Investigating the Impact of Model Eliciting Activities on Development of Critical Thinking

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Abstract—This paper presents a portion of a study on how model eliciting activities (MEAs) impact critical thinking development in first year engineering.

Model eliciting activities (MEAs) are realistic problems used in the classroom that require learners to document not only their solution to the problems, but also their processes for solving them. Studies have shown MEAs to be valuable in helping students to develop conceptual understanding, knowledge transfer, and generalizable problem-solving skills.

This study is investigating the impact of the MEA-integrated course on students’ development of critical thinking skills. Ultimately, the team aims to determine whether the MEA-integrated course facilitates students’ critical thinking. During the fall semester of the 2012/2013 academic year three instruments will be used to evaluate the critical thinking skills (CTS) of first year engineering students. These instruments will be used as both a pre- and post-test in order to benchmark CTS of the incoming first year students, and determine the effectiveness of MEA instruction on developing student critical thinking ability. These instruments are the Cornell Critical Thinking Test Level Z (Cornell Z), the International Critical Thinking Essay Test (ICTET) and the Collegiate Learning Assessment (CLA).

This paper will present the preliminary findings from analysis of the MEA results and pre and post tests from the study.

Keywords: model eliciting activities, critical thinking, problem solving

1. INTRODUCTION

Model eliciting activities (MEAs) are realistic problems used in the classroom that require learners to document not only their solution to the problems, but also their processes for solving them (Shuman, Besterfield-Sacre, Bursic, Vidic, & Sieworciek, 2012). MEAs have been developed and used in a variety of subject areas, including mathematics, economics, and environmental engineering. Studies have shown MEAs to be valuable in helping students to develop conceptual understanding, knowledge transfer, and generalizable problem-solving skills.

MEAs have been integrated into a first-year undergraduate engineering course at Queen’s University. Students in this course are asked to work collaboratively on three different MEAs, introduced in a three-week cycle. While each MEA requires students to employ different areas of subject knowledge, students are taught to approach all three MEAs using critical thinking skills. For example, students are guided to draw concept maps, question the credibility of information sources, incorporate a range of factors into their decision-making, and consider the implications of their conclusions. These skills are what Paul calls “elements” of critical thinking—invaluable thinking processes involved in any complex problem-solving activity[1].

A research team has been formed at the university to investigate the impact of the MEA-integrated course on students’ development of critical thinking skills. Ultimately, the team aims to determine whether the MEA-integrated course facilitates students’ critical thinking. During the fall semester of the 2012/2013 academic year three instruments will be used to evaluate the critical thinking skills (CTS) of first year engineering students. These instruments will be used as both a pre- and post-test in order to benchmark CTS of the incoming first year students, and determine the effectiveness of MEA instruction on developing student critical thinking ability. These instruments are the Cornell Critical Thinking Test Level Z (Cornell Z)[2], International Critical Thinking Essay Test (ICTET) [3], and the Collegiate Learning Assessment (CLA)[4].

The entire first year student body (approximately 650 students) participated in an MEA-integrated curriculum, and were invited to participate in the broad study, which allowed the researchers to use the scores from their MEAs and critical thinking tests. Stratified sampling was used to assign various pre and post instruments. These assessments were part of the course requirements, so the participation rate was close to 100%.

2. MEA-INTEGRATED CURRICULUM
APSC-100 is a team-based, project-based course to promote a sense of curiosity about engineering, and promote creative thought. The course is divided into three modules: Module 1: Problem analysis and modeling; Module 2: Experimentation and measurement; Module 3: Engineering design. This study was embedded into the delivery of the problem analysis and modeling module (module 1)[5].

The problem analysis and modeling module (module 1) is a semester-long integrative experience that uses concepts from engineering sciences, natural sciences, and mathematics courses to solve complex open-ended problems. The course is structured around three complex problems known as model-elliciting activities (MEAs) that were addressed sequentially in three-week blocks over the semester. The situations described in the MEAs require students to create and use a mathematical model of a physical system using MATLAB, and deal with professional issues including ethical dilemmas, conflicting information, and incorrect/missing information. MEAs have been used in the course for the past three years[6].

The three MEAs were:
- MEA 1: Cable ferry failure (Weeks 2-4): This problem focused on the failure of a cable ferry.
- MEA 2: Wind turbine design (Weeks 6-8): This problem will focus on the analysis and design of a wind turbine.
- MEA 3: Building heat loss (Weeks 9, 11, 12): This problem focused on the design of the insulation for a net zero home.

Each MEA required students to develop a model of a physical system that was used to solve a problem presented by a fictitious client, write MATLAB code to implement the model, and self-evaluate their report against 3-5 of nine critical thinking elements identified in the Paul and Elder critical thinking model (clarity, accuracy, relevance, logicalness, breadth, precision, significance, completeness, fairness, and depth). Table 1 shows the elements embedded into each MEA. Critical thinking elements were explicitly targeted in all three MEA activities by discussing principles in class, using in-class activities, and embedding into the MEA requirements.

| Table 1: Characteristics of the three MEAs |
|-----------------|-----------------|-----------------|
| Category         | MEA1             | MEA2             | MEA3             |
| Technical        | Stress and strain, drag | Fluid flow, lift | Heat transfer |
| Design           | Problem definition, concept mapping | Decision making (e.g. weighted evaluation matrices) | Decision making (e.g. weighted evaluation matrices) |
| Professional     | Safety, risk assessment, concept maps | Associations, codes and standards | Economics, codes of ethics, equity |
| Critical thinking| Asking questions, uncertainty in information, identifying erroneous or conflicting information | Assessing information credibility, argumentation, assumptions, inferences | Bias, inferences |
| Communications   | Report format, English usage, argumentation | Report format, English usage, argumentation, concision | Report format, English usage, argumentation, concision |

The conceptual framework for the module is shown in Fig. 1. Course activities were designed to introduce teaming skills, and encourage students to their learning, and processes used to solve these problems, and to continue improving them (self-regulation). These are shown in the centre of the circles below. Students were encouraged to apply the elements of reasoning to the problems they solved (shown in the middle ring below), some of which were discussed in class. Student self-evaluated their submission against the work standards shown in the outermost ring.
3. STUDY DESIGN

In all visual representations, below, \(\text{X}\) represents the intervention, \(i.e.,\) an MEA-integrated curriculum and \(\text{O}\) refers to measurement or observation of CTS. The initial observation of CT (pre-test benchmarking) took place at the beginning of the 2012 fall semester, prior to any critical thinking or MEA instruction. The final observation of CTS (post-test) took place at the end of the 2012 fall semester, after the conclusion of critical thinking or MEA instruction.

3.1 Cornell Z Group

Procedure: Cornell Z group is further divided into two sections—Section A and Section B (about 120 students each). Section A will take the Cornell Z as a pretest and then as a post-test. Section B will take the ICTET as a pretest and then the Cornell Z as a post-test (Fig. 1).

Hypothesis: \(O_2\) should not differ significantly from \(O_4\) given that students from both sections are comparable. However, if results show otherwise (\(i.e.,\) \(O_2 > O_4\)), there may be test-retest effects in CZ Section A.

![Fig. 2 Cornell Level Z Group]

3.2 ICTET Essay Group

Procedure: ICTET group is further divided into two sections—Section A and Section B (about 120 students each). Section A will take the ICTET as a pretest and then as a post-test. Section B will take the Cornell Z as a pretest and then the ICTET as a post-test. (Fig. 2)

Hypothesis: \(O_2\) should not differ significantly from \(O_4\) given that students from both sections are comparable. However, if results show otherwise (\(i.e.,\) \(O_2 > O_4\)), there may be test-retest effects in EW Section A.

![Fig. 3 ICTET Essay Group]

3.3 CLA Group

Procedure: The CLA group is comprised of approximately 200 students. Due to the CLA being part of another study, and to reduce testing fatigue, the CLA was used as a pre test only.

3.4. Pre and Post Test Scoring and Data Analysis

The Cornell Z pre and post tests, a multiple choice test, was graded on Scantron scoring cards. The overall score, adjusted score and critical thinking element sub scores were calculated and normalized to percentage values.

The ICTET pre and post tests, an essay based test, was graded by four graders using a rubric provided by the creators of the test. Each grader underwent training to achieve calibration, and inter-rater reliability was tracked. The overall score and critical thinking element sub scores were calculated and normalized to percentage values.

The CLA pre test was graded through rubric evaluation by the automated system used by the CAE (Council to Aid in Education).

Pre and post test data was analyzed using a paired t-test. Correlations between CTS benchmarks and the CLA group were analyzed using a two-tailed bivariate correlation with Pearson’s correlation co-efficient. In all tests, significance was associated with \(p\)-values less than or equal to 0.05. All statistical tests were conducted using SPSS version 21 software.

4. RESULTS

4.1 Cornell Z Groups

Group A: There was no significant difference between the benchmarked CTS measured by the pre test (CLZ) and CTS measured by the post test (CLZ). (Fig 4.)
3.2 ICTET Groups

Group A: There was no significant difference between the benchmarked CTS measured by the pre test (ICTET) and CTS measured by the post test (ICTET) (Fig. 6).

Group B: There was a significant difference (p<0.001) between the benchmarked CTS measured by the pre test (CLZ, 58.0±0.7%) and CTS measured by the post test (ICTET, 46.6±1.1%) (Fig. 5).
3.3 CLA Group

The CLA group was only written as a pre-test to benchmark CTS. Correlation analysis did reveal that the CTS benchmark measured by the CLA was weakly correlated with both MEA #1 and MEA #2 grades. (Pearson coefficient= 0.241 and 0.260, p<0.05 respectively) (Fig 8).

3.4 MEA Results

Student grades on MEA #1 were the lowest of the three, with student grades increasing over the course of the semester. All groups’ gains were significantly different between each of the three MEAs, with the exception of Cornell Z Group where no significant difference was exhibited between MEA #2 and MEA #3. (Fig. 9)

5. DISCUSSION

This study sought to investigate the development of critical thinking skills in engineering students through integration of MEAs into a first year course. CTS was benchmarked and assessed by CLA, Cornell Level Z and the International Critical Thinking Essay Test. The preliminary results of the study illustrated no notable gain in CTS of students at the end of the MEA-related section of the course. The authors do not attribute this lack of a change in CTS to be related of the MEA instruction but due to a combination of factors:
1. The sensitivity of the instruments may not be capable of detecting a subtle change in CTS over a single semester of instruction.
2. The single semester of MEA related curriculum might not be adequate to affect marked development of CTS[7]-[9].
3. The standardized tests used may not accurately capture the breadth of CTS[10], and the context of the problems reflected in the MEAs.

There were observed differences between the Cornell Z Group B and the ICTET Group B, which used different arrangements of pre and post tests. The authors do not believe that there is a significant test-retest effect due to these differences. They may be attributed to differences in the instruments, as the ICTET focuses primarily on student written responses determining the logical elements of critical thinking, while the Cornell Z is a multiple choice test covering multiple elements of critical thinking concepts delivered by a story-based narrative, developed by Ennis. Both of these instruments measure critical thinking ability, yet there are some differences between the critical thinking models assessed, the test mechanics and the nature and relevance of the questions.

There are issues with multiple-choice assessment of critical thinking being skewed towards the cognitive component while ignoring the dispositional component of critical thought.[10], [11]. The second issue is with the nature of prompting not assessing the ‘real-life’ nature of complex problems, which are often encountered in engineering[10], [11].

Each test assesses different elements of thought, based on the model favoured by the authors. The CLZ assesses student ability in induction, deduction, credibility, assumptions, semantics, definition, and prediction based on the evolving model put forth by Ennis[2]. The ICTET assesses the students ability to determine the purpose, questions at issue, information, inferences, concepts, assumptions, implications and points of view based on the model put forth by Paul & Elder[1]. While a correlation or common ground may exist between the critical thinking models, there is yet to be a definitive analysis proving so.

The CLZ questions may be outmoded and in need of review and restructuring of the story-based narrative in order to be more relevant and easily understood by the current generation of students. The authors also found the test to have little relevance pertaining to engineering related content in the test. The ICTET relied on a ‘supply your own prompt’ basis, which allows for topical, cultural, and disciplinary relevance with careful selection of an engineering related prompt.

Future work for the study involves investigating any correlation between the standardized test sub-scores, which should shed some light on potential similarities between the two critical thinking models. The authors also seek to explore the relationships between MEA performance, CTS, standardized test-sub scores and other factors affecting CTS taken from student surveys conducted during test administration.

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References


