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Improving Conceptual Learning in Engineering Economy using Model-Eliciting Activities (MEAs)

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Abstract

This paper reports on an experiment conducted in an engineering economy course. Two sections of the course were taught by the same instructor, one incorporated three E-MEAs (Ethical Model-Eliciting Activities) to reinforce course concepts while the other was taught in the instructor's traditional manner. A concept inventory was given to students in both sections at the start and end of the semester. Results will be reported with a focus on determining whether the E-MEAs did in fact lead to improved student learning of specific economic analysis concepts and consideration of all relevant criteria (including ethical issues) in an economic analysis.

Keywords
Conceptual Learning, Engineering Economy, Ethics, Model-Eliciting Activities, Open-ended Problems

1. Introduction

Model-Eliciting Activities (MEAs) are a proven methodology for presenting complex, realistic, open-ended client-driven problems to students [1]. The method was originally developed by mathematics education researchers but has recently seen increased use in engineering. These problems require both a general and a specific solution and have been shown to improve student problem solving skills [2]. MEAs are constructed using six specific principles that include model construction, reality, self-assessment, model documentation, generalizability, and an effective prototype. Current MEA research is extending their use to identify and repair student misconceptions, turn student attention to ethical situations (E-MEAs) and introduce laboratory experiments as part of the solution process. MEAs are one of a variety of problem based approaches being used to increase student learning and conceptual understanding as well as improve retention.

This paper reports on the use of E-MEAs in an engineering economy course in Industrial Engineering at the University of Pittsburgh. We tested the conceptual learning benefits of E-MEAs by comparing two groups: the first group was given three E-MEAs while the second was not. We gave a conceptual inventory developed for engineering economy to both groups before and after the course. Results suggest that E-MEAs do have conceptual learning benefits superior to the traditional class assignments.

2. Methodology

Two sections of an introductory engineering economy course were taught in the fall of 2009 at the University of Pittsburgh's ABET accredited industrial engineering program. Both were taught by the same instructor. The instructor incorporated three E-MEAs throughout the semester in a section consisting primarily of industrial engineering students and with a total enrollment of 49 students (experimental group). The second section consisted primarily of civil engineering students but also included students from each of the other engineering departments in the school. A total of 70 students were enrolled in this section (comparison group).

The instructor's principal concern was whether the E-MEAs would contribute to an increase in learning of specific concepts. Thus it was desired to have some measure of student engineering economy concept knowledge. Since the course exams tend to focus on the quantitative aspects of an economic analysis and the researchers did not want conflicting effects from examinations conditions to be a concern, an engineering economy concept inventory was developed. The concept inventory measures students' understanding of the specific concepts that were identified by the instructor as those that the E-MEAs should cover. These included: the time value of money, cost estimation, comparing alternative investments, benefit-cost ratios, consideration of all relevant criteria, economic analysis of contemporary problems, and dealing with uncertainty. In addition, a secondary goal for the use of these types of problems is to provide a measure of three ABET outcomes: f ("an understanding of professional and ethical responsibility"), h ("the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context"), and j ("a knowledge of contemporary issues") [3]. Consideration of all relevant criteria and analysis of contemporary problems are concepts that E-MEAs can focus on and are consistent with these desired ABET outcomes.

Prior to the start of the semester, the concept inventory was developed and pilot tested using former students and edits were made based on their feedback. The instrument focused on those concepts that the instructor felt were important for the course. The final version consisted of nine multiple choice and short answer questions, each of which was worth 5 points for a total of 45 points. The instrument was administered at the start of the term (pre) and repeated at the end (post) to both the experimental and comparison groups. All responses were graded by the same Research Assistant using the instructor developed grading key.

Concurrent with developing the concept inventory, three E-MEAs were created or adapted around the same concepts. The E-MEAs were made up of two parts, an individual portion worth 15-20 points and a group part worth 80-85 points. The individual parts typically consisted of three or four short answer questions aimed at encouraging the students to think about the particular decision situation and the relevant questions. These were assigned on a Tuesday, and due in class the following Thursday. The group part consisted of an assignment to the engineering economy team (student group) by a fictional client to address the particular decision situation, develop a model for solving the identified problem, apply the model to a specific case, and write a memo to a "client" that details the team's results and a decision for the case. The group parts were assigned on a Thursday and due in class the following Tuesday. The students worked in the same three person group for all three E-MEAs which were a required part of the student's course grade. These were graded by the instructor. The E-MEAs are described in Table 1. The comparison group was only assigned traditional homework assignments and some in class group problems (text book style) related to the course concepts.

3. Results

The individual parts of all three E-MEAs (which consisted of short answer qualitative questions relevant to the specific problem) were graded based on the quality and completeness of responses. Grading rubrics were developed for each to ensure consistency and to verify that students met the key requirements of: writing a quality memo to the client, outlining a logical general procedure, clearly stating assumptions, applying the appropriate economic analysis techniques, addressing the ethical issues, applying the general procedure to the client's specific case, and providing a reasonable solution. Average scores on the three E-MEAs (out of a possible 100 points) were 87.1 (standard deviation = 4.0) for Campus Lighting, 78.3 (14.0) for Trees and 88.6 (13.9) for Dams.

The average and standard deviation of the scores on the concept inventory for the two classes at the start and end of the term are shown in Table 2.

Table 1: E-MEAs used in the Engineering Economy course

Title	Originally Developed by	Decision Situation	Ethical Dilemma	Relevant Engineering Economy Concepts
E-MEA 1: Campus Lighting Economics	Purdue University	Which lighting proposal for a college campus is the least costly and addresses the campus community's safety concerns?	Campus safety concerns vs. cost of new lighting	Cost Estimation; Time Value of Money; Comparing Alternative Investments
E-MEA 2: Trees and Road Safety	University of Pittsburgh	Should old trees in parks be removed to provide greater road safety?	Destruction of old trees (environmental concerns) vs. driver/passenger safety	Cost Estimation; Time Value of Money; Benefit/Cost Ratios; Consideration of all relevant criteria; Contemporary Problems
E-MEA 3: Dams, Earthquakes, and Budget Cuts.	University of Pittsburgh	How should a major dam project in Turkey be completed given required budget cuts?	Provision of water, job creation , economic stability vs. risks of construction in earthquake prone regions, environmental concerns, and international relations	Cost Estimation; Time Value of Money; Benefit/Cost Ratios; Uncertainty; Consideration of all relevant criteria; Contemporary Problems

Table 2: Results of Concept Inventory Scores

		Control Group	Experimental (E-MEA) Group
Start of Term	Mean	20.38	17.49
	Std. Dev.	6.45	5.49
	Sample Size	69	47
End of Term	Mean	32.04	30.20
	Std. Dev.	5.77	5.26
	Sample Size	69	45
Effect Size		1.90	2.36

There is a clear statistical difference (*p*-value from independent or paired $t \approx 0$) between the start and end of term mean concept inventory scores for both groups. This is not an unexpected result. Of more interest is whether the effect in the E-MEA group (experimental group) is larger than for the comparison group. Using *Cohen's d* with a pooled standard deviation [4], the effect size for the comparison group, as measured by *Cohen's d*, was 1.90 and for the experimental group it was 2.36. Both can be considered a large effect, but a larger effect is evident in the experimental group.

An additional interesting difference between the two sections of the course comes from the results of the course teaching evaluations. The teaching evaluations contain a number of questions designed specifically to measure ABET outcomes including ones directly aimed at outcomes f, h, and j as described previously. The questions ask students to respond on a 1 (not at all) to 5 (a great deal) scale to:

"The Swanson School of Engineering is interested in learning how this course has improved your competence in a number of important areas. For each of the following, please indicate how much this course has improved your knowledge or skill.

- Knowledge of profession and ethical responsibility (related to outcome f).
- Knowledge about the potential risks (to the public) and impacts that an engineering solution or design may have (related to outcome h).
- Ability to apply knowledge about current issues (economic, environmental, political, societal, etc.) to engineering related problems (related to outcome j)."

The average response to all three questions was higher in the section that implemented the E-MEAs than in the section that did not (f: 3.5 and 3.1; h: 3.97 and 3.39; j: 3.95 and 3.76). The difference was significant for outcome f (p-value < 0.05) and h (p-value < 0.01).

4. Discussion

In general students performed well on the E-MEAs with respect to the direct application of engineering economic analysis tools (such as using an equivalent worth method or a benefit-cost ratio to compare alternatives). The student groups did not perform as well in terms of creating a general model. In addition, although students often recognized them, they did not do a sufficient job of determining the economic impacts (and therefore the impact on the solution decision) of the ethical and other societal issues.

In their solutions to the campus lighting E-MEA, for example, while most student groups created an Excel spreadsheet to compare the costs of the different lighting proposals, these spreadsheets were not always general and flexible enough that they could be used in a different instance of this type of decision. In other words, the students did not create a general model. Many groups used actual values in their computations rather than references to cells where data could be manipulated for a different situation. One group that did successfully create a generalizable spreadsheet as a model described it as follow:

"Our spreadsheet gives a detailed representation of the various expenses required for installation and maintenance of each lighting proposal. It allows for easy manipulation of proposals and time frames. This was accomplished by breaking down labor costs, bulb costs, and replacement frequencies based on lamp types; this will allow the company to not only change proposal details, but lamp types as well. It is also possible to change the details of each fixture, or even alter the length of the project period, making this electronic worksheet reusable for future projects." –Team 14

One of the discussion questions for this problem had to do with whether the decision would change if crime statistics showed two instances of murder on the campus in the past year. While classroom discussion and many of the client memos showed that students clearly recognized that this could impact the decision about which lighting proposal to select, there was typically not a recommendation in the memo to the client regarding how the decision might change if crime statistics were more serious. A typical response to this question:

"The occurrence of two murders on campus would result in an overall effort to make areas safer. More information would be requested on the times and locations of the murders. We also would like to know where people would prefer the lamps to be installed in order to increase safety." –Team 10

In their solutions to the Trees E-MEA, students commonly cited that there were environmental issues that played a role in the decision about whether to make the roadways safer by cutting down old trees, however most student groups failed to determine the economic consequences of environmental damages. Interestingly many groups did use Federal Highway Administration statistics on the cost of traffic accidents and fatalities but they often made the assumption that you could easily justify removing the trees because of the value of a life. Thus although the data for the specific case in this E-MEA do not show a fatality as a direct result of the trees being so close to the road (the data do show one fatality in the roadway of concern but alcohol is listed as playing a role), a number of student groups included the value of a life as a benefit and computed a very large benefit-cost ratio that justified the removal of the trees. For example:

"Even when we included all the alternatives, the benefit/cost ratio was still far greater than 1, meaning even if the rumble strips, signs, speed bumps, and increased cops were all implemented, the benefits of saved lives would nearly always outweigh the costs of implementation. In our benefit/cost ratio we assumed that all costs associated with crashes would be eliminated. This is very optimistic, but we still hope to greatly reduce the number of crashes and still save hundreds of thousands, if not millions, of dollars in crash expenses."-Team 13

On the other hand, there were a number of students groups that recognized that the accident data that was provided did not support the removal of trees:

"It was seen that the average speed prior to an accident was over 54 miles per hour [in a 25 mph zone] *and that all but four accidents involved excessive speeds (excessive speeds were seen as speeds more than 10mph above the posted speed limit). For this reason, we believe that cutting down the redwoods is not necessary, as a majority of the accidents were results of human error, not environmental conditions." -Team 15*

Classroom discussion on this E-MEA focused around the various alternatives to tree removal as other ways to make the roadway safe and the economic consequences of those alternatives. This was probably the most successful of the three E-MEAs in terms of student learning, and reinforcing and integrating concepts as well as students' exposure to real problems involving engineering economic analyses.

In their solutions to Dam E-MEA (set in Turkey), few groups recognized the major political ramifications of drastically impacting water resources in the Western Asia region of the world. In general, however, this was a very rich problem that provided an opportunity for students to consider various environmental and societal consequences of building the dam, including the risks of building in earthquake prone regions, the potential impact on relations with neighboring countries, potential terrorist activity, and the impact on a historic area and its ancient architecture. In addition, because of the similarities in the preferred solution approach for the second (Trees) and third (Dams) E-MEAs and given instructor feedback after the second one, students performed much better overall on this E-MEA. For example, one group describes their solution procedure as follows:

"Next, an organized list would need to be formed to analyze each alternative. Each list should include benefits, and costs, operating and maintenance costs, of the alternative. A benefit-cost ratio would useful in calculating economic implications of the alternative to evaluate which is more attractive. Additionally, in projects of this nature, there is more to analyze than just the economic costs. Societal implications may be a more important focus when determining the correct alternative. Factors to consider would include the region's people, the environment, archeological sites, and most importantly international relations." –Team 12

Team 12 as well as Team 11 quoted below clearly recognized that the decision makers in the dam case must consider criteria other than simply the least cost alternative.

"Another angle which needs to be viewed when trying to select the best option is the impact of safety and the environment that it will have. Earthquakes are common in the area, and decreasing safety of a project that costs this much and putting the entire thing at risk once constructed is not a good idea. You also want to limit the environmental effects of your choice. Finally, you must consider all other consequences not dealt with above, such as how it may affect relationships with surrounding nations and how much it will alter the dam's performance and capacity…..These safety measures far outweigh the other alternatives. A dam which is susceptible to earthquake damage in an earthquake prone area is simply unacceptable. If an earthquake were to damage one of the other dams, thousands of people could potentially die. Preventing this potential loss of life is the most important thing to any ethically responsible company. Human lives are valued more than anything else." -Team 11

As might be expected, student scores on the concept inventory in both sections of the Engineering Economy course did show a significant improvement from the start to the end of the semester. This is evidence of an increase in understanding of the concepts covered by the inventory. However, the effect size for the section that was assigned the E-MEAs was larger. This would indicate that the use of the E-MEAs did have a positive effect on students learning of the identified engineering economy concepts. In addition, course teaching evaluation support the use of the E-MEAs for reinforcing ABET outcomes f and h.

5. Conclusions

Use of E-MEAs does require substantial effort on the part of the instructor in terms of selecting and adapting appropriate MEAs to a particular course, organizing student groups, grading, etc. In addition, the instructor must be prepared to provide feedback and engage the students in a useful discussion of how the problems they have just solved are relevant to the concepts being taught in the course. These types of problems are ideal for engaging students in applying course concepts to realistic, client-based problems that are generally much richer in nature than any textbook problems. If used correctly, they can be very effective in reinforcing and integrating course concepts. In addition they are ideally suited as measures of ABET outcomes f, h, and j. Engaging classroom discussions allow for furthering students' understanding of the applications of course concepts to realistic problems.

E-MEAs are an effective tool for increasing conceptual learning in an engineering economy course. An area for improvement in the application of E-MEAs to engineering economy would be to finds ways to further students understanding of how to make their solutions to client problems more general so that they can be applied in similar decision situations rather than to just the particular case described in the E-MEA. We are also introducing E-MEAs in several other courses at the University of Pittsburgh, including our introductory and second probability and statistics courses, an engineering ethics elective, as well as in courses in bio-engineering. Additional research is focused on the modeling aspects of implementing MEAs in engineering courses and student "reflective" surveys are being used to measure life long learning and other benefits of MEAs. The E-MEAs will continue to be implemented in various classrooms in the school.

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