EVALUATING INTEGRATIVE MODEL ELICITING ACTIVITIES IN FIRST YEAR ENGINEERING

Brian Frank, Jake Kaupp

Queen's University

brian.frank@queensu.ca, kaupp@appsci.queensu.ca

Abstract—This work presents the use and evaluation of model-eliciting activities (MEAs) in a first year engineering course. These MEAs are problems presented in class that require students to create a model of a system as part of the solution to a complex open-ended problem, and integrate technical, professional, and programming skills in a specific context. Three MEAs were used in the 2011-2012 academic year. Students perceived learning gains as a result of the MEAs, and improvements were observed in students' ability to create a mathematical model, and in making effective arguments. A proposal for a more detailed study of how students solve MEAs is presented.

Keywords: model eliciting activities, assessment, critical thinking, problem solving

1. INTRODUCTION

Problem solving is one of the most critical components of an engineering education not explicitly developed in a typical undergraduate program. Most problem-solving activities revolve around abstract and well-structured problems with known information, clear non-competing goals, no ambiguity, constant information, and knowable correct solution. These kinds of problems generally require students to convert a word problem into a set of variables and equations based on course content, mathematical manipulations to solve the equations, and a connection between the equation solution and the original problem.

An ability to solve these types of problems does not necessarily transfer to the ability to solve real-world engineering problems, which tend to have unknown or imprecise information, are highly contextualized, require assumptions and approximation, and have multiple competing goals or even unknown goals. Problem solving skills developed by well-structured problems have been shown to transfer poorly to other contexts, as learners tend to focus on developing an algorithmic approach to solving known classes of problems (1).

Model eliciting activities (MEAs) are problems used in class that are set in a realistic context that requires the learner to document not only the solution to the process, but also their process for solving it (2). The rationale for MEAs is based on the cognitive apprenticeship framework from Collins, Brown, and Newman that builds upon the idea of an apprenticeship which “embeds the learning of skills and knowledge in their social and functional context.” Students develop from novices to experts not only by learning knowledge, but by learning how experts organize, apply, and that knowledge. (3) MEAs require students to integrate knowledge and develop processes for solving problems with support from an instructor.

Engineering MEAs have been developed for a variety of subject areas including mechanics, economics, and environmental engineering, and have been shown to be valuable for developing conceptual understanding, knowledge transfer, and generalizable problem-solving skills. A list of resources in this area is maintained by an NSF-sponsored group website (4).

MEAs naturally lend themselves to an integrative experience course, where concepts from courses of instruction can be integrated and applied in a real-world context to promote both knowledge transfer and retention. The purpose of this research was to assess the impact of MEAs used to provide contextualized problems that require solutions integrating technical, professional, and programming skills in the first year level of an undergraduate engineering program. The setting was a fall-semester first year engineering course of around 700 students at a mid-size Canadian university. The course objectives include development of complex problem solving skills, critical thinking, communications, teamwork, information literacy, and design.

The paper presents preliminary work on evaluating the impact of these MEAs for an integrative first year course. It discusses the MEAs used, student self-reported confidence changes in problem solving, and a comparison of performance against specific assessment criteria over time. Plans for future assessment are also presented.

2. IMPLEMENTATION

Beginning in the 2010-2011 academic year, MEAs were used in a two- to three-week cycle: weekly lectures would introduce a topic appropriate to problem solving which was applied to an MEA, students would develop an appropriate analytical model in a computer studio using MATLAB, and a finally submit a report documenting the process they would follow to solve the problem and the model developed. After the initial pilot year the MEAs were updated and redesigned to meet four objectives. They were to develop:

- Ability to solve ill-structured problems, and to reflect on the process used
- Apply engineering knowledge from other first year engineering topics (physics, chemistry, calculus, and algebra) in a real-world context
- Ability to use MATLAB, a numerical analysis and programming tool commonly used for modeling
- Ability to incorporate ethical and professional factors in decision making

A summary of the three MEAs used in shown below:

MEA1: Elevator failure – students are presented a case in which an elevator aboard a fishing vessel failed. Students are asked to model the elevator and suggest reasons for its failure.

MEA2: Energy recovery ventilation system - students are presented a scenario in which they have to make a case for an energy recovery ventilation system in a new building. Their recommendation is based on a model they build using real-time data from an ERV system in a current building.

MEA3: Solar photovoltaic system – students are presented a scenario in which they are asked to make a recommendation on whether to install a solar photovoltaic system. They are asked to make a model that predicts instantaneous electrical power output from a system, which can be validated using real data from a current building on campus.

Each MEA is designed to help develop and assess multiple objectives identified from the overall course learning outcomes. They are *integrative* activities that require students to incorporate knowledge and skills in technical areas, MATLAB programming, and professional skills. The key objectives of the three MEAs are shown in Table 1.

Table 1 - Objective of MEAs

MEA	Technical	Professional	MATLAB
Elevator failure	Statics, strength of materials	Safety, conflicting information	Variables and plotting
Energy recovery system study	Enthalpy, air quality	Standards and codes, evaluation matrix	Data import, interpolation, loops
Solar PV rooftop feasibility study	Electrical power, spherical coordinate	Net present value, multi-factor decision making, codes of ethics	Data import, conditional statements, loop control

The section below presents an example of one MEA.

2.1 Elevator failure

The text below is a sample of the instructions given to students on their first MEA.

In the scenario presented below you are leading a Transportation Safety Board of Canada (TSB) investigation into the Mersey Venture elevator failure. A preliminary investigation team has provided the information attached below in advance of your visit to the site. Like any information source the information presented to you by the on-site team may be suspect, so you should look out for information that is not realistic. Before you arrive on site you have been asked to submit an investigation proposal report addressed to the Transportation Safety Board that describes the process your team will follow to investigate this incident, provides an analysis of hypothetical situations that may have caused failure, and what factors may have led to the failure. It is expected that you apply principles for complex problem solving, argumentation, and safety analysis.

The deliverable for this was a short report accompanied by a MATLAB model of the elevator system. Students were expected to demonstrate outcomes including the following criteria:

- Assesses credibility of information, including uncertainty and biases.
- Creates justified process for solving problem, supported by information.
- Creates and compares quantitative models in MATLAB using reasonable approximations and assumptions.

- Evaluates validity of results and model for error, uncertainty
- Assesses risk; makes supported conclusions about failures and recommendations for improvement.
- Makes claims supported by data and backing, with appropriate qualifiers

All three MEAs had similar lists of criteria on which students were scored. Students were evaluated on a four level rubric linked to specific scores; the rubric levels were: *not demonstrated* (0 marks), *marginal* (1-2 marks), *meets expectation* (3-4 marks), and *outstanding* (5-6 marks). The 10 sections of approximately 70 students were each scored by a teaching assistant. Before grading each assignment the teaching assistants attended a calibration grading sessions where a sample report was scored using the rubric.

3. ANALYSIS AND RESULTS

Exploratory factor analysis (principal components analysis, varimax rotation with Kaiser normalization) was run on the student scores on each criteria for each of the three assignments to explore relationship between the measured student performance. The analysis identified four factors, each with an eigenvector >1, three of which related exclusively to an individual MEA (factor one related to the 6 criteria in MEA 2, factor 2 related to 6 of the 7 criteria on MEA 3, factor 3 related to the 6 criteria on MEA 1). The fourth related to the evaluation of students' ability to use the code of ethics to resolve an issue on MEA 3.

This result was unexpected; the prediction was that similar criteria would load onto the same factors (e.g. effective argumentation was an outcome for all MEAs). However, correlation between the criteria scores was higher between criteria within a specific MEA than they were between similar criteria on different MEAs.

When student scores on common criteria are compared

Figure 1 - Student perception of learning gains

between MEAs, the most significant changes are in scores related to creating a model of a physical system, and making an effective argument. Most of those gains were made between the first and second MEA, and is reflected in anecdotal comments from students and teaching assistants. This gain is likely due to a combination of three factors:

1. Students expressed an uncertainty about models, argumentation, and overall expectations at the beginning of the semester..
2. Students submitted assignments individually for MEA1, and in teams for MEA2 and 3. This was deliberate, as it required students to develop some comfort with expectations individually before working in teams. Team submissions allow students to pick activities that are their strengths.
3. Due to a variety of factors, the time between submission of MEA2 and MEA3 was much less than that between MEA1 and MEA2. Students had greater opportunity to review feedback and make improvements after MEA1 than they did after MEA2.

The variation between graders was examined to look for reliability of scoring. Since students were randomly assigned into sections significant variations in mean between section scores would suggest that graders were not using the same expectations. Analysis using ANOVA showed that there was a grader effect on student scores

Students were asked to complete a web-based survey on the experience. Questions included course organization, TA support, and their perceptions of learning gains.

- This module improved my ability to solve open-ended engineering problems.
- This module improved my understanding of the roles and responsibilities of an engineer in society.
- The content and activities in the lectures were relevant to solving the problems presented in the

MEAs

- The content and activities in the MATLAB studios were relevant to solving the problems presented in the MEAs
- I feel confident in my ability to use MATLAB to model systems and solve engineering problems.

Histograms of student responses on questions relevant to the MEAs are shown in Figure 1. There were 105 responses out of a approximately 650 students enrolled.

Most students felt that the experience improved their ability to solve open-ended problems, and improved their understanding of the roles and responsibilities of engineers in society. The integration of problem solving approaches and MATLAB instruction appears to have been well received. However, students' self-confidence in using MATLAB to solve future problems is not as strong. This aspect of the experience is being revisited.

4. FUTURE WORK

The next step of this project is to use think-aloud exercises to benchmark student abilities in critical thinking and creative, collaborative problem solving in a group setting. The think aloud exercise can be considered a type of model eliciting activity (MEA) in which a group of students are tasked to provide a solution to a real-world engineering problem. They are introduced into a scenario where they assume the mantle of a local engineering design firm tasked with problem that requires the co-operation of students within the group to draw on their knowledge of dynamics and mechanics, physics, engineering methodology, design, and socio-environmental impact. As a control to the think aloud exercise, a closed-ended physics problem emulating the scenario will be administered and students will be asked think aloud their solutions in a group setting.

Students are presented the problem, along with an amount of supplemental material of varying pedigree that may be required to solve the problem. Students are asked to 'think aloud' the solution to the problem and discuss within the group. Their solution should include an identification of the problems based on the information provided, a proposition for solution along with an evaluation of the proposed solution and any further recommendations they have.

The problem is set up in an open-ended manner. There is no one true solution for the problem, and a variety of suggestions and conditions may comprise the answers. The students must look at the problem from many different viewpoints in order to determine the safety of their solution, and offer workable alternatives to provide a

safe solution to their client. In addition to the technical nature of the problem, the supplemental material provides a measure of uncertainty as student may question the currency and validity of the source. A robust solution will also consider the environmental impact, as well as the social aspects (human factors) involved in a safe, workable solution.

CONCLUSIONS

Several conclusions have been drawn as a result of piloting integrative MEAs in a first year engineering course. In order to evaluate learning gains, grader calibration is critical. Feedback about score distribution must be provided to teaching assistants early in the semester to reduce variation later. Additionally, feedback must be provided to students with sufficient time for use in later MEAs.

Preliminary results are showing learning gains in specific areas over the course of the semester. Think-aloud activities are proposed to learn more about the process students go through in solving the problems. Additionally, standardized pre/post tests are planned to assess their impact on general critical thinking and problem solving skills.

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REFERENCES

1. **Jonassen, D. H.** *Learning to Solve Problems: A Handbook for Designing Problem-Solving Learning Environments*. s.l. : Routledge, 2010.
2. **Zawojewski, J. S., Diefes-Dux, H., & Bowman, K. (Eds.).** *Models and modeling in engineering education: Designing experiences for all students*. Rotterdam, the Netherlands : Sense Publishers, 2008.
3. **Collins, A, Brown, J and Newman, S.** Cognitive Apprenticeship: Teaching the Craft of Reading, Writing, and Mathematics, ch. 16. [book auth.] L. Resnick. *Knowing, Learning, and Instruction. Essays in Honor of Robert Glaser*. s.l. : Laurence Erlbaum Associates, 1989.
4. Models and Modeling. *MEDIA Project*. [Online] [Cited: May 16, 2012.] <http://modelsandmodeling.net/Publications.html>.