# AC 2012-4220: MODELS AND MODELING IN UPPER DIVISION CLASSROOMS: IMPACTING CONCEPTUAL UNDERSTANDING AND THE PROFESSIONAL SKILLS

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# Models and Modeling in Upper Division Classrooms: Impacting Conceptual Understanding and the Professional Skills

Following their development by K12 mathematics educators, Model Eliciting Activities (MEAs) were first introduced into freshmen engineering. As part of a large multi-institution research grant, the MEA construct migrated to upper division engineering courses, precisely: chemical, civil, electrical, industrial, and mechanical engineering fields. During this migration, the MEA construct was expanded to introduce laboratory, conceptual and ethical components. In doing so, students were forced to confront and repair certain misconceptions acquired at earlier stages of their education, to utilize laboratory experiments to gather additional data, and to recognize and then resolve ethical issues.

Here we introduce several issues when implementing MEAs in upper division level classes by providing two case studies. These issues are circulated around the theme of engineering learning systems, and in particular to the professional or "soft" skills. Specifically, the following insights are provided across two MEAs from two different disciplines and engineering schools:

1. The instructional culture challenges involving MEAs implementation in the classroom;
2. How faculty's personal epistemology for teaching their course was enhanced or changed with the introduction of MEAs; and
3. How faculty have help other faculty to migrate MEAs to others at their institution.

## Introduction

Model Eliciting Activities (MEAs) use open-ended case studies to simulate authentic, real-world problems that student-teams seek to solve As the name implies, MEAs are designed to allow students to express, compare, test and revise conceptual "models" that might be useful in problem solving. They were initially developed as a mechanism for observing the development of student problem-solving competencies and the growth of mathematical cognition, it became increasingly clear that well-designed MEAs provide both instructors and researchers with tools to engage learners in productive mathematical thinking and model construction.

A Model Eliciting Activity (MEA) presents student teams with a thought-revealing, model-eliciting[1], open-ended, real-world, client-driven problem. Originally developed by mathematics educators, MEAs were first introduced to engineering students, primarily at the freshman level, ten years ago [2-5]. These early researchers believed that well-constructed MEAs could lead to improved conceptual learning and problem solving skills. Since then, MEAs have found their way into engineering classrooms at various levels. Despite the demonstrated success of MEAs in the pre-college mathematics education literature, their promise and benefits in engineering education are just beginning to be fully investigated and documented. As part of a seven university NSF funded project, a comprehensive effort has been engaged to elucidate the positives and limitations of MEA implementation in undergraduate engineering curricula. The premise of this work is that, in addition to their potential for improving conceptual learning and problem solving, MEAs offer engineering educators a mechanism for assessing these skills. However, successful implementation of engineering MEAs requires that careful and methodical construction and implementation by an informed instructor [6-9].

In addition to the broad project goal outlined above, this work has attempted to extend MEA implementation and complementary student and faculty assessments across our partner institutions; broaden the library of usable MEAs to different engineering disciplines; and extend the MEA approach to identifying and repairing misconceptions, using laboratory experiments as an integrated component, and introducing an ethical decision-making dimension.

In this paper, we introduce several issues when implementing MEAs in upper division level classes. These issues are circulated around the theme of engineering learning systems, and in particular to the professional or "soft" skills. Specifically, the following insights are provided through two case studies:

1. The instructional culture challenges involving MEAs implementation in the classroom;
2. How faculty's personal epistemology for teaching their course was enhanced or changed with the introduction of MEAs; and
3. How faculty have help other faculty to migrate MEAs to others at their institution.

In doing so, we provide a short overview of the MEA, followed by the instructor's personal insights to these issues.

**MEAs versus Problem Based Learning (PBL)**

In discussing MEAs, a question that often arises is "how are they different from PBL"? Part of the challenge in addressing this is that there is not one commonly accepted definition of PBL. Zawojewski has highlighted some of the perceived differences, noting that in PBL a "problem" is defined differently depending on who the problem solver is, and if the goal is to find the solution or if it is about the process. "Model-eliciting tasks, on the other hand, require that the modeler interpret the information in the task and interpret the required outcomes (with respect to an articulated function) for the purpose of mathematically modeling the situation". She explains that "In problem solving, the 'givens' and 'goals' are considered static and unchanging, whereas in modeling the 'givens' and goals' are dynamic, constantly under reinterpretation, and able to be reformulated and modified depending on the level and type of specification made concerning the function the model is to serve, and on the assumptions, conditions, and limitations the problem solver brings to the process [10,11].

MEAs also generally differ from textbook problems in the length of time required for resolution, the access to different information resources, number of individuals involved in the problem-solving process, and the type of documentation required in resolving a problem. A typical MEA is a team exercise; this (sometime multidisciplinary) teamwork practice also reinforces the students' learning. The differences in MEAs and PBL are also in the implementation and application in the educational system. PBL is often course-wide or curriculum wide and used before a concept is introduced, thus requiring the student to become a self-learner with the guidance from a tutor or instructor. MEAs can often be more easily integrated into a traditional course structure, can be used in a variety of roles (e.g., integrator, discover or reinforce as noted above) and the problems have more structure than PBL (which lowers the threshold for both new instructors and students).

As noted above, this work has focused on the development of a series of MEAs ready for use in various upper level engineering classrooms. These new MEAs have been specifically designed to introduce special MEA features that require identification of common student misconceptions, present students with ethical dilemmas (to be recognized and resolved) they might confront in the field, and incorporate a laboratory component enabling students to collect their own data as part of the solution process when resolving the posed problem.

**Case 1- Industrial Engineering**

As the first example, Figures 1 and 2 depict a MEA used in a sophomore/junior level engineering statistics course. Students are provided with a memorandum asking them to serve as a third party consulting group to investigate the possible correlation between tire manufacturers and different vehicle models. As indicated by the MEA, there have been a series of rollovers that now warrant investigation. The students are challenged to provide a cost effective experimental design to address the needs of the client (see Figure 1). In turn, given the teams' various designs, data was generated for each team to analyze and make final recommendations in response to a second memorandum (see Figure 2). A simulator was developed for the various vehicle/tire distributions to produce individualized data within the specifications of the teams' experimental design requests. This allowed for each team's data to be unique regardless if two or more teams provided similar experimental designs.

<u>Challenges implementing the MEA in the classroom</u>:
Implementing a open-ended problem such as this particular MEA were not difficult for the instructor as the instructor typically assigns a project in which teams of students create a hypothesis and an experiment of their choice, followed by data collection, analysis and

**To:** Richards Automotive Consulting (RAC)
**From:** CountryWide Insurance Company (CWI)
**Re:** Tire accident analysis
**Date:** 1/28/08

Dear Mr. Richards:

We are requesting your expert opinion as automotive consultants and professional engineers in regards to a serious situation that our company as recognized. As you know, CountryWide is one of the largest automobile insurance carriers in the U.S. Over the past several years we have received claims from more than 100 of our customers who have experienced car rollover accidents due to tire separation. Too many of these claims have resulted in serious injury and a few have also resulted in death. Many of these claims involve a SUV.

Our claims investigators feel that we may be dealing with multiple problems. First, the design of the SUVs may present a serious safety hazard. That is, as the National Highway Traffic Safety Administration (NHTSA) has pointed out, the high frame and consequently high center of gravity of certain SUVs makes for an unstable design. As a result, rollovers may be more likely than with other vehicles. Further, the weak roofs and lack of crash protections make SUV rollovers deadly when they do occur. In fact, NHTSA has estimated that while 22 percent of passenger car occupant fatalities are attributable to rollover, 61 percent of SUV occupant fatalities are caused by rollover crashes. They estimate that 7,000 people are killed or seriously injured annually when the vehicle they are in rolls over and the roof collapses into the occupant survival space. The drawing below illustrates this problem:


Second, there also appears to be a problem in which certain tires are failing with relatively high frequency. Our understanding is that these failures, especially with SUVs, are occurring because of what is known as "tread separation"; that is, the tread pulling away from the tire carcass. Once the tread separates from the tire there is a high probability, particularly at high speeds, that the vehicle will roll over. We have begun to look into this further, and in a small sample of tires we have discovered fatigue cracks in the rubber separating the two steel belts of the tire. We found these cracks in both new and used tires. We assume that as these cracks propagate (i.e. lengthen) under highway driving conditions, the probability of tire separation and rollover should increase. We also are concerned that weather plays a potential role and, as a result, there may be a seasonal effect.

We are requesting that Richards Automotive Consulting provide us with an experimental design for conducting a series of tests to determine where the particular problem lies. Refer to the table below for SUV and tire manufacturers cited in the various claims. Your design should include an estimate of the cost of conducting the test. CountryWide will provide Richards with sample SUV's and tires through our existing agreements with the manufacturers. Assume that each car used in these tests will cost $20,000 and each set of tires will cost of $500. If the car does not rollover during the test, we are able to sell it for an average of $15,000; if there is a rollover, the car will most likely be totaled and can only be salvaged for $1,000.

To conduct these tests we have contracted with a test track and laboratory; the track is state-of-the-art and able to simulate various weather, road and driving conditions. For example, these various conditions can be grouped into three main categories: poor, fair and good. Use of the track and laboratory costs $5,000 for each test run; $2,500 if vehicle is not damaged and is used for the next test run. We have allocated a maximum budget of $1,000,000 to conduct these tests; however, a proposed experimental design that comes in under this amount is highly encouraged. Refer to the table below for SUV and tire manufacturers cited in the various claims.

Please send CountryWide your complete written proposal detailing your proposed experimental design for these tests. Include any assumptions and/or justifications you have made relative to variables chosen (e.g., which tire manufacturers you have selected). Further, provide the order that you want to conduct the tests. Finally, please provide a detailed budget sheet for the experiment to include your fees along with a budget rationalization. We are looking forward to your team's suggestions.

| SUV Models in Claims | Tire Manufacturers in Claims |
|---|---|
| Wilderness | National |
| Yellowstone | Stonehead |
| Safari | DesignPlus |
| Desertfox | |

Sincerely yours,

John McCray
Vice President, Claims and Safety
CountryWide Insurance Company

Figure 1. MEA Memorandum 1 – Vehicle Rollover

reporting out. Students also account for the cost associated with each data point collected so as to minimize the overarching cost of the experiment while still addressing the hypothesis. This particular MEA met the criteria for the project. Student teams actually were able to put uniqueness into their interpretation of the problem and their proposed solution. Further, given their proposed design and the simulator's results, each team had somewhat different data to draw their conclusions. In addition, the students tend to ask similar questions between the open-ended project idea and the MEAs. Many of these questions have to do with the formation of the initial hypothesis and the experimental design that will best meet the needs of the hypothesis.

**To:** William C. Smith
**From:** Thomas K. Richards
**Re:** CountryWide Accident Analysis
**Date:** 2/11/2008

Dear Bill,

CountryWide has had an opportunity to review your study design for the performance testing experiment; they are comfortable with your cost estimates for the project, and appreciate your timely response and carefully considered proposal. As a result, CountryWide's independent testing laboratory has used your design criteria to conduct the tests as specified. The results are attached to this memorandum, including all the outcome measures that you suggested should be collected.

They are especially concerned about the sensitivity of the data and what it may reveal. As you are aware, they have certain relationships with both the vehicle and tire manufacturers that they do not want to harm. Consequently, they are now requesting that we complete an independent, objective analysis of the data in order to determine if particular car manufacturers, tire manufacturers or environmental conditions have significant roles in the rash of rollover accidents that have plagued CountryWide Insurance.

Because of the nature of this, CWI has requested that we maintain a high level of confidentiality among your engineering team when performing \the data analysis and interpreting the results. They have specifically requested that we do not discuss the data or findings to other Richards personnel and certainly not to any one external to Richards. The report should only be given to CWI.

Given this, please provide me with the final draft version of your report so that I can read it over, and then pass it on to CWI. The report should contain a description of your analysis and findings including your interpretation of which factors are most likely causing these accidents.

On a more personal level, because of the sensitivity of this information, I am also concerned about our obligations given certain findings. Consequently, please provide me with a separate memorandum your opinion as a professional engineer concerning what we should do with this information, especially if the results point to particular companies, even though CWI has requested that we give it only to them. I would like both your draft final report and your separate memorandum by 3:00 PM on February 18 at the latest.

Attachment: Performance Test Data

Figure 2. MEA Memorandum 2 – Vehicle Rollover

Logistically, though, the instructor does see problems with repeatedly using same MEA each term the course is taught, as the author worries that the teams' resulting models will become equally repetitive. As a result, the instructor has only used the MEA twice since its development in 2008. Given time, the instructor hopes to develop additional but different MEAs around the same topic.

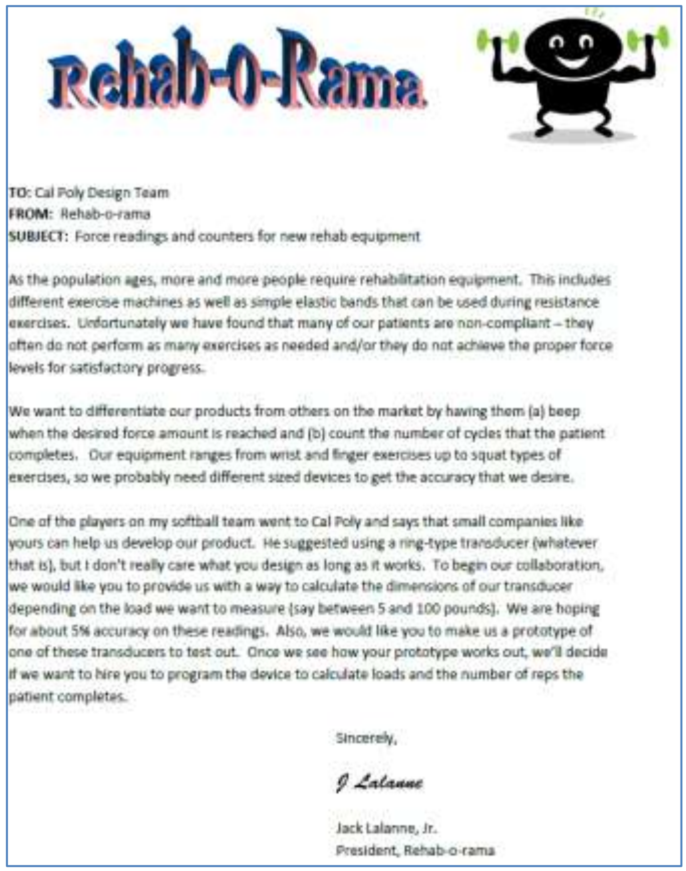
Changes in personal epistemology:
For a class that traditionally focused on experimental design, the instructor's personal epistemology was enhanced as the MEA helped to move the subject matter to provide more "social sciences and business" aspects as indicated by the four dimensions of engineering[12]. As a result of implementing the MEA, there were opportunities to now assess students' value of engineering knowledge[13]; and in particular how student teams addressed both the economic constraints and the ethical dilemma imposed by the MEA's first and second memorandums, respectively. As mentioned, the instructor routinely had students conduct projects around the same theme; however, the realism of the project was never a focus. This was an important aspect to enhance the value of the course.

Helping other faculty to migrate MEAs:
Introducing MEAs to fellow instructors in the area of engineering statistics and industrial engineering has been quite fruitful. Having implemented one MEA and developed several others, four faculty members in the department have implemented MEAs in their courses to

include: introductory engineering statistics, engineering economy, simulation and supply chain. One aspect is clear for its success with other faculty, buy-in by the faculty. Of the courses mentioned, those that were successful in their implementation was: (1) general training about MEAs, (2) the benefit beyond the concepts learn in class, specifically how the MEAs provided a connection between engineering and the "real-world", and (3) the value of feedback to the students. Regarding the first item, faculty needed only minimal background in the construct of the MEA. This is likely because many of the faculty have students do similar project based learning activities in their coursework. Specific to the real-world connection, many engineering faculty are intrigued with how to maximize the value of projects to multiple ABET outcomes. In prior research we have found that although MEAs can improve conceptual understanding of engineering topics, their primary value has come with helping students acquire certain professional skills, such as teamwork, written communications, and understanding engineering in a global and societal context.

### Case 2- Mechanical Engineering

The Load Cell Transducer MEA is used in a junior/senior level Experimental Methods in Mechanical Design technical elective. In this MEA, teams of two or three students are assigned to work as engineering consultants for the owner of a fictitious company, "Rehab-o-Rama", which manufactures physical rehabilitation equipment. The students are given a memorandum from the owner, requesting that the students design a class of load cell transducers to be used to measure the force generated by a rehabilitation patient. The exercises could be for a variety of applications, from finger flexion to leg extensions. Because the required capacities of load cells for which the students' design method must be usable vary from 5 to 100 pounds, a single design is not acceptable; the students must create a design algorithm. The algorithm is then used to design a single prototype transducer which the students build, calibrate, and test in the laboratory. The memo (shown in Figure 3) is deliberately somewhat vague, imitating the instructions often given to engineers by customers. The students are told that the owner is not an engineer, and therefore the students need to communicate with the business owner in terms that the owner can understand. Students also write a simple program to acquire data from the transducer in the laboratory, and test the entire system to verify its functionality.


Rehab-O-Rama

**TO:** Cal Poly Design Team
**FROM:** Rehab-o-rama
**SUBJECT:** Force readings and counters for new rehab equipment

As the population ages, more and more people require rehabilitation equipment. This includes different exercise machines as well as simple elastic bands that can be used during resistance exercises. Unfortunately we have found that many of our patients are non-compliant – they often do not perform as many exercises as needed and/or they do not achieve the proper force levels for satisfactory progress.

We want to differentiate our products from others on the market by having them (a) beep when the desired force amount is reached and (b) count the number of cycles that the patient completes. Our equipment ranges from wrist and finger exercises up to squat types of exercises, so we probably need different sized devices to get the accuracy that we desire.

One of the players on my softball team went to Cal Poly and says that small companies like yours can help us develop our product. He suggested using a ring-type transducer (whatever that is), but I don't really care what you design as long as it works. To begin our collaboration, we would like you to provide us with a way to calculate the dimensions of our transducer depending on the load we want to measure (say between 5 and 100 pounds). We are hoping for about 5% accuracy on these readings. Also, we would like you to make us a prototype of one of these transducers to test out. Once we see how your prototype works out, we'll decide if we want to hire you to program the device to calculate loads and the number of reps the patient completes.

Sincerely,

J Lalanne

Jack Lalanne, Jr.
President, Rehab-o-rama

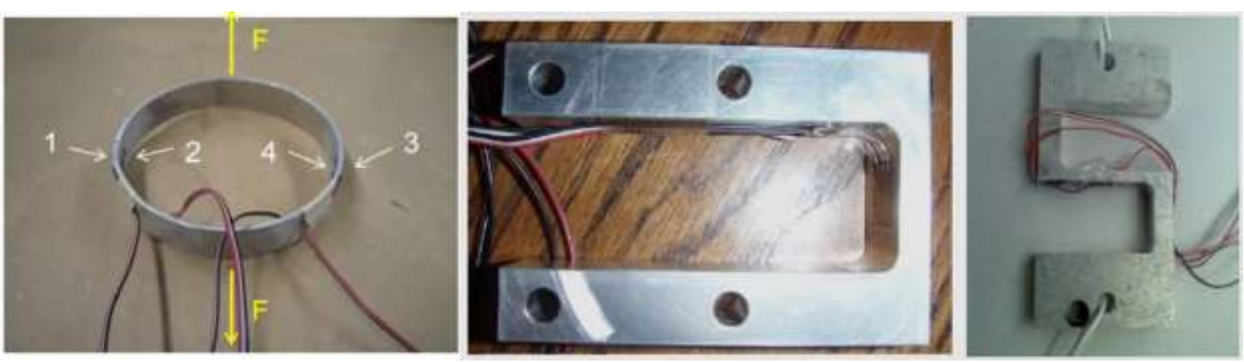
The teams are required to document and submit their transducer designs after the first week of the exercise, providing an opportunity to correct any serious design problems before the sensors are fabricated. A key deliverable is the implementation of the design algorithm, usually in a spreadsheet (see Figure 4).

Students were guided toward designing load cell transducers configured as circular aluminum rings because aluminum rings of various sizes were readily and inexpensively available from the department machine shop. Some student teams whose members had machine shop experience chose to design and fabricate transducers of other types, such as a C-shaped transducer which had multiple attachment points to allow its range to be adjusted and an S-shaped transducer which was similar to some commercial designs (see Figure 5).

**Figure 4: Load cell transducer design spreadsheet created by a student team.**

| Known | | Input Dimensions | | | Stress | | Strain | |
|---|---|---|---|---|---|---|---|---|
| Force [lbf] | E [psi] | Radius [in] | Thickness [in] | Width [in] | Outside [psi] | Inside [psi] | Outside [micro] | Inside [micro] |
| 5 | 1.00E+07 | 2.00 | 0.0625 | 0.75 | -3667.7 | 3774.3 | -366.8 | 377.4 |
| 15 | 1.00E+07 | 2.00 | 0.0625 | 0.75 | -11003.0 | 11323.0 | -1100.3 | 1132.3 |
| 25 | 1.00E+07 | 2.00 | 0.0625 | 0.75 | -18338.4 | 18871.7 | -1833.8 | 1887.2 |
| 35 | 1.00E+07 | 2.00 | 0.0625 | 0.75 | -25673.8 | 26420.4 | -2567.4 | 2642.0 |
| 45 | 1.00E+07 | 2.00 | 0.0625 | 0.75 | -33009.1 | 33969.1 | -3300.9 | 3396.9 |
| 55 | 1.00E+07 | 2.00 | 0.0625 | 0.75 | -40344.5 | 41517.8 | -4034.4 | 4151.8 |
| 65 | 1.00E+07 | 2.00 | 0.0625 | 0.75 | -47679.8 | 49066.5 | -4768.0 | 4906.7 |
| 75 | 1.00E+07 | 2.00 | 0.0625 | 0.75 | -55015.2 | 56615.2 | -5501.5 | 5661.5 |
| 85 | 1.00E+07 | 2.00 | 0.0625 | 0.75 | -62350.6 | 64163.9 | -6235.1 | 6416.4 |
| 95 | 1.00E+07 | 2.00 | 0.0625 | 0.75 | -69685.9 | 71712.6 | -6968.6 | 7171.3 |
| 105 | 1.00E+07 | 2.00 | 0.0625 | 0.75 | -77021.3 | 79261.3 | -7702.1 | 7926.1 |

**Figure 5: Load cell transducers designed and built by students with ring, "C" and "S" shapes**




Challenges implementing the MEA in the classroom:

The MEA construct works extremely well in a laboratory setting. Often, labs employ recipe driven instructions that do not require the use of modeling techniques, innovative thinking, or design skills. Past strain gage labs would simply have students instrument a beam with a hole in it to try to look at stress concentrations. The Load Cell Transducer MEA provides a much more realistic scenario to address instrumentation and mechanics of materials content.

It is not always easy to develop an MEA that meets all six of the governing principles [1], requiring the students to develop a generalized model for a realistic client. The laboratory setting provides a unique way for the students to self assess – their prototype transducers should match their models. As with any laboratory, students sometimes have trouble with the instrumentation. It can be difficult to place strain gages on the inside surface of a ring, and some students have difficulty with the installation procedures (proper surface preparation, adhesion, soldering techniques). A few students were used to more prescribed laboratories, and wrote their reports in the typical Intro/Methods/Results/Conclusions format without addressing it to the actual client.

Changes in personal epistemology:
The instructor has always been a proponent of inductive learning, but had not thought deeply about *modeling* before using and developing MEAs. Typically, assignments might involve a computer program or spreadsheet but had one "correct" solution. Requiring students to develop generalizable models that could be applied to similar situations forced the instructor to reformulate his assignments and to think more fully about the learning objectives of the assignment. Additionally, considerable time went into providing means for the students to assess whether their models were accurate and complete (the Self-Assessment Principle).

Helping other faculty to migrate MEAs:
As mentioned previously, MEAs fit quite well into laboratory classes – it is often relatively easy to find realistic scenarios for upper level courses. A colleague team-taught the Experimental Methods in Mechanical Design course with the instructor, and quite readily adapted the MEA construct to several of the laboratories. It was quite useful to discuss different ideas for development of the transducer MEA with the new instructor, and a better overall assignment was written due to this collaboration.

It has been more difficult to convince other faculty to use MEAs in lower level courses or in non-laboratory classes. In sophomore level dynamics, students are much more accustomed to having the instructor walk them through example problems than forcing them to complete projects, and instructors are hesitant to add to their grading load. Some instructors in lower level laboratory classes have very specific learning objectives that they think can only be obtained using overly prescribed lab steps. As would be expected, the more traditional lecture-style professor is typically hesitant to implement MEAs in their courses.

**Common Threads**

There are a few commonalities between these two case studies. First, regarding implementation challenges, faculty found the migration, for the most part, of MEAs to the classroom unproblematic. Rather, implementation was an easy aspect compared to MEA development issues and student adoption. Second, both instructors experience changes in their epistemology as a result in adopting the MEA construct. For the first case, although project-based learning was a focus, making the connection to ethics, business, and social concerns was not a focus; and for the second case, modeling became an important aspect in ones teaching. Differences have been found, though, when trying to move the MEA concept to other faculty. In one case, migration has been a relatively straightforward, as faculty have seen a useful aspect of the MEA concept beyond the express-test-revise value of modeling – that of ABET professional outcomes.

In the other case, migration has been more difficult, given faculty preferences for teaching. The authors encourage readers to visit the Models & Modeling Website (www.modelsandmodeling.net), which provides a host of MEAs and further explains how they may be implemented in the upper division engineering classrooms.

**Acknowledgement**

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