The Engineering Learning Portal for Problem Solving: Experience in a Large Engineering Economy Class

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In an effort to improve students' problem solving skills with information technology across the industrial engineering curriculum, we created an Internet based problem-solving environment. The module implemented for engineering economy presents a realistic problem that establishes connections with other courses. The design of the learning environment promotes metacognitive skill development by requiring students to explain each major problem solving action taken and to evaluate their own progress toward a solution. Experience in two successive semesters of a large introductory course indicates that information technology can be used effectively to create opportunities for students to collaboratively solve realistic engineering problems, thereby promoting deeper learning and higher order thinking. Greater student engagement and efficient evaluation mechanisms motivate faculty adoption of such a system.

Keywords
courses, engineering economy, engineering problems, instructors, curricula, data acquisition, engineering education, industrial economics, information technology, learning systems, problem solving

Disciplines
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Abstract

In an effort to improve students' problem solving skills with information technology across the industrial engineering curriculum, we created an Internet based problem-solving environment. The module implemented for engineering economy presents a realistic problem that establishes connections with other courses. The design of the learning environment promotes metacognitive skill development by requiring students to explain each major problem solving action taken and to evaluate their own progress toward a solution. Experience in two successive semesters of a large introductory course indicates that information technology can be used effectively to create opportunities for students to collaboratively solve realistic engineering problems, thereby promoting deeper learning and higher order thinking. Greater student engagement and efficient evaluation mechanisms motivate faculty adoption of such a system.

1. Introduction

Engineering economic analysis is primarily concerned with problem solving. Most introductory texts begin by describing the importance of engineering economy in the design process [15], the engineering process [17], the (rational) decision making process [4,12,14], or the problem solving process [18]. While the descriptions of these processes vary, most contain the four basic steps of (1) formulating an objective, (2) generating alternatives for analysis, (3) selecting a preferred alternative, and (4) evaluating its implementation. However, once this open ended problem solving context has been briefly described, textbook coverage quickly plunges into the details of the financial mathematics for analyzing and choosing among predefined alternatives, perhaps surfacing only in later chapters to explore methods for generating cash flows and dealing with uncertainty. Hartman [5] noted the danger of trivializing the course content to focus on tools rather than problem solving and proposed a course outline to

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follow the decision process, assigning scenarios and case studies to emphasize its steps at the beginning and end of the semester.

The challenge for educators is that engineering problem solving is difficult to teach. While scenarios and case studies can help provide authentic learning tasks [6], they tend to be underutilized because writing, refreshing, administering, and accurately assessing student work are all very time-intensive tasks. In addition, students may quail at the unstructured nature of the assignment and flounder through the problem solving process with little or no feedback until they turn in the assignment. The nature of the learning experience and the quality of the resulting solution may fail to satisfy either the student or the instructor. This result occurs in part because students have been conditioned to handling structured problems and taking a less active role in their learning [2].

Some of the difficulties of such assignments may be mitigated by the use of information technology (IT). This paper describes experience with a prototype engineering learning portal to improve problem solving across the industrial engineering curriculum. It was implemented first in engineering economy because of the number and range of possibilities for integrating this course content with that of other courses in the curriculum. Also, due to the large enrollment of students from diverse backgrounds – IEs compose less than 20% of the course enrollment of nearly 200 each semester – it was judged an excellent test environment for proof of concept.

It is widely accepted that IT may be a vehicle to improve engineering education, but doing so will require careful consideration of both technical content and learning objectives so that the technology environment promotes learning that we value [8]. It should also address challenges in the existing curriculum that may be difficult to solve without the enabling technology. One clear potential for IT to improve upon traditional lecture classes is to promote collaborative and active learning [7,9,16]. Sophisticated simulated environments can be created that allow students to address realistic problems in a hands-on fashion using domain knowledge mastered in the relevant course. However, other less obvious challenges in the traditional curriculum can also be addressed effectively using IT. For example, the traditional industrial engineering curriculum encompasses what may seem like loosely connected courses that address different elements of manufacturing and service enterprises. A common computer-based educational platform can be used to integrate these courses. Such an environment can also be used to encourage the development of specific learning skills. For example, higher order cognitive processes, such as the metacognitive activities of planning how to learn a given task, monitoring one's comprehension of the task, and evaluating one's progress towards completion have been found to be an important component of learning [3,10]. But when assigning homework and exams it may be difficult to ensure that students engage in such activities. In a computer-based environment, where each step of a student's progress can be monitored, encouraging (or requiring) reflection and self-evaluation at each step becomes a viable option.

We have designed a new active learning environment where students in each course will complete one or more modules that relate to the course content. These 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. Several industrial partners supply realistic problems and accompanying data.
- 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 the actions they make. Due to the difficulty of devising the appropriate mechanisms, the development of such skills is rarely incorporated explicitly into the curriculum as it is in our new learning environment.
- 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 effective use of IT to enhance learning is 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 will be an integral part of this environment. It has not been implemented as part of the engineering economy prototype to be discussed in the next sections. However, special effort has been made to incorporate student reflection into the environment via student self-evaluations and explanations of actions. This paper outlines some results of a pilot study in an engineering economy course, focusing on implementation issues, student performance and student feedback. A broader description of the project's goals can be found in a companion paper [13]. In Sections 2 and 3 we describe the engineering learning portal and its module for engineering economy. Section 4 describes its phased-in implementation over two semesters of a large lecture class. In Section 5 we discuss how feedback from students and industry advisors has guided the work so far and motivated the next steps, which are described along with conclusions in Section 6.

2. Engineering Learning Portal Software

An effective infrastructure for a learning environment requires three key attributes to ensure success, namely,

1. Accessibility: Students and instructors can access the environment from any location at any time.
2. Extensibility: The environment can be maintained and extended to other knowledge domains.
3. Currency: Instructors can modify the contents to ensure that the knowledge domain represents current thinking in the field.

The engineering learning portal (ELP) was designed to address each of these attributes. For accessibility, ELP is based on a client-server architecture that provides authentication, monitoring, control mechanisms, information transfers, and administrative functions through the Internet. The system is extensible by adding additional information content for each new module. To maintain currency, instructors can update the current information content in a module through a database or additional files related to the module.

The basic functions of the 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 student work in multiple formats from each team,
5. support assessment mechanisms for the instructor, and
6. provide feedback to teams on their progress.

Instructors create teams of students for each module. To gain access to ELP, students are authenticated through a password system based on team membership. Students can belong to multiple teams if they are working on more than one module. After connecting to ELP, students gain access to specific information for a scenario and projects they are working on for the module(s). 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/CAM, or optimization).

The client software provides a mechanism to create projects for a given module. Any team member can log onto the system and access the team's project. 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. Each project consists of the following stages:

- *Objective*: Students specify what they are trying to achieve and how they will measure achievement before they begin the solution process. A justification of the objective is also required by the system before they can proceed.
- *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. Student actions are selected from a list of possible actions that student would perform based on the module knowledge domain. 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 the solution. Students have the opportunity to change their solution at decision points in the scenario timeline based on system performance in a scenario.

- 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.

ELP also encourages student reflection on their work. Along with each choice of objective, action and solution element, students enter a reason for making that choice. As learner centered assessment is an important element of effective learning [6], it plays a key role in our new environment. In order to progress from each of the first three stages, students must complete a self-evaluation. The evaluation criteria can be viewed prior to completing the stage.

3. Engineering Economic Analysis Module

The first module was tested in our Engineering Economic Analysis course during the Fall 2002 and Spring 2003 semesters. This is a 3-credit course required for industrial engineering (IE) juniors. It is also a requirement for electrical engineering majors and a popular elective for majors in mechanical and chemical engineering. Most of the non-IE majors take the course as seniors.

The engineering economy scenario was developed in consultation with a local manufacturer of professional concession equipment that faced a perceived production bottleneck caused by the limited capacity of its turret punch press operation. Alternatives for expanding production capacity include purchasing a new punch press, adding a second shift using the existing press, and outsourcing all or part of the punching operation. The students are faced with the problem of developing a strategy by selecting one of these alternatives to implement in each of the next five years (the outsourcing option is available only in the first two years as the potential contract must be renegotiated after that point). The written problem description includes a general description of the situation, the sequence of metal forming operations, the capacity expansion alternatives, and a range of possible demand projections over the five-year horizon.

The *Objective* stage requires each team to specify a measure by which alternatives are to be compared (for example, expected net present worth), an objective (such as to maximize, possibly subject to some allowable degree of risk), and a justification for these. The system and student actions available in the *Plan* stage are listed in Tables 1 and 2, respectively (some possible actions are intentionally spurious). Selecting a system action results in a spreadsheet containing relevant data being downloaded from the server, after a simulated delay if the time required is positive. For most student actions, a spreadsheet template is automatically downloaded when the action is chosen; after completing the action, students upload the filled-in template. Choosing the market research option in the first year precludes any expansion alternative during the first year. However, the problem description suggests that hiring the marketing firm will both tighten the demand forecast intervals and correct a suspected tendency to underestimate demand. Upon selecting each action, a screen appears with a text box in which to fill in the team's reason for choosing that action.

Table 1. System actions available (Spurious actions indicated by *)

Action Description	Time Required (quarters)	Cost
Get demographic data from Marketing	0	0
Get demand forecast from Marketing	0	0
Get financial information from Accounting	0	0
Get production information from the Supervisor	0	0
Get process information from Manufacturing	0	0
Perform process capability study	1	$8,000
Plot the corn price distribution*	0	0
Hire consultant for market research	4	$25,000

Table 2. Student actions available (Spurious actions indicated by *)

Action Description
Estimate capacitated resource utilization
Compute variable cost of each alternative
Calculate RFM performance for the company*
Determine capacities of current and new machines
Calculate income and cash flow statements
Calculate annual revenues and costs for alternatives
Calculate long term debt ratio*
Perform cost-volume analysis of the alternatives
Choose five-year plan on the basis of equivalence analysis
Perform linear regression on fixed costs
Compute incremental fixed cost of each alternative
Evaluate stock book value*

In the *Solution* stage of the ELP, students specify an action to take in each year, such as outsource or purchase a new press. Completion of this step also requires uploading an Excel spreadsheet with a net income and cash flow statement for the five-year horizon, formatted as in the course text [14]. Students may then progress to the *Performance* stage and view the results of a quarter-by-quarter simulation of the first year, including realizations of variables such as demand, production volume, costs and net income. Probabilistic elements of the simulation include the scrap rate, with mean value equal to the result of the process capability study, and the demand, which is generated from a distribution based on the market research study. Each student team observes different realizations of these quantities. At the end of the simulated first year, they may view the results of the market research study if they chose it, modify the alternatives chosen for years 2 through 5, and then return to run the simulation over the remaining years. After the simulation is finished they complete the final submission of their project.

As students progress through the project, they must evaluate themselves according to a set of rubrics. A general rubric for problem solving has been found to reliably differentiate among student performance on an engineering scenario when the scorers were trained carefully [11]. Table 4 shows the criteria for each rubric in the engineering economy module and a description of an exemplary project, which would receive a score of 6. For each criterion the rubrics also include a description of a satisfactory project (4-5 points) and an unacceptable project (0-1 points). After the projects are submitted, the course instructor and teaching assistants evaluate them according to the same rubrics.

Table 3. Criteria and descriptions of an exemplary project on each rubric

Objective Rubric	
Clarity	Measures are clearly defined and can be quantified for each alternative strategy.
Relevance	Objective is fully aligned with the problem scenario goal and focuses on the most important solution characteristics.
Justification	Reasons for selecting the measures and objectives are clear and credible.
Plan Rubric	
Financial	Financial information is used correctly to determine incremental fixed and variable costs for each alternative.
Operational	Operational information and process capability are used correctly to help determine machine capacity.
Manufacturing	Manufacturing information is used correctly to help determine costs and capacities of alternatives.
Range of plans	The full range of possible 5-year plans is considered systematically.
Demand projections	The impact of different demand scenarios, including the market research option, is carefully considered.
Metacognition	The plan is logical and consistent with the objective, contains appropriate actions, and clear reasons are given for the inclusion of each action.
Solution Rubric	
Net Income	Computation correctly accounts for costs, capacities, terms of the outsourcing contract, depreciation and taxes.

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Time Value of Cash Flows	Conversion to cash flows correctly accounts for investment expense, salvage value and depreciation expense and time value is considered correctly.
Justification	Reason for each year's selected alternative is clearly and concisely stated and is based on action plan results.

4. Experiences in a Large Class

Course enrollment in Engineering Economic Analysis runs between 180 and 200 students each semester. Table 3 shows the distribution of majors and class levels from Fall 2002, which was typical. Because the ELP software was in the prototype stage and the feasibility of evaluating a large number of projects was unknown, we offered the case study as an extra credit project in the fall semester. After some adjustments, it was made a required component worth 20% of the course grade in the spring. Students organized their own teams of 2 or 3. In the fall semester, 63 extra-credit projects involving 151 students were submitted. The spring semester projects numbered 70. The ELP client was available in a large computer lab and by download. We allowed two weeks for completing the project in the fall and four weeks in the spring. These time windows began approximately two-thirds of the way through the semester, after most of the text material concerning cost concepts, time value of money, asset evaluation, and development of project cash flows had been covered in class. Material on project risk and uncertainty was discussed in class concurrently with the project.

Table 4. Distribution of majors and class levels (%)

Major\Level	Sophomore	Junior	Senior	Exchange	Graduate	Total
Industrial	3	9	4	0	0	17
Chemical	0	4	11	0	0	15
Computer	0	2	10	0	0	12
Electrical	1	8	18	0	0	26
Mechanical	0	2	17	0	0	19
Other	0	1	6	3	2	11
Total	4	27	65	3	2	**100**

Despite the high level of detail in the rubrics, which we feared might be too leading, the instructor scores on the rubrics were relatively low. For example, Table 5 compares the average self-evaluation for each rubric with the average instructor evaluation in the fall, as a percentage of the total possible score. It also shows the average percentage by which the teams' self-scores exceeded the instructor scores. In almost all cases, the students gave themselves a higher rating than the instructors did.

Table 5. Comparison of self- and instructor evaluations on the rubrics

Rubric	Mean Self Score (%)	Mean Instructor Score (%)	Mean % Difference
Objective	92.7	64.6	27.6
Plan	89.0	52.0	37.0
Solution	90.1	70.8	17.8

However, intuitively we believe that students with better metacognition will be more accurate in their self-evaluations. We were therefore interested in seeing if those groups that had more accurate self-evaluations did better on the project in terms of the final grade assigned. To that end, we calculated for each of the 63 groups, the average squared deviation between the self-evaluated and instructor-evaluated rubric:

$$\psi_g = \frac{1}{3}\sum_{i=1}^{3}\left(x_{ig} - y_{ig}\right)^2,\ g = 1, 2, ..., 63,$$

where x_{ig}, $i = 1, 2, 3$ are the self-evaluation scores on each rubric, and y_{ig}, $i = 1, 2, 3$ are the instructor scores. We then calculated the correlation coefficient between this measure of 'self-reflection' and the grade for the class and found correlation of $\rho_{gm} = -0.70$, which is a significant negative correlation. This supports the hypothesis that students with better metacognition (i.e., ψ_g value close to zero) tend to have higher grades. This, of course, is a very preliminary analysis from an uncontrolled pilot study, but it does support the importance of metacognition.

On average, the student teams chose 9.2 actions, although there was considerable variation with the standard deviation being 2.6 and one group selecting as many as 15 actions. Finding the best solution to the problem did not require doing all the actions. The two teams that identified the optimal solution included almost identical action plans consisting of 8 and 9 actions, respectively.

In addition, we identified the five year plan that would achieve the highest net present worth (NPW) according to the most likely demand forecast after the marketing study and assigned each team a score based on closeness of their five-year plan's NPW to this "optimal" NPW. Only two student teams chose the best plan, but 10 more groups found a plan with NPW within 1% of optimal. The worst performing plans chosen had NPWs that were 9% lower than the optimal.

Over 75% of the teams specified plans with NPW differences of at least 8%.

5. Feedback from Students and Industry Advisors

We have solicited feedback on the scenario content and software implementation by employing a small group of students to pilot-test an early version, surveying the students who completed the project each semester, and consulting with members of the IE department's industry advisory council.

5.1. Pilot Test

The project has included undergraduate assistants to help develop the scenario and advise the faculty team on implementation issues from their perspective. In addition, we hired four teams of two students each to work through an early version of the module. The students had all taken the course previously achieving a range of grades. This test was very valuable not only for discovering the inevitable software bugs but also for identifying inconsistencies in the data and unclear sections of the scenario description. In addition, we learned that the high level of detail in the rubrics, including what we expected would be obvious hints, had little apparent effect on the methods the students used to solve the problem. Finally, the length of time required to evaluate these teams' performance based on the diverse and largely unorganized spreadsheet files they submitted motivated our adoption of fixed templates for each student action.

5.2. Prototype Test

At the end of the fall semester, two weeks after the projects were submitted, we surveyed the students to learn how much time they had spent on the project, how they felt about working in groups, and how they perceived the project in relation to the course content. There were 138 responses to the online survey. Fifty-eight percent of respondents reported that their group as a whole had spent between 6 and 12 hours on the project, and 22% of the students said their group spent more than 12 hours on it. For 64% of the respondents, at least half of this time was spent directly using the ELP software. Nearly half of the students said that as individuals they had spent between 4 and 8 hours on the project while 21% stated that they spent more than 8 hours on it. The students were overwhelmingly positive about working in groups, with 62% identifying an optimal group size of 3 students.

When asked if the course content had sufficiently prepared them to complete the case study, 80% of students responded positively. Those who cited deficiencies in preparation mentioned the material on project risk and uncertainty, which had not been started when they began the project, and some manufacturing knowledge such as scrap rates (particularly for the non-IE majors). Students also said they were confused by the extraneous actions, lacked problem-solving strategies, or wanted a more detailed problem description. As to whether the project helped them to learn the course material, 25% answered yes, and an additional 53% said that it had mainly helped them to integrate the course material and see how to apply it in a real situation. Another question was whether they had used knowledge gained in other courses. A minority of the students mentioned using material from cost and managerial accounting courses; IE courses in manufacturing systems engineering and optimization; statistics; economics; marketing; and computing/knowledge of Excel. A few of the comments made by students on this evaluation are included below:

> "This was the best part of the course. The more hands on, the easier it is to understand. It helps to see why we do the calculations, and what a benefit it is to forecast such things."
>
> "It helped me visualize a real-life application of the material covered in this course. It also forced me to develop my own problem-solving steps that I can apply to solving problems presented in the course material."
>
> "It was a very good learning experience. It seemed like something that would be assigned on an actual job. It should be assigned every semester for an actual assignment.
>
> "The grids [rubrics] helped determine what was expected of the project."
>
> "It was a good learning tool, really applicable to class studies."

5.3. Advice from Industry

Comparing student performance with that of experts can best assess achievement of our goal of improving students' problem solving abilities. Therefore, we invited a group of industry advisors to each describe his/her individual approach to solving the problem presented in the scenario. We received three quite divergent responses. The first expert immediately rejected the market research option, purposefully ignored the demand variability and discounted manufacturer claims on the capacity of the new machine. He admitted an inherent bias against buying new equipment and pointed out that the true costs of outsourcing exceed the stated costs due to various risks involved. His solution used a combination of overtime and a second shift on the existing punch press. The second expert also expressed a preference for overtime and combinations of options rather than the fixed alternatives that were allowed in the module.

Based on profit after tax, he recommended outsourcing, though he also noted that the risks involved might tilt the decision to another alternative if the numbers were close. The third expert focused on the potential for increasing the existing equipment's capacity through waste reduction, perhaps temporarily relying on a second shift, but rejected outsourcing based on both potential risk and the fact that the operation is an integral part of the company's existing work.

These practicing industrial engineers differed in their approaches and in the amount of detailed computations they performed but they had two characteristics in common: (1) they provided clear explanations of their problem-solving approaches and careful decision justifications (which we had explicitly requested), and (2) they were dissatisfied with the limited set of alternatives that could not be hybridized. The first characteristic confirmed our emphasis on metacognition. As a result of the second, we added an extra credit option to the project in which students could propose an "outside the box" alternative solution. However, to prevent frivolous efforts, the accompanying rubric awarded negative points for responses that were not well thought out or justified. Additional statements were also added to the scenario description to acknowledge the importance of increasing the productivity of the existing equipment before a proper justification of new equipment can be made.

At a daylong meeting of the department's industry advisory council devoted to this project, the group also suggested incorporating more feedback into the project. They suggested having students present an exemplary problem solving process to the class, increasing the amount of instructor follow-up in class, and including a process oriented question or two on the final exam. The last suggestion was motivated by concern about individual participation on a project graded according to teams.

5.4. First Full Implementation

Based on the positive reception from students and the feasibility of evaluating the large number of projects submitted, a different faculty member, who had not been involved with the project but was assigned to teach the course in the spring semester, agreed to assign the module as a requirement. However, we had identified a weakness in differentiating solutions based on their economic performance: based on the mostly estimated data in the module, the impact on NPV of choosing a nonoptimal strategy was not very great. In particular, a simple-minded solution that might be obtained just by guessing could perform well. To encourage the integration of course material and motivate consideration of uncertainty, we wanted to make a detailed analysis worthwhile. Therefore, in the second version, we revised some of the data in order to increase the value of additional information about demand; to make the expected NPVs of alternative solutions differ more dramatically; and to ensure that, according to this criterion, a relatively complicated strategy of investing in new equipment partway through the solution horizon would be optimal.

Another possible revision was identified from the low instructor scores on the Objective rubric. Students seemed to be confused by the open-ended requirement to specify "Measures" by which alternatives would be compared and "Reasons" for choosing those measures. We designed a small controlled experiment to test alternative ways of having students complete the objective phase, again using hired subjects. The subjects were divided into three groups that each received the scenario description and then paired off to complete the objective phase. Group A was presented with a version of the objective phase in which they could select from a menu of predefined measures such as acceptable discounted payback period, maximum net present worth of cash flows, or maximum profit subject to a constraint on risk. Group B had the original objective phase format but also were given an additional written case study describing how an engineer in a different context made the choice to compare alternatives based on annual worth rather than some alternative measures. Group C, the control, used the original format for the objective phase with no additional information.

After completing their version of the objective phase, each group gave their reactions to a member of the research team. Group A completed the task quickly but did so without referring to the scenario description. Group B did not understand the purpose of the additional case study they received. Group C spent the most time on the task and consulted the objective rubric. From their responses we concluded that changing the terminology slightly and explaining the task carefully would provide the most benefit.

In order to more objectively assess student reactions to the project, we asked students enrolled in the spring course to complete a voluntary attitudinal survey consisting of both scaled and open-ended response items. In contrast to the fall semester, this time a graduate student from the College of Education rather than the course instructor administered the survey. Students overall expressed dissatisfaction with the project as a learning experience, citing the need for more information and direction regarding the problem and noting software difficulties. However, several students mentioned that the module "helped reinforce ideas in class" and "showed a real life problem." As in the fall semester, students found it very helpful to work in teams, used the course content extensively to solve the problem, and made comparatively less use of material from other courses. One student mentioned that internship experience as a manufacturing engineer provided relevant experience.

In open-ended responses to the question, "What did you learn from the experience of trying to solve a real-world problem?" students noted several positive learning experiences and indicated changes in their perceptions of the problem-solving process. Several students noted the complexity of the problem, others explained that the decision-making process is not clear-cut, and one summarized it as "a lot harder than doing book work." Students who indicated their learning in this area was limited mentioned the artificiality of receiving data and crunching numbers "to get the right solution rather than the actual real-world solution." Some comments indicated a desire for more flexibility in the alternative solutions. When asked what changes would make this project a more effective learning experience, the most common responses indicated the desire to address software problems, to provide a more detailed overview at the start, and to develop specific directions and support mechanisms throughout the module.

Apart from technical difficulties, the most common complaints registered by students related to the problem being unstructured. As this was done by design to better reflect realistic engineering economy problem solving, we do not feel there is a reason to make the problem more structured. However, to improve the learning experience we plan to better communicate to the students the value of solving open-ended problems, and to improve the way in which students interact with the virtual enterprise to retrieve the information they need and to narrow down the problem.

The course instructor also provided feedback including suggestions to change certain aspects of the module content, emphasize the probabilistic aspect of the problem, and make sure both instructor and students know how the projects will be evaluated. The assessment issue is particularly important in motivating faculty adoption of this type of system. The intention behind developing the detailed rubrics was to communicate clearly to students how the projects would be evaluated so that they could learn from their self-evaluations to improve their own problem-solving. However, evaluation criteria and standards should also minimize the amount of instructor effort required to thoroughly and accurately assess student performance. Since the course instructor was not fully aware of this intention and/or did not find the rubrics useful, he spent some effort developing his own evaluation criteria, which were not completely consistent with the self-evaluation criteria. In future course offerings we plan to devote more effort to training instructors in the use of the rubrics. As more completed projects of various quality levels are gathered, we can use them to illustrate both the criteria and the achievement levels and to ensure, for example, that different teaching assistants are applying them consistently.

6. Conclusions

Our initial experience with the Engineering Learning Portal indicates that information technology can be used effectively to create opportunities for students to collaboratively solve realistic engineering problems, thereby promoting deeper learning and higher order thinking. In contrast to a traditional written case study format, the design of the learning environment allowed us to record some portion of the students' thought processes and engaged them in monitoring and evaluating their own problem solving procedures. The pilot study demonstrated that such learning experiences and assessments could be achieved even in a large lecture class. The software made evaluation of dozens of projects, each with multiple components, much easier than it would have been in paper format. Electronic submission allowed the instructor and two or three teaching assistants to simultaneously evaluate different aspects of the projects without shuffling papers. The student action templates facilitated checking computations, occasionally even by examining the spreadsheet formulas used.

Based on these results, the module has become a permanent component of the course. Future work will develop at least one module for most required undergraduate IE courses, but there is also considerable ongoing and future work on assessing the value of this environment. We are currently designing the second module for the manufacturing systems engineering course that will use the output of the existing engineering economy module to assist in the selection between several manufacturing processes for the same production scenario. The new module will also investigate the impact on the manufacturing system (in terms of work in process, material handling, reduction of operations and set-up times) that a new technology can provide. One of the greatest potential benefits of using information technology for instruction is that it can make feedback easier for the instructor and revision easier for the students [1]. 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 work includes investigating more closely how to evaluate the benefits of encouraging metacognitive skills within a module. Finally, while students utilized only spreadsheets in the engineering economy module, future modules will require students to use several more information technology tools and skills. An enterprise model will replace the system actions in this and future modules to require students to seek out, evaluate and clean the data they need to solve the problem.

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