AC 2012-5166: PHYSICAL EXPERIMENTS TO ENHANCE MODEL-ELICITING ACTIVITY IMPLEMENTATION

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Physical Experiments to Enhance Model-Eliciting Activity Implementation

Abstract

Model-Eliciting Activities (MEAs) use open-ended case studies to simulate authentic, real-world problems that small teams of students address. Our approach for this Phase 3 CCLI Project took the theoretical framework from mathematics education to create a strategic, scalable approach which addressed crucial goals in engineering education. As part of a multi-year and multi-University effort, California Polytechnic State University, San Luis Obispo (Cal Poly) has developed and tested several MEAs which use experiments (or other physical/hands-on activities) to enhance student learning within the mechanical engineering curriculum. The three primary areas in which we have incorporated hands-on physical activities include a) using laboratory experiments to collect data for the models, b) as a method to provide self-assessment of the student models, and c) as a reinforcement tool to help students better understand the concepts being covered in the MEA.

Background

Model-Eliciting Activities (MEAs), which were developed in the mathematics educational community, require teams of students to attack open-ended problems. MEAs are distinctly different from "textbook" problem-solving activities in terms of length of time, access to information resources, number of individuals involved in the problem-solving process, and type of documentation required. However, the most important difference is the emphasis on building, expressing, testing and revising conceptual models.

The six guiding principles of MEAs[1] try to maximize the learning potential of these activities:

> Reality Principle- contains a realistic client with engineering context
>
> Model Construction Principle- a mathematical model and/or decision algorithm must be developed
>
> Model Documentation Principle- a deliverable, often in the form of a memo to the client, should reveal student thinking
>
> Self-Assessment Principle- students should be able to know when their model is "good enough"
>
> Generalizability Principle- the model should apply to multiple related situations
>
> Effective Prototype Principle- the MEA should involve important concepts that are critical in future classes and engineering practice.

Of these six principles, we found that physical experiments most specifically address the Model Construction Principle and the Self-Assessment Principle. The Model Construction Principle requires students to create a mathematical system to reasonably address the needs and purpose of a given client. We specifically use the hands-on experiments to create data that the students can use to build their models, and then to test the validity of their models. The Self-Assessment Principle requires that as students develop the model, they must be put in a position that encourages self-evaluation of their work. The hands-on activities that we describe here encourage students to test and revise their models by pushing them past their initial ways of thinking to create a model that better meets the needs of the client. Finally we have also found that it can be beneficial to use physical laboratories and demonstrations that are not directly related to the MEA, but can still be used to reinforce the concepts that are being stressed.

Using Physical MEAs to Help with Model Construction

Several of the MEAs developed at Cal Poly utilize hands-on physical activities to collect data to help with model construction. We will describe two such MEAs, both of which are used in a senior level thermal systems design course which is taken by all of our mechanical students. Key topics for this course include engineering economics, pumps/piping, heat exchangers, and system simulation/optimization. These MEAs are implemented during a weekly 3-hour laboratory meeting associated with this course. Typically, two such lab meetings are utilized to complete one MEA.

Energy Efficiency Rebate Program Design MEA

Here, an electricity utility has hired the student teams to develop an electricity rebate program which encourages customers to undertake measures to make their homes more energy efficient. This MEA is intended to reinforce concepts from engineering economics, thermodynamics, and system optimization. The desired model is an optimized rebate structure which returns the greatest electricity savings per dollar invested in the program. At its simplest, anyone can easily note that a $20 rebate for compact fluorescent light bulbs (CFLs) would save the customer more money (and conserve more electricity) than a $40 rebate for a new microwave. To develop the framework for their rebate structure model, students use a provided $30 plug-in power meter (Kill-a-Watt model 4460), the utility electricity meter (smart meter or conventional), and their electricity bill to measure and estimate the electricity usage by all major appliances and lighting in multiple residences. At a minimum, they are asked to determine instantaneous power (kW), average power (kW), and estimated energy per month (kWh) of each device. One specific goal here is to directly address commonly held misconceptions regarding energy and power and their associated dimensions.

Each group uses their electricity usage measurements to design the framework of an energy efficiency rebate program for our local electricity utility. The model they develop should provide recommendations, based on economics and electricity usage, which obtain the most “bang for the buck.” In keeping with other MEA principles (specifically the Generalizability Principle), the model they develop needs to be general enough that it could quickly be modified for other types of homes, other price structures, different time frames, and different quantities of available rebate money.

This MEA, with only minor modification, has been used successfully in three consecutive years of this course. After one week, students bring in their electricity measurements to class and we compare values. Through coordinated discussion lead by the instructor, we try to ensure that all groups are on a trajectory for success. We also compare measurement values at this meeting. Some appliances due to their size (refrigerators) or voltage (electric dryers) are more difficult to measure, so we share measurements throughout the class as necessary. Students are provided a grading rubric for their rebate program deliverable, and typical scores earned for this activity are 7-10 points out of a possible 10.

Obviously, appliance electricity consumption data is readily available via the internet, so it could be argued that the first half of this MEA (the data acquisition portion) is unnecessary. In fact, our experience is the opposite. Engineering students are very excited about the opportunity to make measurements of their own appliances. Inevitably, we hear students sharing their experiences of surprise at some of their measurements. Several students have even volunteered that the MEA encouraged them to modify their behavior regarding electricity usage. Their enthusiasm for the measurements helped motivate effort during the calculation-intensive model development portion of the activity.

Viscosity Measurement MEA

Here, a petroleum company has hired the student teams to develop a small, robust device for measuring fluid viscosity quickly in the field. The viscometer is supposed to work over a wide range of viscosities (1-1000 cP), although the device does not necessarily have to measure dynamic viscosity. The projects are evaluated (with lower scores being better) based on the volume of liquid required to make a measurement, the time required per measurement, the measurement error (compared to an unknown standard), and the variability of their measurements.

In an attempt to not bias their creativity, no equipment is provided for this MEA. The first week was occupied with brainstorming and refining their ideas. By the second week, students have developed a working prototype and use the lab period to calibrate their device. It is during this meeting that the students utilize their measurements to develop an appropriate engineering model of their measurement principle. For instance, many students develop devices that involve dropping a mass through a column of the measurement liquid and measuring the descent time (i.e., a “falling ball viscometer”). So based on their measurements and device characteristics, they have to decide how to model the behavior they observed (laminar vs. turbulent, wall effects, is terminal velocity achieved, etc.).

This MEA has been used successfully in two years of this course. A key learning objective was to improve student understanding of the similarities and differences of kinematic and dynamic viscosity. Later in the course, when we discussed pumping of viscous fluids, it was clear to the instructor that student understanding of the two viscosities was greatly enhanced. Also, we wanted to give students an intuitive feeling of the “thickness” of a 1 cP fluid versus a 1000 cP fluid. While not particularly surprising, students commented on how helpful it was to touch fluids of varying viscosity, in order to develop this level of familiarity.

On a downside, our efforts to foster creativity and diversity in their designs were initially unsuccessful. In our first year of implementation, every group came up with methodologies which measured dynamic viscosity, so there was less discussion of the two viscosities than expected. Also, only two groups out of 18 designed anything other than a "falling ball viscometer." Consequently, in the second year of implementation, we adjusted the scoring rubric to encourage diversity of designs. By providing a small adjustment of their score based on the complexity of their methodology, we were able to encourage a wide range of solutions in addition to falling ball viscometers. New solutions developed by students included a) pouring of the liquid, b) sliding glass on a layer of the fluid, c) measuring torque and speed of a motor mixing the liquid, and d) rising of a bubble through the liquid. While some of these techniques measure dynamic viscosity and others measure kinematic viscosity, it became clear after reviewing the students' work that they still were unable to correctly identify which viscosity was being directly measured by their device. Future implementation will target this learning objective more directly.

Using Physical MEAs to Help with Self-Assessment

For many MEAs, providing a means for students to "check" the validity of their models can be quite difficult. Strategies can include providing fictitious data from the client, referring students to peer-reviewed literature, and depending on student experiences to help them determine when a solution "seems" correct. We have found that one of the most powerful ways to provide self-assessment is in the form of actual laboratory or physical activities. Examples of this include the Catapult MEA and the Force Transducer MEA.

Catapult MEA

The Petersborough Museum in England hosts a Medieval Exhibition each year, and plans to hold a catapult launch competition. As part of the competition they want to award a prize for accurately predicting the range of their device for different pullback angles. Student teams are asked to create an algorithm to help contestants analytically determine this range, and then were provided a small-scale catapult to test their algorithm. We provided the student teams with rulers, weights, a scale, and a small force transducer and very little guidance on what else they needed to do to calculate the launch distance. Students had to determine how to model the rubber band (linear vs. non-linear) as well as the mass moment of inertias for the different catapult components (can the arm be modeled as a slender bar or should they use equations for a rectangular parallelepiped?). In a way this initial part of the exercise also addresses the Model Construction principle, as students had to create mathematical models for actual physical systems, rather than being provided with values for the rubber band stiffness and the mass properties of the catapult arm.

Figure 1. Scaled model of the catapult.

After completing their calculations, students tested their models by launching raw eggs at a picture of their instructor. The MEA takes up quite a bit of time – typically an entire class period is used to measure the different components of the catapult. We generally give the students 20 minutes or so in three additional class periods and require them to meet outside of class as well. It generally takes at least half a class period to launch the eggs (we typically do this outside). Follow-on activities after the MEA include calculating the force at the pin about which the arm rotates (rigid body kinetics) and the forces at the impact stopper (rigid body angular impulse momentum).

Figure 2. Projectiles launched at target for Self-Assessment.

A subjective survey compared student opinions regarding the Catapult MEA and traditional homework. Although students still regard traditional homework as being the best way for them to learn the material (or perhaps just do well on the final exam), they did tend to think that the Catapult MEA was more interesting than the homework problems.

Table 1. Student Survey Responses.

	Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree
The individual homework problems helped me learn the material	25	33	4	1	0
The Catapult project helped me learn the material	13	25	16	8	1
The Individual HW problems were interesting and motivating.	1	28	21	12	1
The Catapult project was interesting and motivating.	10	24	17	12	0

Load Cell Transducer MEA

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 they design a class of load cell transducers to be used to measure the force generated by a rehabilitation patient. As the required capacities of load cells vary from 5 to 100 pounds, a single design is not acceptable; the students must create a design algorithm. An example of one of the student spreadsheets is shown in Figure 3.

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 3. Typical sizing algorithm from a student team.

The algorithm is then used to design a single transducer which the students build, calibrate, and test in the laboratory. An example of one of the student load cells is shown in Figure 4. The students are told that the owner is not an engineer, and therefore they must communicate with the business owner in terms that he or she can understand. Students also write a simple program to acquire data from the transducer in the laboratory, and then test the entire system to verify its functionality.

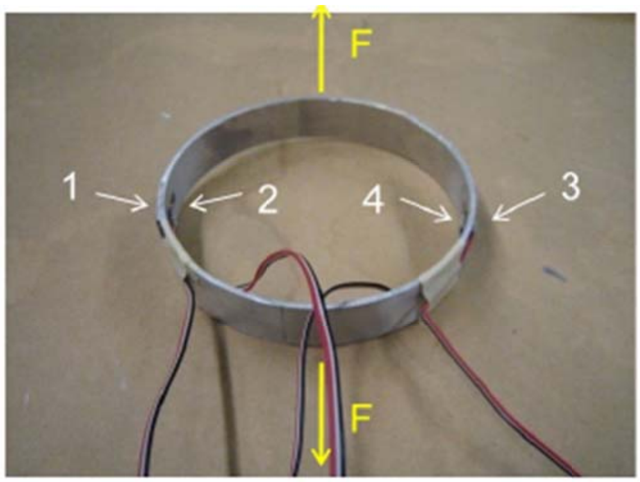

Figure 4. Student built force transducer.

A short survey was given to the students to help determine the effectiveness of the MEA. The students indicated their level of agreement with two statements (see Figure 5):

1. "The transducer lab (ring transducer) tried to use a simulated industrial client. Instead the instructors should just tell the students to build a force transducer."
2. "Writing the memo to the client helped me think about and prepare to work with engineering customers in the workplace."

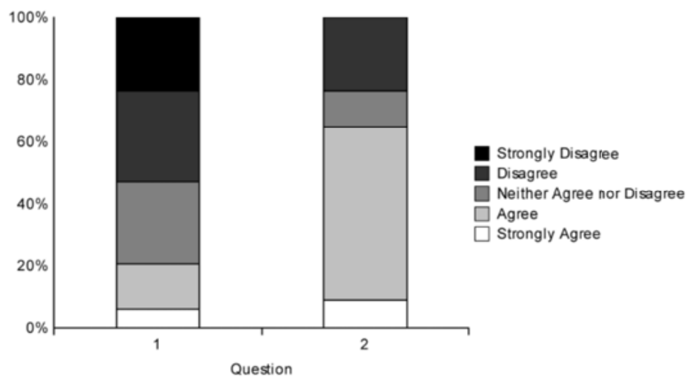

Figure 5. Survey results (see text for questions).

Physical MEAs as a Reinforcement Tool

It can sometimes be helpful to have a laboratory or hands-on activity that simply complements or reinforces the MEA. An example of this is the Motion-Based Flight Simulator MEA, where student teams must create a program to analyze different three-dimensional rotation profiles of a simulator (see Figure 6). The teams are asked to determine the total linear and angular accelerations at the head of the occupant, and comment on what types of vestibular illusions might occur. They then are asked to create their own rotation profiles that would be useful for flight training.

Figure 6. Motion based flight simulator.

Three dimensional motion can be quite difficult to visualize, therefore three different hands-on activities were developed to help students understand the primary concepts of the MEA. In the early stages of the MEA, students were asked to build a physical model, including different rotating coordinate systems that they would use. This helped them develop appropriate transformation matrices and visualize the motions of the cab (this overlaps with the model construction principle discussed above). Once they completed their model, they could use a simulation tool to help them understand if their overall model was correct (so this of course also overlaps with the self-assessment principle). Finally, to help students better understand the different gyroscopic moments created by the multiple rotations, we developed a gyroscope "mini-lab" [2].

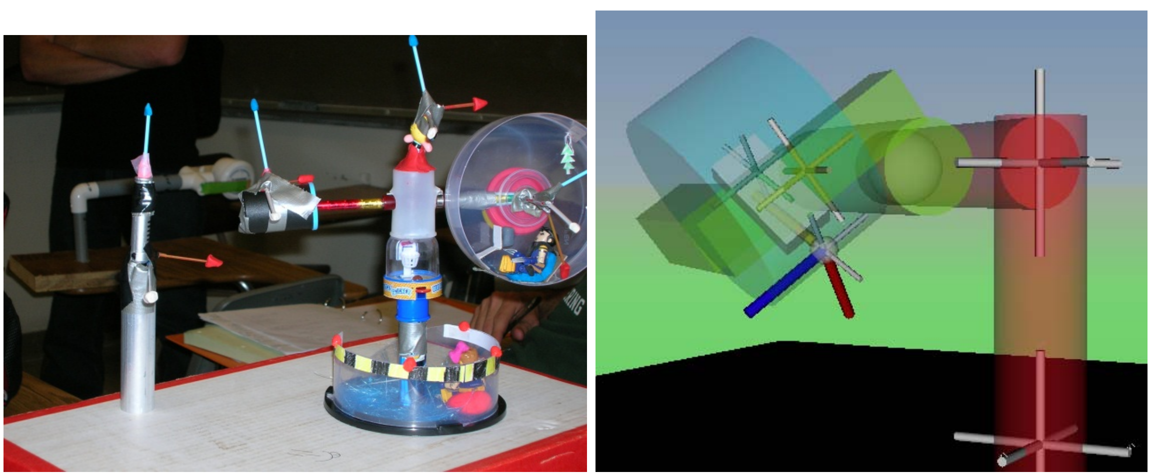
Figure 7. (a) Student-built physical model of motion-based flight simulator and (b) computer simulation of flight simulator

Conclusions

As part of a seven university CCLI Phase 3 collaborative effort focused on models and modeling, we have extended the model eliciting activity (MEA) construct to include hands-on or laboratory components. The three primary areas in which hands-on physical activities were best incorporated include a) using laboratory experiments to collect data for the models, b) as a method to provide self-assessment of the student models, and c) as a reinforcement tool to help students better understand the concepts being covered in the MEA. Of the six guiding principles for MEA development, we found that physical experiments most specifically address the Model Construction Principle and the Self-Assessment Principle.

In an attempt to best promote dissemination of MEAs to other universities, our experiment-based MEAs are very broad in context and application. Some of the MEAs described here are designed for 2nd-year core courses like Dynamics, whereas others described here are intended for upper-division elective courses. We describe MEAs with physical activities that are intended to be used in “lecture-based” courses, and other MEAs with physical activities that are better utilized in dedicated laboratory classes. In addition, for some of these activities, all students use equipment provided to them, whereas in others the students actually develop their own (low-cost) experimental hardware. More information on these and other MEAs is available at http://modelsandmodeling.net/Home.html.

Acknowledgement

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