AC 2012-3847: CCLI: MODEL ELICITING ACTIVITIES

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CCLI: Model Eliciting Activities:  
Experiments and Mixed Methods to Assess Student Learning III

Abstract

As part of a seven university CCLI Type 3 collaborative effort focused on models and modeling, we have extended the model eliciting activity (MEA) construct to upper division engineering programs. Originally developed and validated by mathematics education researchers, MEAs were found to have significant value as an educational tool. Our overall goal has been to use this construct as a means for enhancing engineering students’ problem solving and modeling skills as well as their conceptual understanding of certain engineering topics. In doing this we have pursued two main research thrusts: MEAs as teaching tools and MEA as learning assessment tools. This paper summarizes our results for these two foci as we near the conclusion of our final project year.

In using MEAs as a teaching tool – we have examined three activities:

- **Development of effective MEAs:** We have created a series of over 20 MEAs for upper level students that target students’ problem solving skills and conceptual learning. In doing this we have found that MEAs also enhance such important professional skills as communication, teamwork, and ethical understanding.

- **Implementation of MEAs:** We have introduced and rigorously assessed our MEAs in classroom settings as a means to further understand students’ problem solving, modeling and teamwork processes.

- **Enhancing the learning benefits of MEAs:** Our consortium has added new conceptual dimensions to MEAs to further enhance student learning. In particular, we have introduced an ethical dimension as a means for improving students’ ability to recognize and resolve those types of ethical dilemmas that arise in the engineering workplace.

In using MEAs as a learning tool - we have focused on two additional activities:

- **Assessing the effectiveness of MEAs in various dimensions including improving conceptual learning and problem solving:** We have developed a series of assessment instruments to better understand and measure the educational benefits of using MEAs. Specifically, we are triangulating across three assessment instruments, which we created for this project: (1) pre- and post-concept inventories (or knowledge tests) to assess gain in conceptual understanding, (2) an online reflection tool to assess process, and (3) a grading rubric to assess the resultant artifact (general model and specific solution). We have also developed an instrument to measure students’ self-efficacy scale related to their modeling skills.

- **Assessing the MEA motivated problem solving process:** Through the use of various data collection tools, including PDAs and wikis, in combination with the mentioned assessment instruments, we are identifying the various problem solving processes used by the student teams, as well as the range of problems that can be addressed, to determine how effective the various processes are relative to improved conceptual understanding.

This paper summarizes our achievements in each of these five activities. Particular emphasis is placed on our mixed measurements for student learning and achievement, and a discussion of the
relative conceptual gain for a series of MEA experiments, including those where a comparison
group was available.

Introduction

“Collaborative Research: Improving Engineering Students' Learning Strategies Through Models
and Modeling” is a CCLI Type 3 project involving seven university partners: California Poly-
technic State University, Colorado School of Mines, Purdue University, United States Air Force
Academy, University of Pittsburgh, University of Minnesota-Twin Cities and Pepperdine Un-
iversity. We are building upon and extending the model-eliciting activities (MEA) construct or-
iginally developed by mathematics educators that was first introduced into engineering education
in 2002. These posed scenarios simulate authentic, real-world problems that teams of students
then address. MEAs were first developed as a mechanism for observing the development of stu-
dent problem-solving competencies and the growth of mathematical cognition. However, it has
been increasingly documented that MEAs provide a learning methodology that helps students
become better problem solvers.

We are taking the theoretical framework from mathematics education combined with research
results from a series of NSF funded studies in order to create a strategic, scalable approach for
addressing crucial goals in engineering education. These include:
• Developing effective, transferable competencies in problem-solving and creativity;
• More effectively learning and retaining important concepts; and
• More effectively identifying misconceptions and nurturing positive ethical frameworks.

We also are investigating and extending a suite of assessment approaches that have been deve-
loped and tested in recent MEA research. Our specific objectives have been to:
• Expand the MEA methodology and application,
• Study students’ problem solving strategies and extend the use of MEAs to specific aspects of
undergraduate reasoning and problem-solving,
• Determine solution paths first-year engineering students use in solving MEAs,
• Execute a comprehensive dissemination and infusion effort, and
• Develop a comprehensive research agenda for models and modeling in undergraduate educa-
tion.

In particular, we are extending MEA implementation and complementary student and faculty as-
sessments across our partner institutions; broadening the library of usable MEAs to different en-
gineering disciplines; and extending the MEA approach to identifying and repairing misconce-
ptions, using laboratory experiments as an integrated component, and introducing an ethical deci-
sion-making dimension [1-5].

Our overall research goal is to enhance problem solving and modeling skills and conceptual
learning of engineering students through the use of model eliciting activities. In order to accom-
plish this goal at the University of Pittsburgh, we are pursuing two main research routes: MEAs
as teaching tools and MEA as learning assessment tools. Under the first – using MEAs as a
teaching tool – we are focused on three main activities:
1. **Development of effective model eliciting activities:** The creation of MEAs for upper level students that effectively use the six principles of the MEA construct that can enhance problem solving skills and/or conceptual learning. To date, we have developed or modified 18 MEAs and thoroughly tested six of these multiple times in two courses.

2. **Implementation of (new or adapted) MEAs:** focuses on implementing and assessing the developed and adapted MEAs in classroom settings as a means for studying the problem solving and modeling processes. This provides an opportunity to evaluate both the MEAs and the various assessment tools.

3. **Enhancing the learning benefits of MEAs:** focuses on adding new conceptual dimensions to MEAs in order to enhance student learning. In particular, we have introduced an “engineering ethics” dimension to the MEAs as a means of improving students’ ability to recognize and resolve ethical dilemmas, and have thus created E-MEAs (ethical MEAs).

Under the second stream - using MEAs as a learning tool - we have focused on two additional activities:

4. **Assessing the effectiveness of MEAs in various dimensions including improving conceptual learning and problem solving:** focuses on understanding and measuring the educational benefits of using MEAs.

5. **Assessing the MEA motivated problem solving process:** focuses on understanding different problem solving processes used by the student teams, as well as the various types of problems that can be addressed and how these process lead to conceptual understanding.

**Development of Effective MEAs** - Our initial focus was to develop or adapt MEAs; eleven new MEAs have been created and tested within the classroom at least once. These are primarily addressed industrial engineering coursework and have focused on engineering statistics and engineering economics. These have been described in detail in a series of papers presented at the 2008 - 2011 ASEE National Meetings [6-8] and a second series of papers presented at the past four Industrial Engineering Research Conferences [9-12]. We have found that MEAs have been used in the classroom for three broad purposes: [13]. These are:

- Integrate learning from previous courses with new information (integrator);
- Reinforce the concepts that are currently being covered (reinforcer); and
- Discover a concept that has yet to be formally introduced (discoverer).

Based on our experience, we have identified the major factors that contribute to the success of MEA implementation [13]. An important factor influencing MEA success is the guidance from the instructor throughout MEA implementation. Limited, corrective guidance can best ensure that students are properly focused and are addressing the targeted concept(s), especially when the solution time is constrained. We suggest that if the instructor appreciates the potential benefits that the students could receive from an MEA, he/she should more readily make the extra effort to properly guide students and provide necessary feedback; otherwise the positive effects of the MEA may be limited at best.

Feedback after completion of the MEA plays an important role in students’ understanding key concepts. Such feedback can reinforce student understanding as well as correct misconceptions. Dividing MEAs into several parts and providing feedback at points during the solution
process also ensures that misconceptions are identified and corrected early allowing for student teams to redirect achieving the desired result. Further, corrective guidance can better ensure that students are addressing the correct problem and targeted concept(s), especially when solution time is constrained. Feedback after completion of the MEA plays an important role in students’ better learning key concepts. Such feedback can reinforce understanding as well as begin to correct misconceptions or misunderstandings.

Our research and experience strongly suggests that MEAs can help educators assess their students’ problem solving process through the use of PDAs [14], Wikis, reflection tools, as well as the actual student reports and well-designed examination questions. As a way to enhance problem solving and assess this process, we now require students to reflect on the process they have just used to resolve each MEA. To do this we have modified and extended the set of Reflection Tools first proposed by Hamilton et al. [15]. As noted later in this paper, the use of reflection and reflection tools has become an important assessment methodology, allowing educators to gain insight into the team’s group processes, problem solving strategies, degree of involvement, and their process for iterating among the various problem solving steps as they proceed through the exercise. Further, such information can provide engineering educators with information about the quality of student learning.

Enhancing the learning benefits of MEAs - To enhance the educational benefits of MEAs, we have focused on introducing an ethical dimension. We have accomplished this by embedding an ethical dilemma in many of the MEAs that we have developed. By introducing the ethical reasoning domain, we have created what we call ethical MEAs or E-MEAs. Our objective has been to encourage students to consider how the engineering decisions that they make potentially influence the public, environment, other stakeholders, their firm and/or themselves. In addition, this allows us to better understand the various strategies student teams use to resolve complex ethical dilemmas [16].

Assessing the Impact of MEAs - In addition to extending MEAs to upper level industrial engineering courses and introducing an ethical component, a third focus of our research has been on the use of MEAs as a learning intervention. Specifically, we have identified two issues that need further attention:

- Problem solving process of students while working on MEAs and
- Testing and document the actual learning benefits of MEAs.

Data Collection Tools

We propose that MEAs can improve student learning in four specific domains: (1) conceptual understanding, (2) problem solving, (3) team work, and (4) ethical reasoning. We have been collecting data to support this assertion using a mix of tools. (For more of an overview see [17]). These include:

- **Reflection Tools** - Following an MEA activity, reflection tools help students recall and then record significant aspects about what they have done (e.g., strategies used, ways the team functioned, etc.) so that the instructor might use this information to discuss with students the effectiveness of their various strategies, and types of engagement used [18]. Our reflections tools take the form of a semi-structured instrument.
• **Student Reports** (artifact), i.e., the actual assigned MEA report (typically provided in memorandum format to the client), provide an artifact to assess the success of the MEA implementation. This enables us to assess the extent that the team used the targeted concepts, their level of understanding of these concepts and whether they used them correctly. A successful report should clearly provide a general model for resolving the type of problem presented by the client as well as a specific solution to the given problem. If an ethical dilemma is embedded in the MEA, the report should also identify it and provide an appropriate resolution, in addition to pointing out other issues that might affect the recommended solution.

• **PDA Recordings** - To analyze problem solving patterns, we have used personal digital assistants (PDA) to collect data. We have programmed the PDAs so that students can record: the specific problem solving task being addressed; the perceived progress and level of effort at that point (not making progress, satisfactory, very good progress); and whether the work on the task was done as a group or individually [19].

• **Concept Inventories:** we have been using concept inventories in a pre- and post-test mode as a more effective means of assessing the learning impact of a particular MEA or a set of MEAs [20, 21]. Since most of our MEAs have revolved around statistical concepts, we have used appropriate items from the statistics concept inventory originally developed by Reed-Rhoa and colleagues [22], as well as creating our own concept inventory for Engineering Economics [23]. By using concept inventories in this fashion, we have been able to calculate effect size. This is especially insightful when we have a comparison group (i.e., a second section of a course that doesn’t use the MEAs but covers the same material).

**Assessment of Learning Benefits - Results**

We would expect to see evidence of student learning through the use of MEAs. Specifically, as noted, we would expect that after each properly implemented MEA exercise, students’ (1) comprehension of the engineering concepts, (2) problem solving skills, (3) ethical reasoning ability, and (4) ability to work in teams should be enhanced.

Traditional engineering homework problems are well structured, done individually, and typically have only one correct answer; often they simply require the student to repeat a procedure learned in class that applies concepts recently covered in lecture or the text. In contrast, the problems engineers are asked to solve in the workplace are the exact opposite. As Jonassen, Strobel and Lee [24] found “workplace problems are ill-structured and complex because they possess conflicting goals, multiple solution methods, non-engineering success standards, non-engineering constraints, unanticipated problems, distributed knowledge, collaborative activity systems, the importance of experience, and multiple forms of problem representation.” We suggest that MEAs can be a “bridging” step to bring some of the experience of the workplace engineering problems into the classroom, and help students learn to apply their conceptual framework to less structured problems. Our assessments appear to bear this out, especially relative to the ABET outcomes [25]

**Engineering Economy Example:** Two sections of an introductory engineering economy course were both taught by the same instructor. Three E-MEAs were used in a section consisting primarily of industrial engineering students (49 students). The second section consisted primarily of civil engineering and a few mechanical engineering students (70 students).
The purpose of the experiment was to determine if the E-MEAs would contribute to an increase in learning of specific concepts (conceptual knowledge). Thus a measure of student engineering economy concept knowledge was needed. To do this, an engineering economy concept inventory (concept test) was developed, since course exams tended to focus on the quantitative aspects of economic analysis and the researchers did not want confounding effects from examinations conditions to be a factor. The concept inventory measured students’ understanding of the specific concepts important to the course, and which the E-MEAs were built around. 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. A secondary goal was to determine if the MEAs could provide measures for three ABET outcomes: 3.f (“an understanding of professional and ethical responsibility”), 3.h (“the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context”), and 3.j (“a knowledge of contemporary issues”). In particular, E-MEAs can be constructed to emphasize consideration of all relevant criteria while introducing contemporary problems consistent with these desired ABET outcomes.

The concept inventory focused on those concepts that were judged to be important for the course. It was pilot tested with former students and edits were made based on their feedback. The final version consisted of nine multiple choice and short answer questions. 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 scored by the same Research Assistant using the instructor developed grading key. Note that the instrument was later modified (Fall 2010) and currently includes 10 questions.

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 (15-20 points) and a group part (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 before addressing the MEA. 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) from a fictional client. It required the team to address a particular decision situation, develop a model for solving their identified problem, apply the model to the specific case, and write a memo to a “client” that detailed the team’s results and recommended decision for the case. The group parts were assigned on a Thursday and due in class the following Tuesday. 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 comparison group was only assigned traditional homework assignments and some in class group problems (text book style) related to the course concepts.

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. 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 1.
Table 1: Results of Concept Inventory Scores

<table>
<thead>
<tr>
<th>Start of Term</th>
<th>Comparison Group</th>
<th>Experimental (E-MEA) Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>20.38</td>
<td>17.49</td>
</tr>
<tr>
<td>Std. Dev.</td>
<td>6.45</td>
<td>5.49</td>
</tr>
<tr>
<td>Sample Size</td>
<td>69</td>
<td>47</td>
</tr>
<tr>
<td>End of Term</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>32.04</td>
<td>30.20</td>
</tr>
<tr>
<td>Std. Dev.</td>
<td>5.77</td>
<td>5.26</td>
</tr>
<tr>
<td>Sample Size</td>
<td>69</td>
<td>45</td>
</tr>
</tbody>
</table>

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, which was not an unexpected. Further, while both effect sizes were large, the effect in the E-MEA group (experimental group) was larger than that for the comparison group. Using Cohen’s $d$ with a pooled standard deviation [26], the effect was 1.90 and for the experimental group it was 2.36.

Key:
1: Comparison group (Non-IE section; no MEAs; Fall 2009)
2. IE Section, E-MEAs, Fall 2009
3. Non-IE section, E-MEAs; Spring 2010
4. IE section, E-MEAs; Fall 2010
5. Non-IE section, E-MEAs, Fall 2010.
6. Non-IE section, E-MEAs, Spring 2011

Figure 1: Effect Size – Engineering Economics – Five Experiments

Due to the success of the E-MEAs, they continued to be introduced in Engineering Economics courses for the 2010 and 2011 academic years. Sections were typically either primarily Industrial Engineering students, or mixed (non-Industrial Engineering students). For the four sections, all showed large, significant gains in conceptual understanding as measured by the pre- and post-
concept tests (see Table 2 and Figure 1). For all five experimental sections, the average effect size was 2.17. Note that an additional item was added to the concept test beginning in Fall 2010.

Table 2: Additional Concept Inventory Scores – E-MEA Sections

<table>
<thead>
<tr>
<th></th>
<th>Spring 2010 Non IE section (E-MEAs incorporated)</th>
<th>Fall 2010 IE section (E-MEAs incorporated)</th>
<th>Fall 2010 Non IE section (E-MEAs incorporated)</th>
<th>Spring 2011 Non IE section (E-MEAs incorporated)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Start of Term</strong></td>
<td>Mean</td>
<td>20.79</td>
<td>19.32</td>
<td>24.03</td>
</tr>
<tr>
<td></td>
<td>Std. Dev.</td>
<td>5.23</td>
<td>6.82</td>
<td>6.33</td>
</tr>
<tr>
<td></td>
<td>Sample Size</td>
<td>48</td>
<td>60</td>
<td>71</td>
</tr>
<tr>
<td><strong>End of Term</strong></td>
<td>Mean</td>
<td>32.7</td>
<td>37.61</td>
<td>35.43</td>
</tr>
<tr>
<td></td>
<td>Std. Dev.</td>
<td>4.86</td>
<td>7.14</td>
<td>7.02</td>
</tr>
<tr>
<td></td>
<td>Sample Size</td>
<td>50</td>
<td>54</td>
<td>74</td>
</tr>
<tr>
<td><strong>Effect Size</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Introductory Engineering Statistics: Three sections of an introductory statistics course were taught in the fall of 2009. Each section was taught by a different instructor with a different level of teaching experience. In addition to the weekly homework assignments and quizzes, three MEAs were given to the section that consisted primarily of industrial engineering students (ES-1 - experimental group; 49 students). The other two sections consisted mostly of civil engineering students as well as other engineering majors (CS-1 and CS-2, comparison groups; 65 and 61 students respectively).

Again, the primary goal for introducing MEAs was to reinforce selected concepts covered in the course, and determine if there was an improvement in conceptual knowledge for concepts specifically targeted by the MEAs. Three MEAs were adapted and assigned to students immediately after covering the specific concepts: Tire Reliability, Test Leads and CNC machine. The main focus was on nine concepts: Mean, Median, Variance, Distributions, Outliers, Central Limit Theorem, Confidence Intervals, Sample Size and Hypothesis Testing.

The MEAs consisted of an individual part (15 points) and a group part (100 points). The individual parts consisted of several questions related to each problem situation so that students might start thinking about which concepts might apply. The group part consisted of an assignment to the statistics team (students) from a fictional client. Students were asked to develop a general procedure for solving this type of a problem, apply it to this specific case, then test the given data to reach a conclusion. Students were required to submit a memo that details their general procedure and explains in detail how they applied it. Students were also asked to address an ethical dilemma embedded in each of the MEAs. Detailed description of the MEAs as well as the methodology is presented in Vidic et al. [21].

In order to measure the level of improvement in conceptual knowledge in statistics course we selected the Statistics Concept Inventory (SCI) created by Allen et al. [27]. The SCI is a multiple choice assessment tool designed for introductory statistics courses. Both the question and the response choices are the subject of the well designed research and each question includes one cor-
rect answer and several distractors, based on students’ customary common sense ideas (i.e., commonly held misconceptions or misunderstandings). Initially twelve questions were selected based on the specific concepts targeted by MEAs; this was later expanded to 20 items. Two questions were selected (with permission) from the Comprehensive Assessment of Outcomes in a first Statistics Course (CAOS) [38]. The concept inventory questions were given to students at the beginning and end of the semester.

Grading rubrics were developed for each of the MEAs in order to achieve consistency; the same individual graded both parts of all three MEAs (individual and part). The mean and standard deviation of the concept inventory scores for the beginning of the term and the end of the term are shown in Table 3. The effect sizes for all three groups are also shown.

### Table 3: Results of Concept Inventory Scores – Fall 2009

<table>
<thead>
<tr>
<th>Item</th>
<th>CS-1</th>
<th>CS-2</th>
<th>ES-1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start Term Mean</td>
<td>4.375</td>
<td>3.92</td>
<td>4.19</td>
</tr>
<tr>
<td>St. Dev.</td>
<td>1.65</td>
<td>1.78</td>
<td>1.73</td>
</tr>
<tr>
<td>Sample Size</td>
<td>65</td>
<td>61</td>
<td>49</td>
</tr>
<tr>
<td>End Term Mean</td>
<td>5.73</td>
<td>5.88</td>
<td>6.50</td>
</tr>
<tr>
<td>St. Dev.</td>
<td>1.88</td>
<td>2.19</td>
<td>1.79</td>
</tr>
<tr>
<td>Sample Size</td>
<td>41</td>
<td>57</td>
<td>46</td>
</tr>
<tr>
<td>Effect size</td>
<td>.78 Medium</td>
<td>.98 Large</td>
<td>.90 Large</td>
</tr>
</tbody>
</table>

There is a significant statistical difference ($p$-value $\approx 0$) between the start and end of term average concept inventory scores for all three groups as expected. As to the effect sizes - one comparison group had Cohen’s $d$ “medium” effect size, while the other comparison group and the experimental group had “large” effect sizes.

### Additional Experiments

The instructor who taught the experimental group in the Fall of 2009 also taught one section of the statistics course in the Spring of 2010. This section consisted mostly of civil engineering majors as well as students enrolled in other engineering departments in the school (ES-2; 51 students). Two of the E-MEAs were introduced during the semester. The spring section also had weekly homework assignments and quizzes. The students were given the concept inventory questions at the beginning and at the end of semester. The same instructor taught an IE section (ES-3) in Fall 2010 and a non-IE section in Spring 2011 (ES-4). For both of these sections, E-MEAs were used. Again in Fall 2010, there were two comparison sections (without MEAs; CS-3 and CS-4); there was also one comparison section in Spring 2011 (CS-5).
Table 4 and Figure 2 provide the average pre- and post-concept test scores for the three additional experimental and three additional comparison sections. In all cases, gains occurred; the gains were large for two of the experimental and two of the comparison sections; for the other two cases the gains were considered medium. In total, for the four experimental sections, an average gain of 0.99 was found compared to an average gain of 0.96 for the comparison sections. Note that all of the experimental sections were taught by the same instructor. In contrast, the five comparison sections were taught by different instructors.

### Table 4: Results of Concept Inventory Scores

<table>
<thead>
<tr>
<th>Item</th>
<th>ES-2 S-10</th>
<th>CS-3 F-10</th>
<th>CS-4 F-10</th>
<th>ES-3 F-10</th>
<th>CS-5 S-11</th>
<th>ES-4 S-11</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start Term</td>
<td>Mean</td>
<td>4.77</td>
<td>6.91</td>
<td>6.81</td>
<td>7.21</td>
<td>8.255</td>
</tr>
<tr>
<td></td>
<td>St. Dev.</td>
<td>2.02</td>
<td>2.67</td>
<td>2.82</td>
<td>2.62</td>
<td>4.3264</td>
</tr>
<tr>
<td>Sample Size</td>
<td></td>
<td>48</td>
<td>70</td>
<td>68</td>
<td>58</td>
<td>47</td>
</tr>
<tr>
<td>End Term</td>
<td>Mean</td>
<td>6.17</td>
<td>10.12</td>
<td>10.02</td>
<td>10.56</td>
<td>10.073</td>
</tr>
<tr>
<td></td>
<td>St. Dev.</td>
<td>2.23</td>
<td>2.83</td>
<td>2.72</td>
<td>2.61</td>
<td>9.5481</td>
</tr>
<tr>
<td>Sample Size</td>
<td></td>
<td>41</td>
<td>66</td>
<td>65</td>
<td>57</td>
<td>41</td>
</tr>
<tr>
<td>Effect size</td>
<td>0.62</td>
<td>Large</td>
<td>1.15</td>
<td>Large</td>
<td>1.28</td>
<td>Large</td>
</tr>
<tr>
<td>Notes</td>
<td>Non-IE Section</td>
<td>Non-IE Section</td>
<td>Non-IE Section</td>
<td>IE Section</td>
<td>Non-IE Section</td>
<td>Non-IE Section</td>
</tr>
</tbody>
</table>

**Key**
1. CS-1, Fall 2009
2. CS-2, Fall 2009
3. ES-1, Fall 2009, Instructor Y
4. ES-2, Spring 2010, Instructor Y
5. CS-3, Fall 2010
6. CS-4, Fall 2010
7. ES-3, Fall 2010, Instructor Y (IE)
8. CS-5, Spring 2011
9. ES-4, Spring 2011, Instructor Y

**Figure 2: Effect Sizes – Engineering Statistics Experiments**
**Impacting the Professional Skills (ABET Outcomes)**

As has been discussed, an important value in using MEAs in the engineering classroom is their ability to address a broad spectrum of the ABET “professional skills” by design. We evaluated this impact by examining the responses from the standard Swanson School of Engineering course teaching evaluations, specifically a set of questions designed to measure obtainment of the ABET outcomes – specifically, Criterion 3.a. – k. 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.”

In the engineering economics studies, we found that the average response to the questions related to outcomes a, d, f, g, and h was significantly higher (p < .05, one tailed) for the experimental group (used E-MEAs) than for the comparison group (no MEAs). In the engineering statistics studies, in addition to the significant factors we observed for engineering economics, we also found additional differences between the section using MEAs and the sections that did not including higher results for outcomes e and j. It should be noted that we found a strong consistency between the experimental engineering statistics section, and each of the comparison sections.

**The Impact Of MEAs From The Instructors’ Perspective**

In previous papers we have reported on the impact of MEAs from the instructor’s perspective [28, 29]. These papers have documented how using MEAs do change instructors’ views of teaching and learning. We have also reported on how, if the MEAs are to be effective, then they must be introduced appropriately [30]. Here we have shown:

First, E-MEAs can be as effective as traditional methods of instruction in helping students master important concepts in engineering economics and engineering statistics. Indeed, for all engineering economics sections, large gains in conceptual understanding were observed. For engineering statistics, gains ranged from medium to large, but comparable to those for the traditionally taught sections.

Second, E-MEAs when used appropriately enable students to substantially improve their achieving a number of the ABET Criterion 3.a-k outcomes, especially professional skills which are the more difficult to achieve and measure.

However, before instructors implement MEAs or E-MEAs, certain cautions are advised. Specifically, the instructors in our studies who used E-MEAs in their classrooms offer the following advice for faculty interested in implement this pedagogy:

1. MEAs can be very useful, but require additional preparation work upfront.

   “You must lay out how it is going to fit into your syllabus, and think through all the logistical aspects of the MEAs. For example, the actual due dates of the parts of the MEA (individual part, group part, if you are doing a reflection), format for turning them in (elec-
tronic or paper copy; if you do it electronically there are both Word and Excel files), and how it counts toward the student’s grade (e.g., worth more than a typical homework assignment?). Both pieces of the MEA, the individual part and the group part must be kept separate. The group part solution should ideally be a model or generalizable process, so I try to emphasize that in my instruction.”

2. Feedback is critical. After each MEA part is completed, there must be sufficient time to grade the assignment and provide feedback to the students before moving on to the next part (or the next MEA). This is the opportunity to correct misconceptions or misunderstandings and review common mistakes. However, it is a challenge to determine how much guidance to give to the students without leading them to a specific answer.

“After each section of the MEA gets turned in, make sure there is enough time to grade and give feedback before moving on to the next part (or the next MEA). This is your opportunity to correct misconceptions and review common mistakes or answers on the solutions. It is a constant challenge for me to determine how much information to give to the students to guide them without giving away too much that leads them towards a specific answer. When I return the graded group solutions in class, I spend about 10 minutes debriefing the class and having a discussion about the memos they have written. Students sometimes struggle with the answer to the question “what is the right answer?” since often there are several “right” answers.”

3. Be very clear from the beginning about the concepts and topics that the MEA will introduce:

“MEAs can be used as either: discoverer, reinforcer or an integrator. I often use MEAs to reinforce concepts, but to some extent students must combine several main ideas from the course to be able to write up a successful solution.”

4. MEAs are a very good way to measure certain ABET professional skills; e.g., outcomes f, h and j (understanding of professional and ethical responsibility; broad education necessary to understand the impact of engineering solutions in a global, economic, environmental and societal context; knowledge of contemporary issues):

“The MEAs I have used are very realistic, more so than other projects I have used in my engineering economy class. There are many MEAs that I have used, or could use so it provides me more alternatives for group projects (which sometimes feel more contrived) or allowing students to pick their own project topics (which can lead to higher variability in project success).”

5. Do not underestimate how difficult it is for students to master concepts:

“I now have a better understanding that it is hard for students to apply concepts learned in the class to problems different than homework problems (challenge of knowledge transfer).”

Relationship between Confidence and Correct Confidence Inventory Responses

In studying the relationship between students’ confidence in selecting the correct answer, and the correctness of that answer, only two of the experimental statistics sections and three of the com-
Comparisons were used. As noted, the CI was administered for all five of these sections both pre (at the beginning of the term) and post (at the end of the term). The instructor was the same for both experimental (MEA) sections, and the three comparison (non-MEA) sections each had a different course instructor. All instructors had prior teaching experience in statistics; the instructor using MEAs was part of the research team and was experienced in using this construct within the classroom setting. Similar content was covered in all the sections of the Probability and Statistics for Engineers 1 course; the Fall 2010 experimental section consisted of IE students; the Spring 2011 experimental section and the three comparison sections all consisted of students from across the engineering school.

As noted above, the CIs were given at the beginning (pre) and end of the semester (post) over two consecutive semesters. The concept inventory is used to measure conceptual improvement over the duration of the course. As noted, the CI was a selected subset of 20 multiple choices questions from two different pre-established Statistics Concept Inventories. The CI questions that were included were selected based upon targeted technical concepts that the MEAs reinforced. The pre and post CI tests were exactly the same. (Please see Assessment of Learning Benefits – Results above.)

Figure 3: Average Confidence for correct and incorrect answers for the concept inventory

A level of confidence question was asked after each concept question. These were scored from 0 to 3 (three being the highest confidence level). Specifically, we asked for each item:

0- I feel clueless about the answer
1- I think this might be the right answer
2- I feel pretty good about the answer
3- I am completely sure it is right
This was done to see whether or not the students felt that they knew the concept, they were simply guessing, or they had a misunderstanding or misconception about the technical concept (high confidence level but an incorrect answer). For each student, his or her score on the pre and post CI was recorded, in addition to final course grade and demographic information such as course year, engineering major and gender.

We looked at the relationship between the percentage of students who answered the item correctly (on the post test) and the average confidence. As we might expect, in general the more students who answered the question correctly, the higher their average confidence score was as illustrated in Figure 3. (Note that the highest average score would be a 3); $R^2 = 0.69$ (i.e., 69% of the variation explained). In contrast, if we examine the correlation between the percentage of students who answered the item wrong and their average confidence, we see a negative relationship, again as would be expected. In this case, $R^2 = 0.24$ (24% of the variation explained). Note that Figure 3 is a plot of each of the 20 items on the concept inventory.

**Determining the Cognitive Factors that Affect the Development of Modeling Ability**

A major overall goal has been to investigate the impact of cognitive factors in development of students’ modeling ability [31-35]. The most in depth of our studies has been an examination of the relationship between engineering modeling skills and students’ cognitive backgrounds including self-efficacy, epistemic beliefs and metacognition using model-eliciting activities (MEAs) as an assessment tool. Data were collected from sophomore students at two time periods, as well as senior level engineering students. The impact of each cognitive construct on change in modeling skills was measured using a growth curve model at the sophomore level, and ordinary least squares regression at the senior level.

The findings suggest that self-efficacy, through both its direct and indirect impact (as measured by our statistical models), influences the growth of modeling abilities of an engineering student. When sophomore and senior modeling abilities are compared, the difference can be explained by varying self-efficacy levels. We found that epistemology influences modeling skill development in the following manner. Overall, the more sophisticated the student beliefs are, the higher the level of modeling ability students can attain, after controlling for the effects of conceptual learning, gender and the student’s grade point average (GPA). This suggests that development of modeling ability may be constrained by the naïveté of one’s personal epistemology. Finally, metacognition, or ‘thinking about thinking,’ has an impact on the development of modeling strategies of students, when the impacts of four metacognitive dimensions are considered: awareness, planning, cognitive strategy and self-checking. Students who are better at self-checking show higher growth in their modeling abilities over the course of a year, compared to students who are less proficient at self-checking. The growth in modeling abilities is also moderated by the cognitive strategy and planning skills of the student. After some experience with modeling is attained, students who have enhanced skills in these two metacognitive dimensions are observed to do better in modeling. Therefore, inherent metacognitive abilities of students can positively affect the growth of modeling ability.

A result from this study is that self-efficacy in engineering modeling is not well developed as students move from the sophomore to the senior level. Attempts to increase the modeling experi-
ence through the use of MEAs (e.g., having students with demonstrated modeling abilities as mentors to novice student modelers, and training them to be ‘role models’ for modeling) may be a way to reduce low self-efficacy. Further, faculty can focus developing self-efficacy in their courses, by providing further practice for modeling, giving verbal encouragement to help increase the level of self-efficacy, as well as enabling students to observe successful modeling outcomes of their peers. Reducing math anxiety levels also can be beneficial by leading to increased modeling self-efficacy, which in turn increases modeling outcomes.

**Professional skills development**

Further evidence of the benefits of MEA can be seen when a deeper look at the student solutions to the engineering economy E-MEAs is taken. When first introduced, nearly all of the student teams at least identified the ethical and societal issues in the given situations and most groups specifically address these ethical issues and made recommendations to the client regarding how to address them. As a result, the instructors for experimental courses have continued to incorporate E-MEAs for the 2010-2011 and 2011-2012 academic years. Specifically, in the engineering economy course, all sections are now assigned two or three E-MEAs throughout the semester.

We have found that scores on the E-MEAs continue to show improvement in students’ ability to recognize and understand the importance of the professional skill areas. Students begin to understand that in most case, real problems require the decision-maker to go beyond the rational, analytical, and mathematical solutions to problems and recognize the impact on non-quantifiable factors such as safety, environmental effects, and ethical dilemmas. Increases in successful teamwork and improvement in students’ communications skills (via the written memos) have also been observed. When reviewing the “reflection” data, we have also observed an increase in the percent of students that recognized and addressed the ethical issues as more E-MEAs were introduced to the same group of students (see Siewiorek, et. al., “Comparison of Instructor Perceptions and Student Reflections on Model Eliciting Activities” [36]).

In order to determine if the differences found with respect to the ABET outcomes between the engineering economics experimental and comparison sections (Fall 2009) were due to the experimental group consisting entirely industrial engineering students while the comparison group consisted of students from multiple engineering disciplines, an additional statistical comparison was made. In this case it was between a section of engineering economy taught in Spring 2009 with no MEAs introduced and one taught in Spring 2011 with MEAs by the same instructor. These two courses were the similar otherwise (with respect to student make up and course structure). Significant differences (p-value < .05) were found for students’ self-ratings of their knowledge and skills obtained for outcomes a, b, c, d, e, f, g, h, and k. This lends support to the conclusion that the MEAs are an effective for increasing student attainment of the ABET professional skills regardless of the specific engineering discipline of students in the course.

As noted, the E-MEA are specifically designed to present students with realistic scenarios that require them to function effectively in a team environment, develop a generalized mathematical model for solution, identify and address an ethical dilemma, and report their results in a well-crafted memorandum to a fictitious client. Hence, it is not surprising that appropriately introducing a set of well-designed E-MEA within a course by an instructor who understands how to ef-
fectively provide the necessary support for the student teams, would have a positive impact on achieving many of the professional skills, especially when compared to a traditional course that relies primarily on homework problems that are taken from the “end of the chapter.”

**Discussion and Conclusions**

To date, we have developed and implemented MEAs with the aim of enhancing conceptual understanding and problem solving skills of engineering students. We have collected data from these implementations with the aim of validating such benefits. We have developed and tested eleven new MEAs in addition to adapting and implementing seven more developed by our colleagues. These have been implemented primarily in industrial engineering courses including a pilot engineering course that was devoted to using MEAs as a mechanism for teaching problem solving. We have introduced an ethical component into the majority of the MEAs that we developed, and have designated these as E-MEA.

We have found that MEAs as a teaching tool are ideal for getting students to apply particular concepts to realistic, client-based problems that are generally much richer in nature than those found in a textbook. Our research strongly suggests that if used correctly, they can be effective in reinforcing and integrating course concepts as well as increasing student knowledge and understanding of various ABET professional skills. While this paper describes the important value we have found by using MEAs in the classroom, we must emphasize that the use of MEAs or E-MEAs requires an effort on the part of the instructor, beginning with selecting and adapting appropriate to the particular course, organizing the student groups, grading promptly and consistently, and providing rapid, appropriate feedback.

MEAs and E-MEAs in the classroom also have other advantages. These include

- An opportunity for multiple solution approaches. Too often students provide a single solution. However, in the work environment engineers typically examine several alternatives. MEAs provide an opportunity for encouraging students to consider and report on different approaches. This, in turn helps to build metacognition through cognitive strategies.

- Introducing real-life experiences into the classroom. Students too often think in terms of short term goals, such as getting an A or graduating, rather than preparing for the long term goal of being a successful engineer. By providing real-life modeling exercises, students become better prepared and should be more motivated act like engineers. MEA, are typically built around real-life, engineering situations.

- MEAs provide opportunities for students to improve communication skills. For example, by expecting students to submit their solutions as if they were reports from working engineers can help reduce such thinking as ‘it is just a class assignment’ or ‘this contributes very little to my grade’ (so it is not important). This should help students to further benefit from modeling exercises.

We have also shown that MEA can lead to improved self-efficacy and metacognition, especially as applied to modeling. However, to do this we would suggest interested instructors:

- Encourage students - when an instructor feels that a student is not demonstrating her full ability, by encouraging the student to do better, the instructor can help repair low self-efficacy, which, in turn, will result in higher modeling learning.
• Make modeling exercises relevant, and gradually increase their difficulty. When increasing the self-efficacy level of a student, it is important that the modeling tasks assigned match their capability, as well as their knowledge. Introducing tasks that match their capabilities and then gradually increasing the difficulty is likely to result in higher self-efficacy, helping them to learn to model.

• Ask for multiple solution approaches. Often instructors ask students to provide a single solution for a model; however, in real life it is not uncommon for an engineer to examine several options and to come up with alternatives. Encouraging students to think and report a number of different ways can help to build metacognition through cognitive strategy.

• Use reflective exercises. Metacognitive abilities of students can be improved by implementation of reflective statements over the course of a project. Carrying out reflections during and after the modeling exercise can help students master the planning and self-checking dimensions of metacognition.

In summary, we have found that the proper use of MEAs can result in substantial learning gain, certainly as much as the more traditional instructional methods that use “back-of-the-book” problems as the sole homework exercises. However, with the E-MEAs, we have found something else – in addition to assessing problem solving skills as originally suggested by Besterfield-Sacre and Shuman [37] – we found that they could also improve students’ abilities to better obtain almost all of the professional skills. Hence, we propose that when used in combination with the concept inventories, grading rubrics, and reflection tools, they offer engineering faculty with not only a learning intervention but also with an assessment method for a large portion of the ABET outcomes. By utilizing MEAs or E-MEAs in a select set of courses, faculty can obtain a comprehensive set of assessments for ABET while enhancing student learning.

Together with our six collaborating universities, we are providing the engineering education community with a collection of MEAs backed up by rigorous research that contributes to engineering education in several ways. (See modelsandmodeling.net.) As engineering faculty continue to focus on providing realistic learning environments for their students, improved learning and assessment tools are needed. We propose that MEAs can improve student learning and they can be used to assess the attainment of particular important learning outcomes.

Acknowledgement

This research is supported in part by the National Science Foundation through DUE 071780: “Collaborative Research: Improving Engineering Students’ Learning Strategies through Models and Modeling.”

References


