in various places. Two students also explained that there was a great amount of information. They clicked on the company page, but they were unsure what to do with the amount and type of information provided. The two mechanical engineering students explained that ME students are used to problems that have one solution. In the class, the instructor explained that students will find multiple solutions. They also heard a statement regarding the fact that there is one solution that is preferable. These students were anxious about grading due to the uncertainty of finding the preferred solution. The students explained that they are used to going to the professor to find out if they are solving the problem correctly.

Two students wondered, “What is the point of grading ourselves?” A student team from computer engineering commented that they were initially overwhelmed by the amount of data and information. They recommended spreading out this portion of the module by conducting the module throughout the semester. Students would receive pieces of information regarding the company and the problem throughout the semester. The student team thought that the information would be in one data sheet, but commented that this process is more realistic. The student team commented that they took another course in computer engineering that also tried to mimic a real world problem. They stated that the module in IE 305 was better at accomplishing this goal.

When asked about examples of things that helped you learn, students commented that everything that the module required students to do was covered in the lecture course. It pulled together the information and helped students learn how to apply the concepts. One student explained that creating a five-year plan was new. They had not experienced a problem where they would evaluate alternatives and could switch plans from year to year. This aspect of the problem was unclear to the student at first.

In response to the question of how has the project influenced your thinking about solving engineering problems, the student from industrial engineering commented that problems are not “clean cut.” The problem adds information that seems applicable to the real world. Some problems are complicated and cannot be answered in a simple way. Another student explained that the process helps students to trace through problems by seeing the relationships between different steps of the problem solving process. The actions list helped to provide students with some order. One student explained that they are typically given information. The module, however, required students to go and get information.

In describing problem-solving strategies, one student team placed all of the information into one spreadsheet to compile the data in one place. A different team did each action in small parts. A third group stated that they found their own order of problem solving strategies. One student...
commented that it was a pain going through all of the memos. Another stated that there was a lot of extra information. One student group commented that they wanted to simply get past the objective phase in order to get a better understanding of the project. Later this group used the actions that they selected in the action phase to define their objectives.

When asked what they learn through the project, one student explained that it was not “what” they learned, but their ability to learn “how” to use the information. This student explained that it was more important to use what they had already learned to solve the problem. The student thought that it was a good application that encompassed what they had learned. The student also added that this successful application activity was unlike most other activities in that it was successful in requiring students to use what they had learned.

The focus group for IE 448 students was administered in the same manner. The group consisted of 15 students. The participants included third-year students \(n = 6\) and fourth-year students \(n = 9\). Ten males and five female students participated. As before, we report below what was actually said by the students during this session.

When asked what they thought of the project, students responded that it was realistic. However, some though that the directions were unclear and jumbled, and students were not sure when they should end. While students liked the project because it was encompassing, time was a factor, and there was pressure to be in the lab. They thought it was an unrealistic project to accomplish in one week, and prefer it to be semester long time. Students also explained that it requires additional time to complete group work due to the need to coordinate schedules. It was nice to have a lot of information to sort through, but it was hard to find some information, which students found realistic. There was some conflicting information. One student explained that some energy costs were not given and so the student went to the Internet to find the information. Several other students used a similar strategy to solve the problem.

When asked to describe the problem solving process, the groups described various processes.

- One group initially removed extraneous options and data.
- One team described working backwards by finding out trends and percentage of growth.
- One team delegated various parts of the project.
- Another team worked as a group and “bounced ideas off one another.”

Students offered various reactions to the open-ended nature of the module. Some said that the format “bothered” them, but then they saw what they had to do. The students explained that the format was different from what they are used to and it required them to find information for themselves. Students described an “initial shock” to the format. Students also explained that in the workforce they would have more familiarity with the context and that it simply took time to find information in the module. Some students explained that it was difficult to remember where they saw information initially. In retrospect, it was good, but at the time, they had a different view. Students appreciated that there was not one way to do the problem. They enjoyed the open-
ended nature of the problem and explained that they would think about other things and explore various tangents.

In response to being asked what they would change, students said that they liked the open-ended nature of the problem. They explained that it is not what they are used to, but that they appreciated the format. Students explained that they used various skills to solve the problem, including information from the manufacturing courses, engineering economy, and accounting. The open-ended nature of the problem allowed for creativity, but some students were worried that they did not do enough or provided enough information. They suggested having the module in segments, and emphasized the need for feedback. For example, one team explained that when their objectives were approved, the instructor recommended that the team rewrite the objectives for the final project. The team thought that it would be helpful to get some feedback to assist in revisions. Overall, students expressed the need for more communication. They explained that communication is emphasized in other classes and that the absence of communication in the module made it less realistic.

6. Conclusions

We have described an industrial engineering curriculum reform project involving a new active learning environment that uses information technology to allow students to tackle realistic problems using state-of-the-art tools, and at the same time, it promotes the engineering problem solving process and students’ metacognition. Currently, two modules have been developed and a pilot study conducted in a classroom setting. As more modules are developed, this environment will serve to integrate required undergraduate classes in the curriculum by highlighting the connections between topics and providing a common learning environment.

Future work will develop at least one module for each required undergraduate course, but there is also considerable ongoing and future work on assessing the value of this environment. One of the greatest potential benefits of using information technology for instruction is that it can make feedback easier to give by the instructor and revision easier for the students. We are therefore considering how to effectively incorporate formative assessment into the current module and how to design more effective feedback mechanisms for students’ reflection on their solution process. Other future research includes for example investigating more closely how to evaluate the benefits of encouraging metacognitive skills within a module.

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Appendix: Student Survey

Self-efficacy (Material)

I think I will be able to use what I learn in this course in other courses

It is important for me to learn the course material in this class
The most satisfying thing for me in this course is trying to understand the content as thoroughly as possible.

I am very interested in the content area of this course.

Understanding the subject matter of this course is very important to me.

I like the subject matter of this course.

In a class like this, I prefer course material that really challenges me so I can learn new things.

In a class like this, I prefer course material that arouses my curiosity even if it is difficult to learn.

Self-efficacy (Confidence)

I'm confident I can do an excellent job on the assignments and tests in this course.

I'm certain I can master the skills being taught in this class.

Considering the difficulty of this course, the teacher, and my skills, I think I will do well in this class.

I'm confident I can understand the most complex material presented by the instructor in this course.

I expect to do well in this class.

Teamwork and Problem Solving

I am good at analyzing and interpreting data generated from analytical procedures.

I know the elements of effective teamwork.

I am good at giving information to the team of my partner in a way that helps them learn.

I feel comfortable encouraging other team members or my partner as they complete their tasks.

When working on a specific engineering problem, I can usually identify relevant issues.

I am good at asking questions that help clarify the problem.

In trying to solve a problem, I am able to incorporate alternative strategies or new information if current techniques are not producing a reasonable conclusion.
Learning Strategies

I often find myself questioning things I hear or read in this course to decide if I find them convincing.

I try to play around with ideas of my own related to what I am learning in this course.

I try to relate ideas in this subject to those in other courses whenever possible.

Whenever I read or hear an assertion or conclusion in this class, I think about possible alternatives.

I try to apply ideas from course readings in other class activities such as lecture and discussion.

Bibliography


Biographies

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