AC 2010-1900: SPECIAL SESSION: MODEL ELICITING ACTIVITIES -- INSTRUCTOR PERSPECTIVES

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Model-Eliciting Activities – Instructor Perspectives

Abstract

As part of a larger NSF-funded project to develop Model-Eliciting Activities (MEAs) in engineering courses (MEDIA), the authors of this paper have piloted selected MEAs in their courses. This paper will describe their experiences within the context of available student learning data. An MEA is designed to present student teams with a realistic, thought provoking scenario that requires the development of a generalized mathematical model. A well-designed MEA is built around a main concept that the instructor wants students either to discover and/or better understand. Data from these experiments can be used to determine the value added for students completing MEAs compared with other types of problem-solving activities including problem-based learning exercises. Using an MEA also causes documented, positive change in the faculty members themselves.

Introduction and Background

Recently many STEM (Science, Technology, Engineering, and Mathematics) Education fields have actively tried to develop and implement Model-Eliciting Activities (MEAs) with their powerful functions in the educational and methodological aspects. MEAs were initially created in the mid-1970s by mathematics educators as research tools to explore students' conceptual development and problem solving strategies (Lesh, Hoover, Hole, Kelly, & Post, 2000; Lesh & Lamon, 1992). Based on this inherent function of MEAs as a cognitive detector, research has found the potential for them to also be powerful educational tools; instructional tools for effective learning (Lesh & Zawojewski, 2007; Zawojewski & Lesh, 2003) and authentic assessment tools (Chamberlin & Moon, 2005; Lesh & Lamon, 1992).

An MEA is a problem-solving task related to real world situations requiring documentation of students' thinking and procedures, not only a final product. In other words, it requires the "modeling" process itself as well as a "model" from students. The main characteristics of MEAs are: 1) Client-driven, open-ended, and realistic problems, 2) Designed based on multiple threads related to a realistic context, 3) Address higher-order thinking skills, 4) Products are models and modeling processes, and 5) Team work oriented (Lesh & Doerr, 2003; Lesh, Doerr, Carmona, & Hjalmarson, 2003; Lesh & Harel, 2003; Lesh & Zawojewski, 2007). Thus MEAs engage students in a real disciplinary community, where it is necessary to welcome multiple perspectives in teams, allowing them to develop collaboration skills (Moore & Diefes-Dux, 2004). Through eliciting and multi-cycle revision (express-test-revise) of models, students optimize their conceptual models and develop complex reasoning skills in the given contexts based on their experiences (Hamilton, Lesh, Lester, & Brilleslyper, 2008).

These characteristics of MEAs and their implementations are comparable to the main principles of engineering professional practice. The similarities between MEAs and engineering practice have made MEAs increasingly used in undergraduate engineering programs, and supported by several NSF grants to expand their implementation. Current engineering education research involves the following active areas of expanding the utility of MEAs: development of student reflection tools; implementation of learning technologies; detection and repair of misconceptions; development of engineering students' ethical frameworks; and development of advanced curriculum (Hamilton, Lesh, Lester, & Brilleslyper, 2008).

An MEA has to be carefully constructed on six design principles that assure the MEA will provide the student and instructor with the learning experience desired. The MEA framework presents opportunities to address the Accreditation Board for Engineering and Technology (ABET) criteria, especially the crossing disciplinary boundaries and interpersonal communication (Diefes-Dux, Moore, Zawojewski, Imbrie, & Follman, 2004; Hamilton, Lesh, Lester, & Brilleslyper, 2008; Moore & Diefes-Dux, 2004; Moore, 2008). An interesting finding is that when developing MEAs for students the MEA framework provides the developers with a learning experience involving the four basic steps: 1) description; 2) manipulation; 3) translation (or prediction); and 4) verification in modeling cycles which the students will go through in the task (Moore & Diefes-Dux, 2004).

In addition, Diefes-Dux, et al. (2004) argue that "the MEA framework fosters significant change in the way engineering faculty think about their teaching and their students" (p. F1A-3). As a result, the opportunity to develop, implement, and assess an MEA could be a good professional development for engineering faculty to promote positive changes in their beliefs about teaching and student learning, ultimately improving their teaching practices. Other studies have documented change in engineering instruction and the instructors' beliefs and found that that instructors using MEAs change the way that they think about their students' prior knowledge and try to elicit and build upon it (Diefes-Dux & Capobianco, 2008). This research adds the utility of MEAs as professional development to the previous five areas related to MEAs in engineering education research.

Using MEAs in Engineering Classrooms

In this section, we include testimonials from instructors who have developed and/or used MEAs in their engineering classrooms. In all cases, this represents the first time these instructors have used MEAs with their students and their observations are offered to guide other faculty considering the use of MEAs.

Brian Self – Cal Poly, San Luis Obispo. At Cal Poly we have begun to institute MEAs in several of our classes, including dynamics, thermodynamics, and mechanics of materials. Three different instructors have implemented MEAs in dynamics over multiple quarters, with varying levels of success. Our first MEA has students develop an accident reconstruction procedure for a police department in Sri Lanka. Concepts involve particle work-energy and impulse momentum. The second MEA we have tested over several quarters asks students to analyze a catapult for the Petersborough Museum in England. To help with their Medieval Exhibits, student teams use rigid body work-energy principles to determine the range that a projectile would fly. They then test their algorithm on small-scaled models by launching raw eggs at a target. Both of these MEAs lasted over a week and required students to meet several times outside of class.

We have found that it can be difficult to introduce new learning techniques such as MEAs in a "fundamental" course, especially when there are multiple sections that take a common final examination. Most of our instructors teach dynamics in a traditional manner, and our final examination problems are similar to back-of-the-book homework problems. Given this, and the short 10 week quarter, some students do not appreciate having to write memos and to model complicated realistic scenarios (especially when they hear from their friends that their instructor spends most of the time working example problems on the board). To improve student motivation for these projects, we made improvements over the past three implementations.

Being relatively new to MEAs, we did not understand the importance of stressing the exact deliverables to the students. Many are used to simply applying equations and writing down a final answer and don't think about modeling authentic engineering problems. Writing clear, explicit procedures to a realistic engineering client can also be quite challenging for them. Another important lesson we learned was how to scope the assignment appropriately. We took several portions of the original MEAs out and included them as part of our typical weekly homework assignments – this provided feedback to the students on some aspects of the MEA and made the project more manageable. It is also possible to add valuable follow-on activities; for example, after the Catapult MEAis completed we have the students calculate the forces at the pin about which the arm rotates (Newton's 2^{nd} Law) as well as the impact forces at a stopper pin (angular impulse momentum). Using an actual physical catapult has also proven to be very successful. Students grapple with deciding whether to model the rubber band as an elastic or inelastic spring, and if they should model the catapult arm as a slender rod or a parallelepiped – usually this type of information is provided to them. Launching the eggs provides them with a method of self-assessment to determine if their model was accurate or not.

Although subjective comments were mixed, students in the classes with MEAs scored as well or better on the common final exam as the traditionally taught courses, and also showed higher gains on the Dynamics Concept Inventory. By providing engineering context to help anchor important engineering concepts, we also hope that the students have better long-term retention of the material.

As we move forward to develop MEAs in "fundamental" courses, particularly statics and dynamics, we plan to develop shorter MEAS that can be completed in one or two lecture periods. One in development deals with developing sporting equipment for people with mobility impairments, while a second involves designing a rotating chair for children with developmental disabilities.

Ron Miller – Colorado School of Mines. I have piloted two MEAs in chemical engineering core courses at the Colorado School of Mines. "Wetsuit" requires that senior-level student groups in a transport phenomena course develop a mathematical model for a wetsuit company to estimate the time a user can stay in the water using a wetsuit made of a specified type and thickness of material. This will allow the company to screen new materials without incurring cost to create a prototype model. To successfully create this model, students must draw on their knowledge of energy balances from thermodynamics and heat transfer rate equations and they must make decisions about the geometry to use (usually cylinder or flat plate), about which heat transfer resistances to consider and which to ignore, about how to simplify the temperature profile in the human body, and about how to estimate the rate of heat generation in a human as a function of exertion rate. Successful groups obtain an ordinary differential equation relating body temperature to time in the water that then can be analytically or numerically solved for specified initial conditions. Models that are carefully developed and solved will agree within engineering accuracy (~10-20%) for available literature data on hypothermia onset.

"Wetsuit" has been piloted with two groups of senior-level chemical engineering students. In both cases, students needed more coaching and guidance to start modeling than I expected. For example, the MEA asks students to start by creating a physical model of the wetsuit system before writing any equations. Although we had used physical models for every problem solved in transport phenomena (e.g. drawing and labeling a picture of the system, etc), students seemed puzzled by the term "physical model" and weren't sure how to start this task. I realized that in all previous problems solved in the course, the textbook provided a labeled picture of the system while the MEA asks students to think about important modeling decisions and assumptions at this early stage. For example, should a human body be modeled as a cylinder or will a flat plate be sufficient? It turns out not to make much difference if a lumped-parameter model is used. Which resistances to heat transfer are important and which can be ignored? These are important decisions and engineering judgments faced by real-world modelers but are often not apparent when solving a textbook problem – one of the many benefits of using MEAs in class.

"Human Thermometer" has been piloted with one group of chemical engineering students in a junior-level heat transfer course. This MEA was specifically developed to help students repair (often strongly) held misconceptions about the apparent temperature of objects based on touching them (i.e., actual temperature compared to sensation). "Human Thermometer" requires the student teams to develop a model that will estimate the sensation (e.g., hot, cold or neutral) that a person experiences using kitchen utensils as a function of the utensil material and temperature. The key to this model is estimating the interface temperature between human skin and the solid object being touched – this can be done using either a steady-state or transient model and reasonable results (e.g. metals feel colder than most other materials) can be obtained with either approach. In the future, this MEA will be coupled with hands-on temperature sensation experiments in the classroom to further address the misconception that touching an object provides information about surface temperature.

In both cases, introducing the MEA into my classroom has been a success, providing students with an opportunity to model more realistic problems than commonly provided in their textbooks and providing me with rich opportunities to coach groups through the many decisions, assumptions, and approximations required to develop simple but reasonably accurate analytical models of heat transfer processes and systems. Further work is required to more systematically evaluate the impact of MEAs on student learning but student work products are generally of high quality and indicate a significant amount of learning about engineering model-building.

Jack Patzer – University of Pittsburgh. BioTransport Phenomena at the University of Pittsburgh is a first semester, junior year course that explores the similarities between the fundamental principles of momentum, heat, and mass transfer; develops analogies between the fundamentals that apply at microscopic and macroscopic scales; and uses the fundamentals in conjunction with conservation laws to develop mathematical descriptions of physiological and engineering systems using a curriculum developed by the VaNTH consortium. Special emphasis is placed on identifying assumptions that may be used in developing the mathematical descriptions. Biothermodynamics, a rigorous application of thermodynamics to biological systems, is a prerequisite.

Students were administered 14 questions from the Miller Heat Transfer Concept Inventory the first day of class, prior to any formal instruction on heat transfer. The students were randomly assigned to four-member teams and introduced to the Wetsuit MEA project at the next class period, which coincided with the introduction to transport phenomena through the study of heat transfer. Thus, the Wetsuit MEA became a "just in time" exercise where the students were learning concepts in heat transfer and being required to apply the concepts to the project.

The project was divided into three stages: the physical model with brief description was due after one week; the analytical model was due two weeks later; and the final report with functional spreadsheet tool due two weeks after the analytical model. Students were provided with the project evaluation form that would be used in evaluating their work. Additionally, after the project was complete, but before formal evaluation was returned, students were asked to provide an assessment of relative contribution to the project by each team member. The final project activity was a formal debriefing by the instructor that addressed the various physical and analytical models that were offered by the teams and the resulting spreadsheet implementation of the modeling efforts.

Students were readministered the same 14 questions from the Miller Heat Transfer Concept Inventory after completion of the project and formal instruction in heat transfer. Students were also asked to (voluntarily) complete an assessment of the project and their learning in the project. Extra credit was the carrot for completing the voluntary assessment.

Andrew Kean – Cal Poly, San Luis Obispo. I have been supporting Dr. Brian Self with development and implementation of MEAs at Cal Poly. My efforts focus on thermal science courses, with particular emphasis on MEAs that have a hands-on or laboratory component. With assistance from undergraduate researchers, I have developed and tested 6 MEAs, half of which incorporate some sort of experimental activity. In developing these hands-on activities, I have tried to ensure the requisite equipment is readily available and inexpensive, which will hopefully enable a greater number of other schools to adopt use of these MEAs.

One MEA that has proved particularly successful is called "Electricity Efficiency Rebate Program Design." For this, upper-division mechanical engineering students perform two main tasks. First, student teams (3-4 students per group) use $40 in-line power meters to measure electricity consumption of all the major electrical appliances in their homes. This data is supplemented with measurements from their household electricity meter. The teams use these measurements to develop a framework for distributing energy efficiency rebate funds. The client for this MEA is the local electricity utility, which hopes to effectively incentivize appliance replacement to reduce electricity use. Key concepts addressed in this MEA are the First Law of Thermodynamics (conservation of energy), electricity efficiency, engineering economics, demand-side management, time-of-use billing, and sustainability. Over 140 students (or 40 teams) have run this MEA in a Thermal Systems Design course (which includes engineering economics), the capstone thermal science course in our curriculum. This MEA is part of my attempt to make sustainability/efficiency a central theme of this course, and it was implemented during a 3-hour "lab-period". While I implemented this MEA in an upper-division course, there is nothing inherent in the MEA that would prohibit its use much earlier in the curriculum.

Informal assessment of learning from this MEA occurs during its implementation, through discussions with the entire class and further discussions with each student team. Formal assessment occurs during my grading of their deliverables: a memorandum that explains their rebate program structure, and their electrical power and energy measurements. I provide a detailed grading rubric to students prior to their completion of the project, and students have generally done an excellent job at meeting my high expectations. Students complete anonymous surveys at the completion of each MEA, and while challenging efforts are rarely universally popular, student learning and student experiences have both been quite positive. One general complaint from students regarding this MEA (and others), is that the open-endedness of the project makes it difficult to know when they have achieved sufficient progress. At first, I tried to alleviate their unease, but these days I think it is an important part of the learning process. As engineering practitioners, they will frequently encounter the same circumstance of having to decide what amount of analysis is sufficient, so I would rather provide this experience in the relatively low-risk environment of a classroom.

This NSF-funded project was my first exposure to engineering education research, and it has played a major part in my evolution as an educator. I am an early-career mechanical engineering professor, and prior to participating on this project, my classes consisted of entirely lecture-based teaching. Now, even when a course does not have a "lab-period", I will take time out of lectures to run MEAs or other group-based learning exercises. I recognize that I will not be able to cover as much material in class, but instead my students are achieving greater depth of learning on key concepts. Model-Eliciting Activities enhance my ability to convey difficult concepts to students and have provided an invaluable tool for identifying misconceptions in understanding. On a personal level, it has been extremely rewarding to observe improved understanding of fundamental concepts that results from implementation of these MEAs.

Changes in Faculty Perspectives

Research regarding how MEAs help instructors change their beliefs about teaching has been taking place through the MEDIA Project for the past two and one-half years. This section will summarize the current findings on five instructors at three institutions. In order to preserve identity, each instructor will be assigned a number and we will use male pronouns for all instructors.

Each instructor has been interviewed during each year of the project and completed a written survey prior to the start of the project using a modified version of the Teachers' Beliefs Interview (TBI) (Roehrig & Kruse, 2005) which asks questions about the instructor's beliefs regarding Learning, Teaching, and Assessment (seven questions). Interview 1 was performed by an experienced interviewer in all five cases, while interview 2 was performed by the same interviewer for Instructors 1, 3, and 4, but was performed by a graduate student interviewer for Instructors 2 and 5. The results have been analyzed using a rubric that classifies statements made by the instructors in one of five categories: traditional, instructive, transitional, emerging, and reform-based (Luft, Roehrig, Brooks, & Austin, 2003). Responses that are traditional or instructive represent teacher-centered beliefs. Reponses that are emerging and reform-based represent student-centered beliefs. Transitional responses reflect a view that, unlike teacher-centered responses, includes students. These responses demonstrate an affective response toward students, as opposed to emerging and reform-based responses, where the student is viewed as having a critical voice in classroom decisions and construction of knowledge (Roehrig & Kruse, 2005). Table 1 represents the number of times each instructor had a response that was coded in each of the five categories. The top row for each instructor represents responses from the first interview or survey and the bottom row represents responses from the second interview - one year later. For this paper, shifts in beliefs have been defined as at least three questions codes moving in the same direction.

Table 1. Number of instructor responses that were classified into each of five categories.

	Interview year	Traditional	Instructive	Transitional	Emerging	Reform-based
Instructor 1	**1**	1	2	1	3	---
	2	---	---	4	2	1
Instructor 2	**1**	3	3	1	---	---
	2	4	3	---	---	---
Instructor 3	**1**	---	1	3	1	2
	2	---	1	1	2	3
Instructor 4	**1**	1	5	1	---	---
	2	1	1	4	1	---
Instructor 5	**1**	---	---	4	2	1
	2	---	3	3	1	---

Instructor 1's Case:
Instructor 1 believes that MEAs have the potential to change the way that engineering students learn to be engineers. He is particularly interested in how MEAs can facilitate ethics education in engineering and how models and modeling can be ramped up in engineering education. His interviews indicate that he has made a positive change his beliefs in all three categories: Learning, Teaching, and Assessment. Instructor 1 has shifted his beliefs toward a student-centered perspective.

Instructor 2's Case:
Instructor 2 believes that MEAs are just open-ended problems, so he thinks that they are not any more beneficial to the students than any other problem. He believes that he hasn't really learned anything through the use of MEAs. These views of MEAs did not allow any change in his beliefs of Teaching, Learning, and Assessment. The static patterns in his beliefs are shown in Table 1. Instructor 2 showed no net shift in his beliefs.

Instructor 3's Case:
Instructor 3 believes that MEAs are very beneficial for all Learning, Teaching, and Assessment in engineering education. However, most of all, he is interested in the potential of MEAs for

detecting and repairing student misconceptions. The belief of MEAs, which might be solidified through the use of them, seems to make a positive change especially in his belief of assessment. For both interview questions regarding assessment, his beliefs have changed from transitional to reform-based. Instructor 3 has shifted his beliefs toward a student-centered perspective.

Instructor 4's Case:
Instructor 4 believes MEAs are useful for Learning and Teaching, especially valuable as teaching tools. Through the use of MEAs, he has realized the importance of quality of instruction and educational activities. These beliefs of MEAs seem to promote positive changes in overall his beliefs of education. As seen in Table 1, there are significantly positive changes overall. His realization of the potential of MEAs to be powerful teaching tools seems to make a steep positive change in his belief of Teaching that maximizes student learning; here, his belief is changed from traditional to emerging. Instructor 3 has shifted his beliefs toward a student-centered perspective.

Instructor 5's Case:
Instructor 5 believes that MEAs are valuable for Learning, especially the development of collaboration and writing skills. Despite his positive feelings for MEAs and their usefulness, his interviews reported negative changes in all three categories. Instructor 5 has shifted his beliefs toward a teacher-centered perspective.

Conclusions

Overall, the results show that instructors involved in the MEDIA project have shifted their beliefs toward a student-centered perspective. Instructor 2 and Instructor 5 (both associate professors) are two cases in which the instructors did not move toward a student-centered view. For Instructor 2, one possible reason for these patterns is that he didn't have enough opportunities or experiences to learn about MEAs. He mentioned that he did not participate in any of the writing of MEAs and was doing this because it had been asked of him. This feeling of being coerced may be a contributor to his lack of change in beliefs. Instructor 5's interviews focused on very different aspects of teaching and learning. In his first interview, he was focused more on a teaching philosophy, whereas in interview 2 his focus was on requirements of his department. This change in focus may have played a role in the difference seen. His interviewer also asked probing questions in the first interview and the second interviewer did not ask him to elaborate (this also may have been an issue with Instructor 2). Despite these two examples, MEAs have played a significant role in changing the beliefs of three of our instructors toward reform-based, student-centered perspectives. Instructor 4 made the most significant change. He is an assistant professor and his interviews show that working with MEAs has helped him understand that students bring knowledge to the classroom and that he is hoping to capitalize on that prior knowledge in his teaching. Instructors 1 and 3 are each full professors whose commitment to student-centered learning was evident even in the first interview, but both attributed their positive change in beliefs to the use of MEAs in their classrooms.

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