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Model-Eliciting Activities: Assessing Engineering Student Problem Solving and Skill Integration Processes*

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A Model-Eliciting Activity (MEA) presents student teams with a thought-revealing, model-eliciting, open-ended, realistic, client-driven problem for resolution. Here we extend the original MEA construct developed by mathematics education researchers to upper-level engineering coursework and introduce an ethical component. Our extensions also require students to integrate previously learned concepts as they gain new understanding. We propose that MEAs offer engineering educators at least two potential benefits: improved conceptual understanding and a means for assessing the problem solving process. However, these benefits will only accrue if the MEAs are properly implemented. Consequently, relative to the first we propose certain strategies, learned through experience, for successful MEA implementation, recognizing that this is not a simple task. In addition, we suggest using MEAs as assessment tools and illustrate how they can help analyze students' problem solving processes. Our findings are based on experiments conducted in different learning environments over a two year period at the University of Pittsburgh's Swanson School of Engineering. This paper should serve as a resource for those engineering educators and researchers interested in implementing MEAs.

Keywords: Model-Eliciting Activity (MEA); ethical reasoning; teaching engineering concepts; assessment of problem solving

1. INTRODUCTION

A MODEL-ELICITING ACTIVITY (MEA) presents student teams with a thought-revealing, model-eliciting [1], open-ended, real-world, client-driven problem. MEAs are purported to improve conceptual learning and problem solving skills. Originally developed by mathematics educators, they were first introduced to engineering students, primarily at the freshman level, at Purdue University, seven years ago [2–4]. Since then, MEAs are slowly finding their way into engineering classrooms at various levels; and have the potential to become a widely used engineering education tool. Besides their potential for improving learning, MEAs offer engineering educators a mechanism for assessing problem solving and engineering concepts. Although MEAs have been well published in the pre-college mathematics education literature, their promise and benefits are still relatively novel in engineering education. The purpose of this article is to better inform the engineering education community of MEAs and how our use of them in upper-level engineering courses is leading us to improve students' conceptual understanding, problem solving and ability to recognize and address ethical dilemmas. Further, through our modified design experiment approach and assessment tools for studying MEAs in the classroom, we provide early lessons for those seeking to add MEAs to their instructor's tool kit.

The paper is organized as follows: we provide a theoretical background supporting MEAs and MEA research. Next we describe our experiments to date and assessment tools, including MEA implementation strategies, the introduction of an ethical component and insights from using MEAs as an assessment tool. In our last section, we provide a summary of the findings and advice to faculty.

Specifically, we overview the literature that addresses three facets of MEAs' instructional benefits: improved conceptual understanding, problem solving, and teamwork skills, to which we now add a fourth–improved ability to recognize and resolve ethical dilemmas. However, here we stress an important lesson learned from our experience: these benefits will only be realized if the MEAs are correctly implemented. Factors that influence the success of MEA implementation include: the nature of the embedded concept and course, the MEA's purpose in the exercise, the time allocated for resolving the MEA, the extent of guided discovery provided by the instructor during the MEA solution session, the feedback given after completion, and the instructor's training relative to MEA use. We explore using MEAs for assessing important engineering outcomes. Based on our experiments, we illustrate how they can be used to analyze problem solving patterns showing how

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personal digital assistants (PDAs) and reflection in particular can provide important information to the instructor.

2. BACKGROUND

MEAs were originally developed by mathematics education researchers [5, 6] to both promote problem solving by encouraging students to build mathematical models and provide a mechanism to understand students' thought processes. They used MEAs to observe the progress of student problem-solving competencies and the growth of mathematical cognition. Concomitantly, MEAs became a tool for both instructors and researchers to not only observe but also design situations that engage learners in productive mathematical thinking [5, 8, 9].

MEAs are constructed using six specific principles as shown in Table 1 [4, 7]. It is proposed that a well-designed MEA following these principles can contribute to student's understanding of engineering concepts, problem solving, communications and teamwork skills. Diefes-Dux et al. [4] emphasize that MEAs are not about the solution itself, but the process of problem solving. Specifically, it is the process that students follow while solving an MEA combined with elements of model generation and reporting that differentiates MEAs from other typical engineering problems, as well as differentiating it from problem based learning.

This emphasis on building, expressing, testing and revising conceptual models is also what differentiates MEAs from 'textbook' problem-solving activities. Other distinguishing characteristics include the length of time required for resolution, access to different information resources, number of individuals involved in the problem-solving process, and type of documentation required in resolving an MEA. A typical MEA is a team exercise; this (multidisciplinary) teamwork practice also reinforces the students' learning. We posit that MEAs can play three distinct roles in helping students learn an engineering concept:

- 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*).

Since MEAs often require students to apply mathematical or other structural interpretations to situations that cut across multiple disciplines, they may have to make new connections, combinations, manipulations, predictions or look at the problem in other ways in order to resolve the posed scenario. Hence, MEAs can require students to employ learning from previous courses, integrating it with new information.

Since MEAs have been introduced into the engineering classroom, a rich body of research has begun to emerge. We generalize this literature into three streams: (1) studies that provide examples for MEA implementation, (2) studies that suggest using MEAs to achieve specific learning goals, (3) studies that investigate the MEA solution process. Our study contributes to all three of these streams.

Diefes-Dux et al. provide an example of the

Table 1. MEA Construction Principles

Principle Description
Model Construction: Student team must create a mathematical model (system) that addresses the needs of a given client. A mathematical model: a system used to describe another system, make sense of a system, explain a system, or to make predictions about a system
Reality: The activity is set in a realistic, authentic engineering context and requires the development of a mathematical model for solution. A well-designed MEA requires students to make sense of the problem context by extending their existing knowledge and experience. The MEA should create the need for problem resolution, ideally making the student team behave like engineers working for the particular organization.
Self Assessment: As the model develops, students must perform self-evaluation of their work. The criterion for 'goodness of response' is partially embedded in the activity by providing a specific client with a clearly stated need. The criterion should also encourage students to test and revise their models by pushing beyond initial ways of thinking to create a more robust model that better meets the client's needs.
Model Documentation: The model must be documented; typically students write a memo to the client describing their model. The MEA is not only model-eliciting, but thought-revealing; i.e., the team's mathematical approach to the problem is revealed in the client deliverable. This process enables students to examine their progress, assess the evolution of the mathematical model, and reflect about the model. It provides a window into students' thinking, which can inform instruction.
Generalizability: The created model must be sharable, transferable, easily modifiable, and/or reusable in similar situations. It must be generally useful to the client and not just apply to the particular situation; i.e., it must be capable of being used by other students in similar situations, and robust enough to be used repeatedly as a tool for some purpose.
Effective prototype: The solution to an MEA provides a useful prototype, or metaphor, for interpreting other situations. The activity needs to encourage the students to create simple models for complex situations. The underlying concepts must be important ideas. Students should be able to think back on a given MEA when they encounter other, structurally similar situations.

studies within the first stream; they describe the use of MEAs with first-year engineering students, demonstrating that not only did they effectively introduce engineering concepts in context, but they also increased female students' interest in engineering [3]. Ahn and Leavitt [10] summarize their experiences with MEA implementations and recommend: (1) keeping the student team size to three or four, (2) arranging students with similar weaknesses in groups together, (3) making sure that there are enough instructors to guide students during the activity, (4) using activities that are relevant to students, (5) creating a prior engagement and (6) recording data from the related activities for consequent MEAs. Although their suggestions are based on experiments with eighth graders, our experience with engineering students supports these findings as explained in section 4.

Studies in the second stream suggest that the benefits of MEAs involve decreasing the educational gap between majority and underrepresented students, advancing students' creativity, and motivating them to use advanced engineering knowledge and techniques. As noted, Diefex-Dux et al. [3] documented that MEAs can advance the interest and persistence of women in engineering by providing a learning environment tailored to a more diverse population than traditional engineering course experiences. Chamberlin and Moon [11] used MEAs to develop creativity and identify creatively gifted students in mathematics, asserting that MEAs 'provide students with opportunities to develop creative and applied mathematical thinking; and analyze students' mathematical thinking . . . aiding in the identification of those students who are especially talented in domain-specific, mathematical creativity.' Moore et al. [12] discussed the opportunities for MEAs to motivate students to use upper level knowledge. Hallagan [13] used MEAs as exercises in analyzing the ways teachers think about and interpret their practice. Similarly, Berry [14] used MEAs to interpret the instructor's role in supporting and enhancing student teams' functioning. More recently, Hjalmarson et al. [15] used MEAs in analyzing the teacher actions that supported the design abilities of students. Self, Miller, Kean, and Moore, et al. [16] developed and used MEAs to help reveal the misconceptions of student in dynamics and thermal sciences courses. Most recently, Teran in Mexico has begun using MEAs to improve learning in upper division industrial engineering courses [17], spreading the use of engineering MEA applications into the international arena.

In the third and least developed stream, Moore et al. [18] investigated the impact of teamwork effectiveness on the solution quality. Using self-ratings, she found a positive correlation between how effectively the team functioned and the goodness of its solution. Dark and Manigault [19] noted that two processes during an MEA solution make a difference: collaborative learning and model development. Working in groups develops critical thinking abilities and helps to reflect group thinking in the model. However, objective assessments of MEA effectiveness remain as a gap in the literature. How students and teams of students navigate the problem solving process and how MEAs impact student learning still requires further exploration.

3. RESEARCH METHODOLOGY AND ASSESMENT TOOLS USED IN CONJUNCTION WITH MEAs

Our MEA research, to date, has focused on identifying the factors that influence implementation success and studying how the construct can be used to assess student learning. Our research methodology has involved four steps—MEA construction, implementation, assessment, and revision.

Pilot MEA construction began in early 2007 with initial implementations in summer 2007. Appendix A provides a summary of these MEAs and the environments in which the implementation occurred, and the concepts and skills targeted. In addition, we modified previously developed MEAs for use in upper level Industrial Engineering courses.

Table 2 provides a list of MEA implementations to date, giving the course where MEAs were introduced, student profile, concepts targeted, instructor training, the MEA's role in student learning, and how it was assigned. In general, an instructor chooses to implement a particular MEA that complements a specific engineering concept for a course. Depending on the instructor's personal teaching style, schedule, and course requirements, an implemented MEA may be used as an integrator, reinforcer or discoverer. Potential assessment tools (discussed below) are then determined to evaluate the potential student learning. Based on the evaluation of learning and feedback to the students, the MEA and assessment tools are modified for future use. As part of the engineering concept feedback, an engineering ethical component is also addressed with the students.

MEAs have been developed and are being developed in such different core engineering subjects including thermodynamics, materials, statistics, quality control, engineering economics, supply chain management, linear programming and engineering ethics. In our project alone, we have developed nearly 20 MEAs. Yet, the engineering problem solving process and aspects of modeling differs from that for mathematics education. Math educators define problem solving as 'searching for a means (i.e., procedures, steps) to solve the problem, where the goal is to find a correct way to get from the given information to the goal(s) set forth' [20]. This is only one dimension of the engineering MEA, but not the primary objective. In contrast, engineering MEAs are created to elevate students' problem solving, modeling and decision making

Table 2. MEA Implementations at University of Pittsburgh

Course	Student Profile	MEAs Implemented	Nature of MEA Implementation	Assessment Data Collected
Open Ended Problem Solving	Industrial Engineers / Juniors	Supplier Development, Condo Pricing, Quality Improvement, Compressor Reliability, Volleyball, CD Compilation, Disaster Decision Modeling, Trees, Gown Manufacturing	• Instructor trained • MEAs used as integrator and discoverer • In class assignments	Reflections
Engineering Ethics	Mixed Engineering Disciplines / Juniors and Seniors	Trees	• Instructor and TA trained • MEA used as integrator • Take home assignments	PDA Data Reports
Statistics II	Mixed Engineering Disciplines / Sophomores	SUV Rollover, Hazardous Material Transport	• Instructor trained • MEA used as reinforcer: students apply fundamentals learned in the class • Take home assignments	PDA data Reports
EMPOWER Energy Sustainability	Mixed Engineering Disciplines / Juniors and Seniors	Ethanol, Windmills	• Instructor trained • MEA used as reinforcer students had mixed understanding of the energy concepts • Take home assignments	Wikis
Decision Models	Mixed Engineering Disciplines / Graduate students and Seniors	Ethanol, FEMA Disaster Relief Dam Construction	• Instructor trained • MEA used as reinforcer • Take home assignments	No data collected
Engineering Statistics I	Mixed Engineering Disciplines / Juniors and Seniors	Tire reliability, Defibrillator Lead, CNC Machine	• Instructors not trained • MEA used as reinforcer • Take home assignments	PDA Data Reports Test questions Reflections
Engineering Statistics I	Mixed Engineering Disciplines / Juniors and Seniors	Tire reliability, CNC Machine	• Instructors not trained • MEA used as reinforcer • Take home assignments	Behavioral Observation Reports Test questions Reflections
Engineering Statistics II	Industrial Engineering/ Sophomores	Process Quality Control	• Instructor trained • MEA used as reinforce and discoverer • Assigned as a in-class followed by take home exercise	Reflections Reports Test questions

capabilities for the long term, even where the team is not developing an appropriate solution to the posed problem.

MEAs provide instructors with a medium for assessment; in response, tools have been developed to identify and analyze the steps students utilize while solving an engineering problem. Our experience suggests that these assessment tools used in collaboration with an MEA can provide valuable insights into the extent of the students' conceptual learning, and can enable the instructor to assess the actual teamwork process. We have used five different methods that were initiated by engineering education researchers for collecting student responses to MEAs: reflection tools, student reports, PDAs, Wikis, and test questions as described below. (A sixth, pre- and post- concept tests have been used successfully by Self and Miller, et. al. and are now being added to our tool kit. [16]).

3.1 Reflection tools

Reflection tools were originally suggested by Lesh, Hamilton and their colleagues. Following

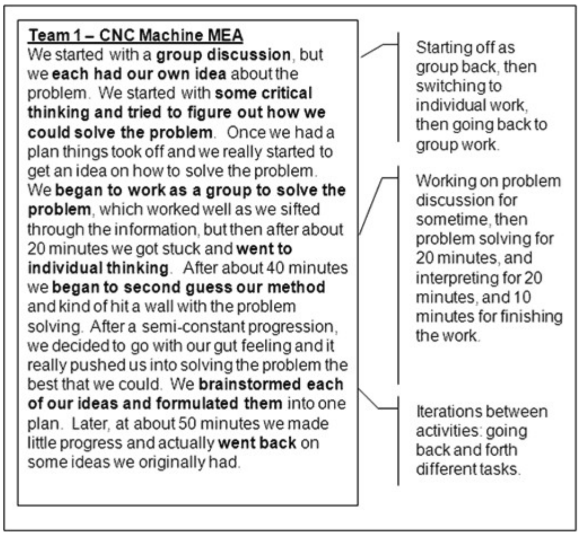


Fig. 1. Examples of Team Problem Solving Analyzed using Reflection Tools.

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 various roles, strategies, and levels and types of engagement [21]. Reflection tools enable students to better develop their conceptual frameworks for thinking about learning and problem-solving by requiring them to reflect on aspects of the exercise or process just completed.

We have used surveys as reflections tools. We recently moved from paper to digital surveys to provide ease of data classification and collection. An example reflection survey is found in APPENDIX B. When implemented to assess the underlying problem solving process, reflection tools provide powerful information about three major identifiers of students' problem solving process:

- Whether or not students worked effectively as a team or relied primarily on a single individual,
- The extent that the team used an iterative problem solving approach, and
- The particular stages in the problem solving process, which the students focus on.

An example of the summary response from a reflection tool is given in Fig. 1.

3.2 Student reports

Student reports, i.e., the actual assigned MEA report (typically submitted in memorandum format to the 'client'), are another way to assess the success of MEA implementation. Their level of understanding of the targeted concepts, whether the team used them, and whether they used them correctly can be determined from the report. Indications of how concepts are incorrectly used include:

- Inappropriate background to understand the targeted concept
- Insufficient guidance to students about expectations
- Insufficient time to fully solve the problem (or students failing to allocate sufficient time and effort to properly solve the MEA)
- Poorly written report; (students failing to clearly communicate the use of concepts.

A successful report should clearly describe the general model developed for resolving the type of problem presented by the client as well as the team's specific solution to the given problem. Assumptions should be clearly stated. If an ethical dilemma is embedded, the report should also address it and provide an appropriate resolution, in addition to pointing out other issues that might affect the recommended solution.

3.3 PDA recordings

We have used PDAs to collect data on problem solving patterns. Here, each student on the team is given a PDA. At specific time intervals when solving the MEA students are asked to record their current task. To record the process, we utilize software enabling students to identify (1) the specific problem solving task being addressed, (2) the degree of progress at that point (not making progress, satisfactory, very good progress), and (3) whether the task is done as a group or individually. The PDAs were programmed to 'alert' every 10 minutes, at which point each student recorded the task, his/her progress and whether it was conducted by an individual or in a team setting. The number of data points collected using the PDA depended on the total time each student devoted to the project. Figure 2 provides an example of one student's problem solving pattern.

In Fig. 2, the vertical axis shows the general problem solving tasks, where non-productive tasks are shown below the timeline to indicate no progress at these instances. Triangles denote that the team is working on the task together; the squares indicate individual task work. The larger the triangle or square, the more engaged the student(s) is (are) and progressing for that particular task (and the project, in general).

PDAs have allowed us to capture not only the problem solving steps for each team member, but also the combined process followed by the team.

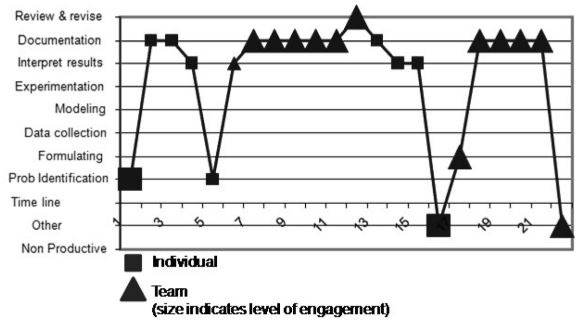


Fig. 2. An Example for PDA Output for one Student in a Group.

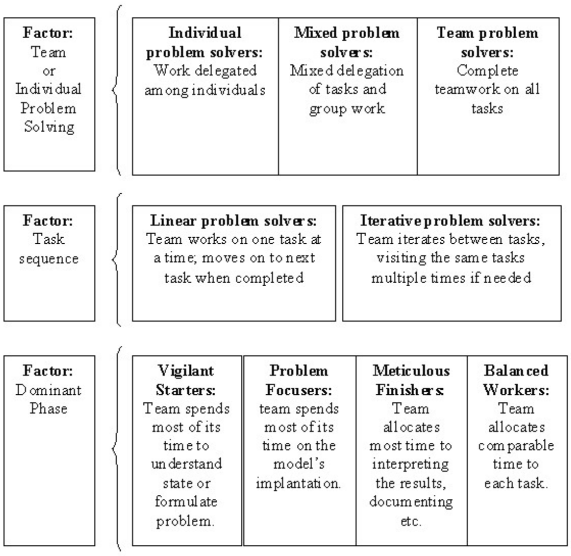


Fig. 3. MEA Solution Approaches.

Figure 3 presents a suggested summary of different team problem solving patterns gleaned from our PDA data. As shown, tasks might be divided up among individuals, or solved by the full team. The team may solve each task sequentially or iterate among tasks. The team may devote a disproportionate amount of time to a particular task (e.g., problem formulation or implementation), or divide its time equitably among tasks. PDAs allow the instructor to determine how the team is proceeding and therefore provide more informed feedback upon completion of the exercise.

3.4 Wikis

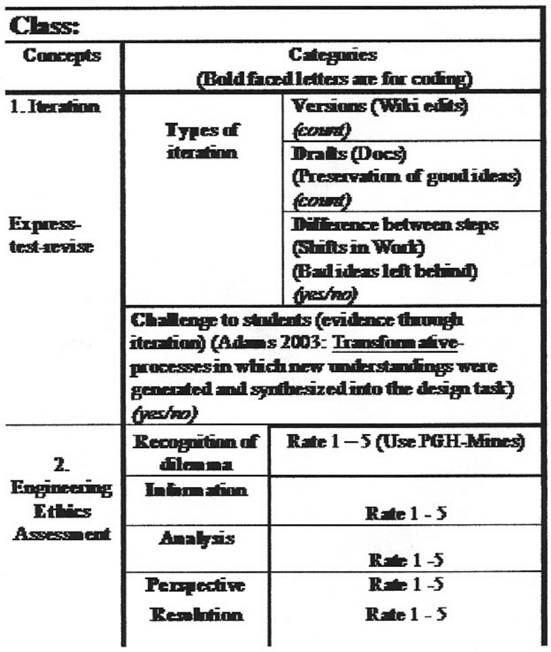
Wikis are especially useful for the teams that meet virtually (i.e., students are in different locations). When using Wikis, we asked students to upload their work in progress to a common website and converse on this site via the Wiki. In this manner we were able to observe (or recreate) the student work and final report as the group progressed, while viewing their text/chat conversations related to the MEA. This enabled a determination of how the students divided up tasks and worked on various aspects of the MEA. It also enabled us to see the various solution approaches attempted, their discussions concerning these approaches, and how the team traversed the problem solving process.

3.5 Test questions

Following the submission of the MEA and the instructor's feedback to the students, follow-up exam questions were then asked to ascertain the extent that the concepts were learned. Using well-crafted questions, the instructor determines the extent that the students had mastered the concept, and if misconceptions remain. Note that this will not enable the instructor to determine the extent that the MEA process was helpful, but only if the goal was achieved.

To assess the students' overall performance on the MEA, we developed an evaluation rubric based on four of the six MEA constructs: (1) Generalizability, (2) Self Assessment/Testing, (3) Model Documentation, and (4) Effective Prototype. Supporting elements have been delineated together with expectations for each solution-related principle. For example, for Effective Prototype, we have expanded the principle to include refinement and elegance of the solution. Each dimension is graded on a five-point scale, indicating the degree to which the solution achieves or executes the principle. The scores across the four dimensions can be averaged to obtain an overall score. Specifically:

- *Generalizability*: Assesses the degree to which the model is a working solution for the particular problem and future similar cases. Is the model robust, and can it be easily 'handed over' to others to apply in similar situations?
- *Self-Assessment/Testing*: Assesses the extent to which the solution has been tested and reflects thought and procedural revision. Have nuances or special conditions in the data or problem been uncovered and accounted for in the procedure?
- *Model Documentation*: Evaluates the level of detail and explicitness in the written procedure. Clarity of expression, correct grammar, and ease of reading are also assessed. Have the assumptions that were made been clearly stated? Has all information specifically requested by the client been included?
- *Effective Prototype*: Measures the refinement and elegance of the solution procedure. Is the procedure based on thorough application of engineering concepts and principles? Have



Class:

Concepts	Categories (Bold faced letters are for coding)	
1. Iteration	Types of iteration	Versions (Wiki edits) *(count)*
		Drafts (Docs) (Preservation of good ideas) *(count)*
Express-test-revise		Difference between steps (Shifts in Work) (Bad ideas left behind) *(yes/no)*
	Challenge to students (evidence through iteration) (Adams 2003: Transformative-processes in which new understandings were generated and synthesized into the design task) *(yes/no)*	
2. Engineering Ethics Assessment	Recognition of dilemma	Rate 1 – 5 (Use PGH-Mines)
	Information	Rate 1 - 5
	Analysis	Rate 1 -5
	Perspective	Rate 1 -5
	Resolution	Rate 1 - 5

Fig. 4. Assessment Rubric Screenshot.

appropriate engineering ideas been used? Is the solution accurate and of high quality?

A score of a '1' on any given dimension indicates that the principle was not achieved or executed in the solution. A score of '2' indicates some, but insufficient, achievement or execution. A '3' indicates sufficient, or minimum, level of achievement and satisfaction of the base requirements. A score of a '4' indicates that the solution embodies the principle for the most part and that the solution has gone beyond the requirements; the team has achieved more than expected and has generally done a good job. In order to achieve a '5' on a given dimension, the principle must be executed in an outstanding manner as delineated in the rubric. The ethics component are scored using the Pittsburgh-Mines Ethics Assessment Rubric (P-MEAR) previously developed and validated [22]. Figure 4 shows a partial view of our rubric scoring sheet.

4. USE OF MEAS AS TEACHING TOOLS

In this section, we describe the factors that were found to play an important role in implementing MEAs successfully in engineering classrooms. We discuss (1) the factors that are crucial in implementing MEAs and (2) how adding an ethical reasoning domain to an MEA can increase its effectiveness as a teaching tool.

4.1 Contingencies to Successfully Implementing MEAs as Teaching Tools

We have learned from our experiments that MEA implementation must be a carefully planned process that follows several important steps. We list these factors and their impact on MEA implementation particular to the upper-level engineering education context next. See Fig. 5 for a summary representation of these contingencies that impact MEA implementation success. We have determined these factors by carefully reviewing the artifacts from our experiments as described above. Of particular value has been data obtained from the reflection tools, MEA reports, and combining the individual PDA results for each team and comparing that to the first two data sets. Clearly, an important determinant of the success of an MEA implementation was whether the students used the targeted concepts appropriately when solving the MEA. We also reviewed post experiment student and instructor feedback. We analyzed the differences between those experiments for which favorable results (improved conceptual learning) were achieved and those in which the results were less than favorable. Where a significant portion of the student teams missed the targeted concept (which happened in several experiments), or used the appropriate concept but in the wrong manner, the implementation was considered to be unsuccessful, although such instances do present the instructor with an important teaching opportunity if appropriate feedback is provided to the students in an expeditious manner.

Certainly there will be additional factors that will be added to this list, particularly as we continue to extend the MEA construct to larger, more complex problems. However, the results reported here are based on data obtained from a relatively large number of students and instructors. Further, we have used pairs of trained coders to review the data, ensuring that they obtain a high degree of consistency before finalizing their scores.

4.1.1 Embedded MEA concepts and courses

The embedded concepts are a key factor in designing an MEA. Our MEAs have targeted measures of central tendency, the central limit theorem, hypothesis testing, design of experiments, quality control, supply chain, multi-criteria decision making, and economic analysis. Clearly, the success of the MEA may vary based on the difficulty in recognizing and understanding the embedded concept. More advanced engineering concepts require students to have the proper background receive appropriate guidance through the implementation process.

The course in which the MEA is used is another complicating factor. We have introduced and tested MEAs in introductory and intermediate engineering statistics, supply chain, quality control, decision analysis, operations research, human factors and engineering sustainability courses. For certain courses where students typically solve textbook problems, (e.g., statistics and quality control), we found very positive student reactions to the MEAs. In particular, after the Quality Control MEA implementation, a follow-up reflection survey found that 90% of the students stated that they enjoyed working on the MEA better than the textbook examples.

4.1.2 MEA's role in conceptual understanding

We have noted that MEAs can play three different roles in learning engineering concepts: *integrator*, *reinforce* or *discoverer*. That is, the MEA can be developed and: (1) introduced in a

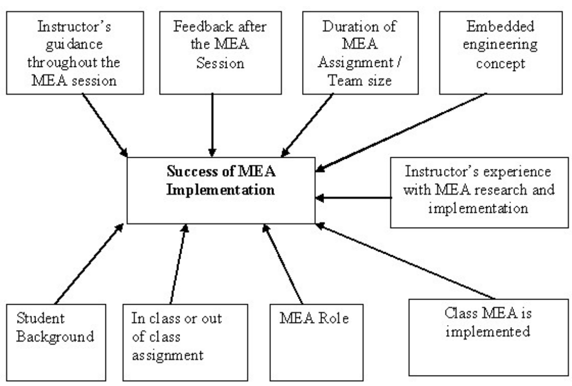


Fig. 5. Contingencies on MEA Implementation.

manner that requires students to integrate concepts from earlier courses; (2) implemented in a manner so that a concept recently introduced will be reinforced; or (3) implemented so that the students will discover a new concept (with some instructor guidance), as well as combinations of these three roles. We have learned that the success of a given MEA can vary based on its particular role. For example, the CNC MEA (see Appendix A) has been implemented twice in a statistics course from both a *reinforcer* role (i.e., assignment given after the concept—hypothesis testing—was introduced in lecture) and a *discoverer* role (i.e., where the concept hadn't been introduced). Under this latter scenario, the effectiveness of the MEA was significantly reduced; in fact, none of the student teams correctly applied the targeted concept in their solutions! (This latter experiment also highlighted the need for the instructor to provide guided discovery so that such situations do not occur.)

4.1.3 Team size and number

The size of the team addressing the MEA can also have an impact on its success. We have followed Ahn's and Leavitt's suggestions of three to four person teams, and have observed no substantial difficulties [10]. In addition, the number of teams in a classroom is another factor for a successful MEA implementation. As the number of teams increase, the effort or guidance that the instructor can provide per team is decreased proportionally; negatively impacting MEA success.

4.1.4 Instructor's experience (past involvement) with MEAs

The instructor's past experience and involvement (with MEAs) was not initially predicted to be as important a factor in the MEA implementation success. However, when investigating the factors that might have impacted student learning, student feedback indicated both higher involvement and satisfaction with the activity when the instructor provided sufficient guidance. Where instructors provided insufficient feedback, further examination revealed that these instructors were not sufficiently familiar with the MEA construct and the ways it could be used in the classroom; in some cases, too much was left to a teaching assistant, who also was not sufficiently prepared to administer an MEA scenario. Thus, instructor experience is included as one of the significant contributors of MEA implementation success.

We have been able to divide the faculty who has introduced MEAs as part of our experiments into three categories: (1) familiar with the MEA construct, prior research and implementation, (2) familiar only with MEA implementations, and (3) no familiarity with MEAs.

To reiterate, MEA implementations were most successful when the instructor was both familiar with prior MEA research and had been trained on how to implement MEAs. It became apparent that proper training of how to implement an MEA was one of the most significant factors in its success. When the instructor was fully aware of the learning benefits that can result from an MEA, he/she typically put more effort into its planning and execution.

4.1.5 Instructor guidance

As noted above, even when faculty had experience with MEA implementations, but did not fully appreciate its benefits, we have noticed that the guidance given to students during the execution and feedback phases was at best insufficient. If the instructor had no training on MEA implementation, the MEA was much less likely to produce its targeted results. Hence, we have concluded that unless the instructor had been formally trained on purpose, philosophy, and implementation of an MEA, the results may be substantially less than desired.

Stated another way, an important factor in MEA success is the level of guidance provided during the solution process. Our MEA implementations have been either in class or recitation exercises or solved at home, and occasionally a combination of both. We have learned that the success of the MEA depends on the guidance given students while working on the MEA. In-class exercises enable the instructor to quickly identify when and where students make mistakes; the instructor can then help students reflect and redirect by clearing up misunderstandings. However, the instructor must be careful not to give too much guidance. As noted, we have seen a '*reinforcer*' MEA implemented in which the instructor did not interact with the students during the solution process. As a result, all of the teams missed the key concept receiving no direction that might have provided the necessary hints to abandon their non-productive approaches. In short, it is important that the instructor monitors each team's progress, and provides some direction or hints when the team is floundering or missing the point. This is a potential risk when giving the MEA as an out-of-class activity. As we develop more complex MEAs (exercises that may require two or three weeks to resolve), the instructor will need to periodically utilize mechanisms for monitoring the solution process, such as requiring intermediate reports on the developing models and reflection tools (that will be discussed later).

4.1.6 Time allotted for solution

Our experiments also varied in time students were given to complete the exercise. Time is often a function of exercise complexity and whether or not the MEA was assigned to be solved within the class or at home. We observed that the solutions (models and documentation) for MEAs solved outside the classroom had more depth, since students had access to a wider range of information and no time restrictions.

Both doing the activity in-class and out-of-class have benefits and potential risks. In the former, students are able to obtain guidance from the instructor on how to carry out certain steps in the MEA solution (i.e., guided discovery), but may not have sufficient time to appropriately complete the assignment. In the latter case, students can be provided with as much time as they need to carry out the tasks to complete the MEA, but may not receive appropriate guidance, and hence, continue in the wrong direction. Clearly, it is important to balance the benefits of each task. To achieve this, we suggest that MEAs start in class, with students working on the exercise for sufficient time so that the instructor is comfortable that each team understands the problem and is beginning to address the concepts embedded in the MEA. After that, the teams could be allowed to continue to work on the MEA outside of the classroom, giving them a chance to better deal with broader subjects covered in the MEA.

4.1.7 Feedback

Hattie and Timperley [23] define feedback as 'the information provided by an agent (e.g., teacher, peer, book, parent, self, experience) regarding aspects of one's performance or understanding'. Feedback builds students' self-efficacy as learners and writers [24], and is essential for assessment processes since it (1) identifies strengths, (2) suggests strategies for improvement, (3) reflects a view of the teacher student relationship [25]. Moore and Smith [26] suggest that feedback is most useful when instructor enters into a dialogue with students about the ideas they have expressed.

Providing feedback to students better ensures that they are likely to reach a desired level of expected understanding when the activity is completed. We have provided feedback to students in oral and written forms. Feedback that points out common mistakes and expected solution methods provides students with a perspective to solve similar problems. The effectiveness (or ineffectiveness) of feedback was clearly seen in the students' reflection surveys. Where feedback was limited or not provided, concepts were not reinforced, and in too many instances students missed fully grasping and using the key concept.

One way to provide feedback is to use two part MEAs. The first part (typically done individually) serves to get the student thinking about the concept embedded in the MEA and the situation to be presented in the second part. The second part, which is the actual MEA, then is addressed by the full team. However, the first part needs to ensure that the students confront the concept. For example, in the 'Tire Reliability' MEA, students were asked questions that required them to conceptualize reliability, but did not ask them specifically to define it. As a result, in the second part of the exercise, the student teams, having to use the concept of reliability for the first time, were not clear as to its meaning.

4.2 Extending MEA concept to include the ethical reasoning domain

The use of context-based case studies provides ideal subject material for the development of modeling exercises. This is particularly true in the case of ethics-based models, which often require the synthesis of such intangible concepts as environmental justice, international policy, and resource conservation during solution. By adding an ethical reasoning domain, we created ethical MEAs or E-MEAs [9]. Our objective was 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, we were able to better understand the various strategies student teams use to resolve complex ethical dilemmas. Table 3 provides a description of the ethical issues embedded to date in our MEAs.

An E-MEA should be created for a specific purpose, typically as a learning exercise to intro-

Table 3. Illustrative Ethical Issues that are embedded in MEAs Developed

SUV Rollover: Students were asked to address the sensitivity of the results they have just found. Specifically, what should they (the testing company) do with the results (that the carrier has asked them to keep confidential). That is, they must consider issues related to non-disclosure versus the safety of the public; at what point does public welfare trump non-disclosure?
CNC Machine Purchase: In second part of the MEA, students were asked to re-do their analysis in order to now show that the replacement is, in fact, better (assuming the team originally concluded that it was not), or provide more specific details about how it proved the replacement is better. That is, students were given the dilemma of whether to fudge data to please the boss or not.
Ethanol: Students were asked to address ethical issues of ethanol use and production.
Hazardous Materials: This E-MEA involves a decision with ethical implications concerning possible investment in countermeasures for reducing or preventing hazardous materials spills. The team must address unknown material costs and the values attached to accidents in which injuries and fatalities could occur.
Pilotless Airplane: This MEA involves a NASA sponsored student competition in which the entrants must design and test a 'pilotless plane.' The team must propose a method for dealing with potential rule violations related to using last year's designs; i.e., does the design have to be original? This MEA was used in an introductory engineering statistics course.
Trees: Part 1 of this MEA concerns possible removal of old growth trees along a road through a public forest to reduce traffic accidents. Part 2 ups the stacks by making the trees redwoods.

duce or reinforce one or more concepts. Steps to develop an E-MEA include determining:

- The conceptual issue(s) requiring engineering ethical reasoning that will be presented,
- Other fundamental concepts required for resolution,
- How the E-MEA will be used (e.g., within a lecture, a recitation exercise, or in a workshop.)

Once these steps are decided, a storyline must be developed that describes a realistic situation in which the concept(s) will be embedded. We have developed a number of our storylines from incidents in the news, as well as from personal experience, and the experience of colleagues in industry. After the storyline has been developed, the ethical dilemma can then be introduced. The dilemma may come from personal experience or adapted from a text or case. It should not be a 'black or white' issue, but rather lie in a 'gray area.' Its resolution might require a creative 'win-win' resolution. It should be written in a way that requires the student to carefully read the case in order to recognize it. We have learned to frame the case first, and then have the students address the dilemma once they have obtained their results.

Although we believe that adding an ethical dilemma into MEAs is a novel contribution to the engineering education research, we list it as a factor to elevate effectiveness of teaching in classroom and refer the interested readers to Shuman, Besterfield-Sacre and Yildirim [9] where we provide more detail.

5. MEAs AS MEDIA FOR ASSESSING ASPECTS OF LEARNING

We next illustrate how using the assessment tools given in section 3, the instructor can learn about the student problem solving process. Figure 6 gives the PDA results for the three members of a team addressing the Defibrillator Lead MEA. This MEA, which was based on a series of incidents with implantable defibrillator lead malfunctions, required student teams to estimate how many samples they would need to collect in order to detect if a batch of leads did not meet specifications. Since the calculated sample size was relatively small, the team would then have to determine if the central limit theorem would hold so that they could assume that the mean of the sampling distribution was approximately normally distributed. This MEA was designed to reinforce the primary concept (central limit theorem) while also requiring the student to discover how the sample size could be estimated in order to achieve a desired confidence limit. Note that the triangle indicates that the team was working together while the square indicates that the team member was working individually. Again, the size of the symbol indicates the level of engagement—from not very engaged (satisfied), to satisfied with their effort to very good progress.

Figure 6 suggests that students two and three were working closely together for over three hours (time steps are every 10 minutes), although for much of this time very little progress occurred, including the first hour which was devoted to problem formulation. Student one appears to have only participated for this first hour period and then dropped out, leaving his two partners to complete the assignment. We have taken the students' individual reflection statements and combined them to obtain a fuller picture of the solution process:

> The problem solving strategy our team used at the beginning was to derive our information from the text. We started by stating what we knew, but we were caught up in the fact that the distribution of the samples was uniform. However, we reached a point where the text did not help us, and on the contrary confused us. At 30 minutes we sorted out our confusion. At 50 minutes we were even more confident and were able to proceed more quickly. We were trying to

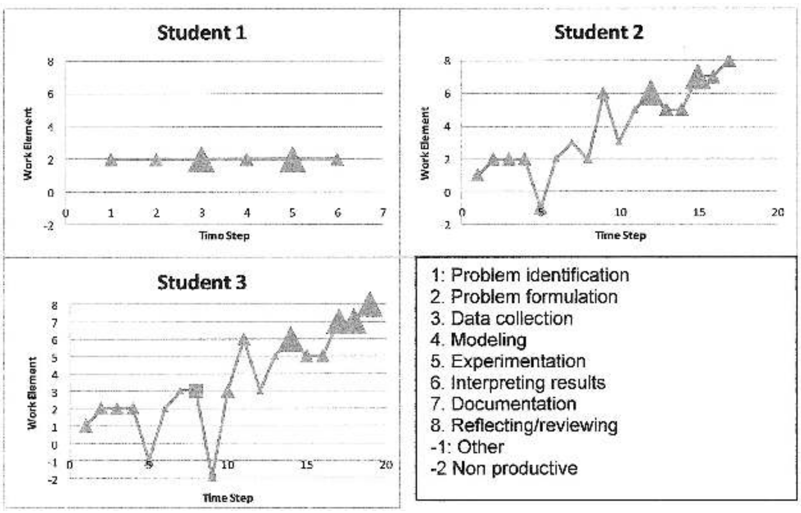


Fig. 6. Combined PDA and Reflection Data—Defibrillator Lead Example

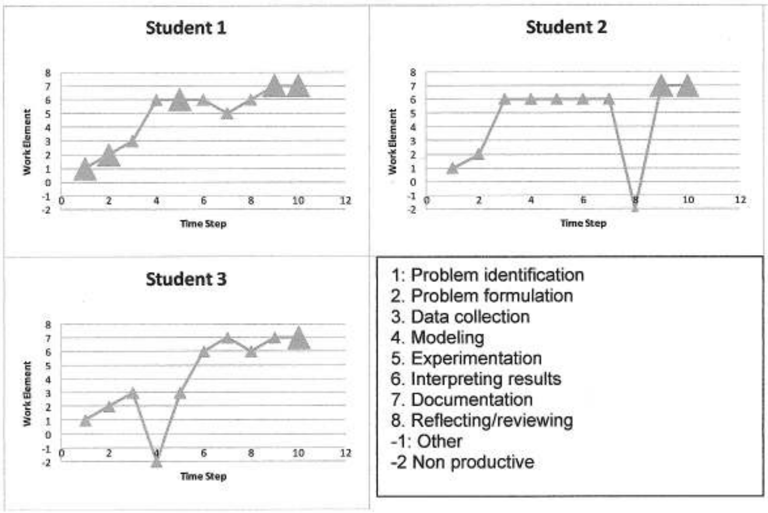


Fig. 7. Combined PDA and Reflection Data—CNC Machine Example

> figure out how to create confidence intervals on uniform distributions when we decided to research whether the means of samples [were] taken from a uniform distribution. When we found that this was true, we were able to use the information and statistics to construct intervals and proceed. For the whole problem, we continually questioned what we knew to make sure our reasoning was sound.

Combining Fig. 7 with the combined reflection statement provides the instructor with a clear picture— a team that struggled for the entire in-class portion of the MEA. Two of the team members then worked together outside of class and eventually came up with a solution. They were able to develop the confidence interval (needed to estimate sample size), but missed the key concept concerning the central limit theorem. This strongly suggests that the instructor should have reviewed the MEA in the context of the central limit theorem during the next class period.

A second example is given by Fig. 7. Here the students were solving the CNC Machine MEA. This was designed to reinforce the concept of hypothesis testing (two samples). It also contained an ethical dilemma—the plant manager was 'highly suggesting' that the teams select one particular machine, and, if necessary, manipulate the data to prove that point. The students' combined reflection statement provides insight into how they approached and resolved this MEA:

> We began by trying to standardize the data and use the z table. We started the project by attempting to perform a simple z-standard test to see if the data was acceptable. At 15 minutes we decided to use a confidence interval instead since the z-standard test didn't really answer the question. At 20 minutes we realized that was incorrect, we almost started over with the process. At 45 minutes we thought of setting up confidence intervals and we took this thought further and came closer to a final answer before realizing we were incorrect. At 50 minutes we again saw that the confidence interval wasn't the best way to answer the question and decided hypothesis testing was the best solution strategy to follow. After more thinking and brainstorming we figured out that we should use hypothesis testing and we finished out the problem that way. These were our three main strategies.

It is interesting to note that while the team members felt they were working together, student two spent much of the time interpreting the results (analyzing the data) and student three was not fully engaged until the end of the project, and even spent part of the class time in a non-productive mode. The combined reflection does show that the team undertook a process of reviewing and revising their progress, as is required by a well-designed MEA.

6. SUMMARY AND CONCLUSIONS AND FOR ENGINEERING EDUCATORS

We have addressed the educational benefits of MEAs, relative to learning important engineering concepts and in evaluating students' problem solving and engineering ethical reasoning abilities. Further, we have provided several tools and methods by which MEAs and problem solving can be assessed. We further discuss the factors for success in the classroom for MEA implementation.

Our experience points to several factors that impact the success of MEA implementation. An important factor influencing MEA success is the guidance from the instructor throughout MEA implementation. Corrective guidance can make sure that students are properly focused addressing the correct problem and targeted concept, especially where the solution time is constrained. Such guidance is positively correlated with instructor's training on MEA implementation. If the instructor appreciates the potential benefits that the students can 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 are limited.

Feedback after completion of the MEA plays an important role in students' understanding of 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 to achieve the desired result.

Our research and experience strongly suggests that MEAs can help educators assess their students' problem solving process through the use of PDAs, Wikis, reflection tools, as well as the actual student reports and well-designed examination questions. Using such tools allows educators to gain insight into the team's group processes, problem solving processes, degree of involvement, and their process of iterating through the exercise. Further, such information can provide engineering educators information about the quality of student learning.

This study contributes to engineering and engineering education fields in several ways. As engineering schools focus on providing realistic learning environments for their students, improved learning and assessment tools are needed. We propose that MEAs can improve student learning. Further, we have suggested how educators might use these tools to better understand team processes.

One important issue needs to be resolved: the improvement of student learning. Specifically, although we have documented some means by which we can assess problem solving and conceptual understanding, research is needed to understand how MEAs might be used to improve students' problem solving abilities and conceptual understanding of critical engineering concepts. In addition, the effectiveness of MEAs should be compared to other learning tools and methodologies. (For example, we view MEAs as a complement to problem based learning and believe that the potential benefits are comparable.) As our work with MEAs continues we intend to address these outstanding questions.

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REFERENCES

1. R. Lesh, M. Hoover, B. Hole, A. Kelly and T. Post, Principles for developing thought-revealing activities for students and teachers. *The Handbook of Research Design in Mathematics and Science Education*, Kelly, A. and Lesh, R. (eds), Lawrence Erlbaum Associates, Mahwah New Jersey, 2000, pp. 591–646.
2. H. Diefes-Dux, T. Moore, J. Zawojewski, P. K. Imbrie and D. Follman, *A Framework for Posing Open-Ended Engineering Problems: Model-Eliciting Activities*. Frontiers in Education Conference, Savannah, Georgia, October 2004, pp. 20–23.
3. H. Diefes-Dux, D. Follman, P. K. Imbrie, J. Zawojewski, B. Capobianco and M. Hjalmarson, *Model eliciting activities: an in-class approach to improving interest and persistence of women in engineering.* Proceedings of the American Society for Engineering Education , Annual Conference & Exposition, Salt Lake City, Utah, June, 2004.
4. M. Hjalmarson, *Engineering as bridge for undergraduate and k-12 curriculum*. 9th Annual Conference on Research in Undergraduate, Mathematics Education. Piscataway, NJ, 2006.
5. R. Lesh, The development of representational abilities in middle school mathematics: the development of student's representations during model eliciting activities. In: I.E. Sigel (ed.), *Representations and student learning*, Lawrence Erlbaum, Mahwah, NJ, 1998.
6. R. Lesh, Research design in mathematics education: focusing on design experiments in L. English (ed.), *International Handbook of Research Design in Mathematics Education*, Lawrence Erlbaum, Mahwah, NJ, 2002.
7. R. Lesh and H. Doerr, Foundations of a models and modelling perspective on mathematics teaching, learning and problem solving, in R. Lesh and H. Doerr (eds), *Beyond constructivism: A models and modeling perspectives on mathematics problem solving, learning and teaching*, Lawrence Earlbaum, Mahwah, NJ, 2003.
8. R. Lesh and A. Kelly, Teachers' evolving conceptions of one-to-one tutoring: a three-tiered teaching experiment. *J. for Research in Mathematics Education*, **28**(4), 1997, pp. 398–430.
9. L. Shuman, M. Besterfield-Sacre, T. P. Yildirim, *E-MEAs: Introducing an ethical component to model eliciting activities*. ASEE Conference Proceedings, ASEE Annual Conference, June, 2009.
10. C. Ahn and D. Leavitt, Implementation strategies for Model Eliciting Activities: A teachers guide, accessed 4/27/2009, http://site.educ.indiana.edu/Portals/161/Public/Ahn%20&%20Leavitt.pdf, 2009.
11. S. A. Chamberlin and S. M. Moon, Model-Eliciting Activities as a tool to develop and identify creatively gifted mathematicians. *J. of Secondary Gifted Education*, **17**(1), 2005, pp. 37–47.
12. T. Moore, H. Diefes-Dux, *Developing model-eliciting activities for undergraduate students based on advanced engineering content*. 34th ASEE/IEEE Frontiers in Education Conference, Savannah, Georgia, October, 2004.
13. J. E. Hallagan, The case of Bruce: a teacher's model of his students' algebraic thinking about equivalent expressions. *Mathematics Education Research Journal*, **18**(1), 2006, pp. 103–123.

14. S. E. Berry, *An investigation of a team of teachers' shared interpretations of the teacher's role in supporting and enhancing group functioning*. University of Indiana Electronic Dissertation, 2007.
15. M. A Hjalmarson and H. Diefes-Dux, Teacher as designer: a framework for teacher analysis of mathematical model-eliciting activities. *Interdisciplinary J. of Problem-based Learning*, **2**(1), 2008, Article 5.
16. B. P. Self, R. L. Miller, A. Kean, T. J. Moore, T. Ogletree and F. Schreiber, *Important student misconceptions in mechanics and thermal science: identification using model-eliciting activities*, 38th Annual Frontiers in Education Conference, Saratoga Springs, NY, October, 2008.
17. A. Teran, *Use of Model Eliciting Activities: Lessons Learned*, Industrial Engineering Research Conference, Miami, FL, May 30–June 3, 2009.
18. T. Moore, H. Diefes-Dux and P. K. Imbrie, How team effectiveness impacts the quality of solutions to open-ended problems. 1st International Conference on Research in Engineering Education, Honolulu, HI, June, 2007.
19. M. Dark and C. Manigault, Information assurance model-eliciting activities for diverse learners. CERIAS Tech Report 2007–92 by Center for Education and Research Information Assurance and Security Purdue University, West Lafayette, IN, 2007.
20. J. G. Greeno, The structure of memory and the process of solving problems. In: R. Solso (ed.), *Contemporary issues in cognitive psychology*. The Loyola Symposium. Washington, DC: Winston, (1973).
21. E. Hamilton, R. Lesh, F. Lester and C. Yoon, The use of reflection tools to build personal models of problem-solving. In: R. Lesh, E. Hamilton, J. Kaput, J. (eds.), *Models & Modeling as Foundations for the Future in Mathematics Education*, Lawrence Earlbaum Associates, NJ, Inc. (in press).
22. Shuman, LJ, B. Olds, M. Besterfield-Sacre, H. Wolfe, M. Sindelar, R. Miller and R. Pinkus, *Using Rubrics to Assess Students' Ability Resolve Ethical Dilemmas*, Proceedings of the 2005 Industrial Engineering Research Conference, Atlanta, GA, May 2005.
23. J. Hattie and H. Temperley, The power of feedback. *Review of Educational Research*, **77**(1), 2007, pp. 81–112.
24. T. J. Crooks, The impact of classroom evaluation practices on students. *Review of Educational Research*, **58**, 1988, pp. 438–481.
25. J. Orrell, Feedback on learning achievement: rhetoric and reality. *Teaching in Higher Education*, **11**(4), 2006, pp. 441–456.
26. B. S. Moore and R. Smith, R. Curriculum leadership and assessment and reporting, Adelaide, South Australian College of Advanced Education, 1989.**Figure 1.** Examples of Team Problem Solving Analyzed using Reflection Tools

APPENDIX A. University of Pittsburgh MEAs

MEA	Skills Targeted	Description
		Probability, Statistics and Data Analysis
SUV Rollover	• An experimental design with a cost constraint • Statistical analysis using ANOVA	A major insurance carrier has noticed a relatively large number of claims involving SUVs that have rolled over after tire tread has separated. The carrier contacts an engineering testing firm to design a series of potentially destructive tests on a combination of vehicles and tires to identify a potential problem with either a vehicle or tire model in various environmental conditions. Students are given costs for conducting the experiment, a budget, and are then asked to provide a design for the experiment—i.e., identify each combination of vehicle and tire to test. A simulator provides each team with a unique set of test results based on their design in order to conduct a thorough statistical analysis. In their final report the team must address what should they (i.e., the testing company) do with the results (that the carrier has asked to keep confidential). They must consider at what point does public welfare trump non-disclosure?
CNC Machine Purchase	• Hypothesis testing to determine the whether a CNC machine investment is justifiable • Concepts of mean and variance • Economic analysis	In Part 1, a manufacturing plant has an opportunity to replace an older CNC machine with a newer model. The plant manager views this as a significant opportunity, especially since the purchase would not come from his budget. He requests that the team prove that the new machine will outperform the current one as measured by unit production time, cost, and quality, in order to build the best case for purchase. In Part 2, the team is asked to re-do its analysis in order to show that the replacement is, in fact, better (if the team had concluded that it was not), or provide more specific details about proving that the replacement is better.
Hazardous Materials	• Categorical data analysis	The team is asked to create a procedure for deciding whether a small, rural Pennsylvania county with a major highway running through it and faced with a series of hazard material spills, should invest \$2 million in countermeasures that should lead to a reduction in such accidents. The team must address unknown material costs and the values attached to accidents in which injuries and fatalities could occur. The students are given a large accident data base, although some data are missing.

MEA	Skills Targeted	Description
Defibrillator Lead MEA	• Central Limit Theorem	This MEA is based on a series of incidents with implantable defibrillator lead malfunctions, required student teams to estimate how many samples they would need to collect in order to detect if a batch of leads did not meet specifications. Since the calculated sample size was relatively small, the team would then have to determine if the central limit theorem would hold so that they could assume that the mean of the sampling distribution was approximately normally distributed.
		Decision Analysis
Dam Construction	• Multi-criteria decision making	A dam will be constructed in the South Eastern Anatolia. The Turkish Government, for economic reasons, must reduce the dam's budget. Alternatives include making the dam less safe by decreasing its height, eliminating some material, or lengthening the project. Ethical issues include the dam's impact on its neighbors; harm to local population; having a historical region go under water.
		Supply Chain
Ethanol Production	Determining whether a 'green,' socially-conscious agricultural company should become an ethanol producer or remain solely in grain production for food and livestock.	In Part 1, the team is asked to create a procedure for determining whether a 'green,' socially-conscious Midwest agricultural company should become an ethanol producer or remain solely in grain production for food and livestock. The team also must evaluate various sites for an ethanol production facility, which could be fueled by any one of several feed stocks. In Part 2, the company has decided to move forward and locate its ethanol production facility in Ames, Iowa. The producer will need one or more distribution points for its ethanol. Should it pursue a centralized or de-centralized distribution scheme, given a set of potential distribution center locations? The team must also address issues involving ethanol use and production.
		Engineering Ethics
Trees	Recognizing and resolving ethical dilemma Reducing auto accidents vs. preserving old growth trees	Part 1 concerns possible removal of old growth trees along a road through a public forest. There have been a series of accidents although many may be due to excessive speed. The county's department of transportation has decided to remove the trees, but a citizen environmental group is protesting. The team is asked to resolve the dispute. Part 2 involves a similar scenario reset in a California State Park that contains redwood trees. It is based on a case initially developed by Harris, Pritchard and Rabins.
		Global Decision Making
Outsourcing Gown Manufacturing	Deciding whether or not to outsource Deciding where to outsource	A company is planning to outsource its gown manufacturing to one of three countries and will also sell to that country. Students must determine adjustments to the gowns according to the anthropometry measures of females in the selected country. Issues of the expected use of child labor and preventing the selected manufacturers from selling its designs to competitors.
		Quality Control
Quality Process Control	Understanding how to dynamically follow a quality control process Obtaining a manufacturing process that is capable	A car parts manufacturer is about to sign a contract with a Japanese car maker t well known for quality. First, the parts manufacturer needs to make sure that it can produce parts within the desired quality level. The manufacturer asks a consulting firm to provide a report that documents that the parts t are of the desired quality. In part 1 students are introduced to the problem and requirements. They are given data to measure whether the process manufactures parts are of the required quality using quality control charts. In the second part, students are provided with longitudinal data showing changes in the process over time. In the third part, students are asked to provide an overall report about whether they think the process is indeed in control, and how to measure it in the future. They must link their recommendations to quality control procedures.
		Sustainability
Windmills	Deciding where to build a windmill considering a long term planning Forecasting	A company is considering a windmill farm investment in one of several regions. The team must pick the most economical location, considering long term demand for electricity and price estimates. In addition, the team must consider locating the farm in the ocean versos on land.

APPENDIX B. Example Reflection Sheet

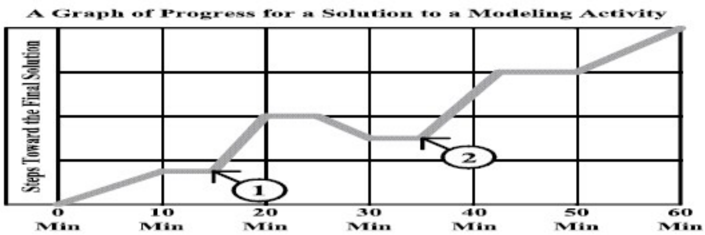
Name____________________________

Reflections Questions

Please answer all questions as best you can and turn this in to the Digital Dropbox on your Courseweb. This is to be completed individually by each person.

Due: Friday, October 24 by 5:00 PM.

1. Draw a simple graph with time on the x-axis and percent progress on the y-axis. Mark two points on the graph (early and later) where significant changes in your thinking occurred. See below for an example.



2. With respect to your graph, describe the problem solving strategy your team used at the start of the assignment and then how it changed t each of the two points. Were there any other strategy changes?
3. For each of the two critical transition points that you marked in your graph, did you change: (a) from being bored to being highly engaged? (b) from feeling lost to feeling in control of the situation? (c) from feeling frustrated or overwhelmed to feeling like things are going smoothly? (d) from being distracted by things unrelated to the problem to feeling well focused?
4. If any of the preceding changes occurred, did your ways of thinking about the problem also change? Did you recognize the importance of some new relationships, or patterns, or mathematical models?
5. What concepts from science, math or engineering did you use in order to obtain the solution? Do you feel that this exercised enabled you to better understand any of these concepts? (Explain).
5. What alternatives did you discuss in resolving the issue: 'Please do not share these results with anyone else either inside or outside of SAFETY+.'?

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