AC 2010-1756: SPECIAL SESSION: NEXT GENERATION PROBLEM-SOLVING: RESULTS TO DATE - MODELS AND MODELING USING MEAS

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Next Generation Problem-Solving: Results to Date:
Models and Modeling using MEAs

Abstract

This paper presents results from a series of learning experiments conducted across a seven university (California Poly San Luis Obispo, Colorado School of Mines, Minnesota, Pepperdine, Pittsburgh, Purdue and the US Air Force Academy) colloborative research effort focused on models and modeling. In particular, the collaborative effort has developed, implemented, and rigorously tested the model eliciting activity (MEA) construct as an innovative tool to improve student learning in undergraduate engineering education. This work has extended the MEA construct originally developed by mathematics education researchers to various areas of engineering including bioengineering, chemical engineering, electrical engineering, environmental engineering, industrial engineering and mechanical engineering. In doing this we have specifically designed three MEA extensions to:

- Identify and repair misconceptions;
- Introduce ethical dilemmas of the workplace; and
- Require laboratory experimentation in order to develop more robust models.

Examples of each category will be presented.

When applied at the upper undergraduate level, MEAs require students to integrate previously learned concepts into their new understanding. We have been testing MEA effectiveness through a series of experiments that attempt to measure improved conceptual learning. Results to date suggest that MEAs do, in fact, provide engineering educators with at least two benefits: (i) improved conceptual understanding by the students and (ii) a mechanism for assessing student problem solving and modeling processes. A well constructed MEA, properly implemented, can inform educators concerning students' achievements of the large majority of ABET 3a-k outcomes, including professional skills. This is the fourth paper in a special models and modeling session. The paper summarizes the various MEAs that we have developed, the experiments that we have conducted, the assessment instruments that we have used, and results to date. In doing this, we provide engineering educators with a series of both proven MEAs and assessment tools that can be implemented in the classroom.

Introduction

"Collaborative Research: Improving Engineering Students' Learning Strategies Through Models and Modeling" is a Course, Curriculum, and Laboratory Improvement Type 3 (CCLI) project involving seven university partners: California Polytechnic State University, Colorado School of Mines, Purdue University, United States Air Force Academy, University of Pittsburgh, University of Minnesota-Twin Cities and Pepperdine University. It builds upon and extends the model-eliciting activities (MEA) construct, a proven methodology originally developed by mathematics education researchers and more recently introduced into engineering education.

MEAs use open-ended case studies to simulate authentic, real-world problems that are addressed by student teams. First 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. Specifically, 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, at Purdue University, seven 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 slowly 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 remain to be fully investigated and documented. This project is the first comprehensive effort 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 at the undergraduate level requires that they be well-constructed and carefully implemented by an informed instructor [6].

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. The purpose of this paper is to highlight MEAs and inform the engineering education community on how their use in upper-level engineering classes is leading to improved students' conceptual understanding, enhanced problem solving and teamwork skills and, a better ability to recognize and address ethical dilemmas. In conjunction with the three companion papers [7-9], this work presents early results to inform others as MEAs permeate throughout engineering curricula.

Development of Effective MEAs

As outlined 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. What follows are MEA descriptions developed, implemented, and tested as part of this project. Additional detail on designing MEAs may be found in Zawojewski, et. al, Chapter 2 [5]. These are organized according to suggested areas, but in almost all cases they may be adapted for use with general engineering students. This is especially true of the number of industrial engineering focused MEAs that have been designed for Engineering Statics 1 or 2, or for Engineering Economy. Comments have been provided concerning their testing and student reaction.

Bioengineering

Ethanol Production: This two-part MEA was motivated by the proposed use of biofuels as an alternative energy source. In the first part, 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. If the company is to become an ethanol producer, then the team also must evaluate various sites for the production facility, which might use any one of several feed stocks. In the second part, 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. The team now must determine whether it should 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.

Concepts targeted: Facility location, optimization, economic analysis, evaluating the trade-off between growing corn for fuel or for food.

Ethical Issues: Should the company grow crops for biofuel or food? What are the consequences of such an action on the environment?

Implementations: This MEA was implemented in Supply Chain course in Fall 2007 and Fall 2008.

MEA Success Rating: Students were able to identify the concepts targeted within the MEA as well as some consequences of using biofuel.

Chemical Engineering

Human Thermometer: This MEA, developed originally for junior-level chemical engineering heat transfer courses, was specifically designed 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 which 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. It requires two class periods plus out-of-class work to complete model development and analysis. This MEA has been piloted twice and extensively evaluated using data collected from video and audiotaping of individual teams in two class sessions.

Concepts targeted: thermal sensation; heat transfer; misconceptions

MEA Extensions: Misconceptions

Implementation: twice in junior year ChE courses.

MEA Success rating: At least four different types of models emerged (with at least one unexpected); most groups developed a model that met client needs and provided reasonable results.

Wet Suit: Student teams work for a research and design division of a wetsuit company that wants to extend their business by developing new wetsuits to market to users that might normally chose a dry suit for their needs. The teams will produce a procedure for the company to estimate the time a user can stay in the water using a wetsuit made of a certain type and thickness of material. This will allow the company to have an initial performance screening for new materials without incurring cost to create a prototype model. Specifically, this MEA focuses on traditional topics in chemical engineering. Students, working for a hypothetical client, must develop a mathematical model to predict the time until hypothermia occurs in divers and surfers using input data about the diver/surfer (e.g., mass, height), wetsuit properties, and water conditions. Principles of thermodynamics (energy balances) and heat transfer (heat transfer rates) are required to complete this MEA along with a documented record of assumptions and simplifications required to develop and analytically solve the model.

Concept Targeted: energy balances, heat transfer rates, model building

Implementation: Wetsuit was piloted with 75 senior chemical engineering students at Colorado School of Mines in a chemical engineering transport phenomena course in 2008. It was again used in 2009 in two sections of the course. It was also used in a comparable bioengineering course at the University of Pittsburgh.

MEA Success Rating: Three types of models (one unexpected) emerged. All developed models adequately met or exceeded client needs (and agreed within engineering accuracy with limited available literature data). However, seniors working on Wetsuit needed more coaching to get started on this MEA than expected but once they got started, did well. Most groups were motivated by the "non-textbook" nature of the project; several showed unexpectedly high levels of creativity in their modeling work. Students did not initially understand the terms "physical model" and "analytical model" even though the entire CSM course is focused on model development for transport processes (heat transfer, mass transfer, fluid flow).

Ethanol "Finding a Home for Pine Wine": This MEA allows both chemical and industrial engineering students to engage in an emerging technology that has the potential to greatly offset the United States reliance upon foreign oil. Producing ethanol from cellulose has not yet reached a point of economic feasibility in the United States. Considering the amount of biomass derived from forests and used for a variety of purposes, separating the inherent sugar from both pre and post treatment presents a viable source of energy that has potentially far-reaching economic affects. The student objective is to develop a mathematical model that successfully quantifies the feasibility of a community hosting an ethanol plant using this type of technology.

Concepts Targeted: Basic statistical analysis, decision analysis,

Drinking bird -- concept MEA focused on the performance of heat engine using a toy 'drinking bird' as a simple engine which can be studied in engineering classrooms. This MEA addresses several key misconceptions about heat engines including the assumption that an engine can be made 100% thermally efficient (i.e. all thermal energy can be converted to mechanical work) if heat losses to the surroundings or mechanical inefficiencies can be eliminated. Instructors will have the option of collecting 'drinking bird' data in class as part of the modeling process.

Implementation: This MEA is currently under development.

Civil Engineering

St Cloud Bridge Replacement MEA: In this MEA, students are responsible to create a procedure to design a new bridge and generate a description of how the process would work by applying the procedure to the eight bridges in the U.S. After 35W Bridge collapsed, MN/DOT conducted a special inspection on a bridge that has a similar design configuration of 35W Bridge. This bridge is located over the Mississippi river in St Cloud. Critical deficiencies observed during the inspection. Thus, MN/DOT did shut down the bridge on Thursday, March 20, 2008. Originally, the bridge was scheduled for the replacement in 2015 but now MN/DOT decided to replace the bridge soon. In the MEA, MN/DOT is asking students to create a procedure to select a type of bridge to build in St Cloud. MN/DOT provides the following information: The new bridge will be located in the same place as the old one. It will carry highway 23 and run west to east. The length of the bridge will be 890 feet. The bridge deck should have three lanes in each direction and should also have 5 ft wide sidewalks along both sides of the bridge. MN/DOT also provides the necessary information about the most common structure types, advantages and disadvantages of these types of bridges (truss, arch, suspension, and cable-stayed bridge).

Implementation: This MEA is currently under development

Bridge Structure: In this MEA engineering students are responsible to create a procedure to find the most appropriate structure type for each span to build a new bridge over Mississippi River. The total length of the bridge will be 200 feet. There will be three piers and two spans. The short span will be 80 feet and the long one will be 120 feet. The bridge deck will have three lanes in each direction and should also have 5 ft wide sidewalks along both sides of the bridge. Students in teams need to consider length of the bridge and initial cost. Construction time and location are also need to be considered. In this MEA, necessary information about the most common structure types, advantages and disadvantages of each structure, span limits, and costs of each structure are provided to the students.

Implementation: This MEA is currently under development

Electrical Engineering

Debugging: Teams work for an alumnus who is a vice president at a semiconductor company that wants to create a guide for its engineers who are struggling with debugging circuit designs. Each team must develop a general systematic procedure for digital circuit debugging, which includes a detailed explanation of the reasons behind the decision points in the proposed procedure. The intent is to allow the circuit designers in the company to have a guide for debugging of any digital circuit, increasing overall product quality with shorter verification time and less development cost. The MEA is designed for students to 1) Identify different types of errors in digital circuits, starting with a simple error and then getting into more complex errors, through inspection of a correct state diagram and incorrect waveforms; 2) Make sure a digital circuit is working correctly through debugging; 3) Develop technological literacy in logic design, especially in state diagrams, circuits, and waveforms; and 4) Develop the debugging skills that are one of the most important skills in logic circuit design.

Concepts Targeted: Technological literacy in digital logic designs, especially in state diagrams, digital circuits, and waveforms in order to detect and correct the errors in digital circuits that produce incorrect waveforms.

Traffic Controller: This MEA is designed for electrical engineering students. The team works for a rural county's traffic operations division. The task is to redesign many of the rural highway/county road intersections to provide effective traffic signal systems for the various local communities. The team must develop a general procedure to design an effective traffic signal system for an intersection of a four-lane highway and a two-lane county road including information on when to use pre-timed controllers or semi-actuated controllers, where and in what situations do they place sensors, and how to develop the logic circuit for each situation. This will allow the agency to design any intersection of this type anywhere in the local community, improving traffic flow, safety, and environmental conditions around the area. The MEA is designed to have the students: 1) Identify basic principle of traffic signals; 2) Develop a conceptual understanding of logic design; and 3) Develop conceptual skills with logic circuits

Concepts Targeted: logic design skills with digital circuits

Wind Energy: A company is considering investing in a wind energy farm in one of several regions. The team must pick the most economical location, considering long term demand for electricity using price and cost estimates. In addition, the team must consider locating the farm offshore versus on land; and, if offshore – whether it should be close in, or further out so as to not block the view of those with shoreline homes. Issues of technical feasibility should also be addressed.

Concepts targeted: long term planning, forecasting, and economic analysis.

Ethical Issues: The consideration of both the potential benefits and harm caused by the wind energy including, if offshore, the right of those living on the coast to an unobstructed view.

Implementations: This MEA was implemented in a Sustainable Energy course in Summer 2008.

MEA Success Rating: Although this MEA needs further refinement, students were able to address the issues raised; some students addressed this MEA in virtual teams. The MEA will be revised and retested.

Bio-fuel cell as a source of electricity to charge your I-Pod: Bio-fuel cell MEA provides students scientific as well as mathematical concepts used in bio-fuel cell research. The task requires students to develop a procedure to increase the power density of a bio-fuel cell. A company called "SGO Labs" engages in the development and commercialization proprietary bio-fuel cell technology. The company develops portable fuel cell technologies for battery replacement. However, the company's bio-fuel cells are not yet powerful enough to be commercially viable. To see some real applications of bio-fuel cells with commercial success in the next few years, the company needs to improve bio-fuel cells? current power output capacity. To do so, the company asks students to develop a procedure to increase the power density of a bio-fuel cell that can be applied for multiple applications. Students can apply their procedures to the company's various kinds of bio-fuel cells to test their procedure.

Implementation: This MEA is currently under development

Environmental Engineering

Hazardous Materials: The team is asked to create a procedure for deciding whether a small, rural Pennsylvania county faced with a series of hazardous material spills on its sole major highway should invest $2 million in countermeasures that might lead to a reduction in such accidents.

The team must address unknown material costs and impute the cost of accidents including injuries and fatalities in addition to material and property. The students are given a large accident data base that includes missing data. (This MEA comes from a researcher's PhD dissertation.)

Concepts targeted: Categorical data analysis; dealing with missing data; valuing life.

Ethical Issues: What is a county's responsibility to protect people using its roadways? What value should be attached to human life?

Implementations: This MEA was implemented in an advanced engineering statistics course in Spring 2008; it will be repeated in Spring 2010.

MEA Success Rating: Students were able to address the statistical concepts in the MEA, but did poorly when addressing the ethical issues; i.e., they failed to take into account costs other than property.

Dam Construction: This MEA concerns the actual proposed construction of a dam in the South Eastern Anatolia (Turkey). Having approved the initial plans, the Turkish Government, for economic reasons, now must reduce the dam's budget. Alternatives include reducing the dam's safety factor by either decreasing its height or substituting certain material; a third alternative would be lengthening the time for completing the project. Ethical issues include the dam's impact on its neighbors, potential harm to the local population, and preservation of a historical region. (This MEA originated from the personal experiences of one of the research team members with constructing a dam in an earthquake prone area of Turkey. A similar situation exists in Kazakhstan.)

Concepts targeted: Multi-criteria decision making, economic analysis, international perspective; ethical issues involving dams and risk.

Ethical Issues: The imbedded ethical issues are quite rich, especially the environmental and societal consequences of building the dam including the potential impact on relations with neighboring countries, potential terrorist activity, risk to local population, and the impact on a historic area and its ancient architecture.

Implementations: This MEA was implemented in a Multi-Criteria Decision Making course. Students were asked to use Analytical Hierarchy Process to decide on the best option to deal with the budget cuts for the dam's construction. It was also implemented in an engineering economics course.

MEA Success Rating: Students were able to address certain of the possible effects of building the dam; however, as the consequences and the problem were quite complex, their solutions did not meet expectations. More time and better instructor guidance is necessary for students to reach richer solutions.

Trees: This MEA is based on an engineering ethics case originally developed by Harris, Pritchard and Rabins [10]. It concerns possible removal of old growth trees along a road through a public forest in order to reduce traffic accidents. Specifically, there have been a series of accidents on a stretch of road through a forest. Consequently, the county's department of transportation has decided to remove the trees. However, a citizen's environmental group after learning of the decision has raised objections. The team must now assist in resolving this dispute. They are provided with accident data which indicate that excessive speed may be the cause of many of these accidents. Part 2 involves a similar scenario reset in a California State Park that contains redwood trees. Will the team now come up with a different decision?

Concepts targeted: Recognizing and resolving an ethical dilemma; trade-offs between the environment and public safety, economic analysis, data analysis.

Ethical Issues: The tradeoff between protecting the environment and reducing the risk to human life, is this dependent on the type of tree?

Implementations: this MEA was implemented in an upper level Engineering Ethics course in Fall 2008; it was re-tested in an engineering economics course in Fall 2009.

MEA Success Rating: Students were able to both address the economic and data analysis concepts and the ethical issues. General reaction was positive.

Disaster Decision Modeling: a consulting firm (student team) is hired to develop a model to support an evacuation decision prior to an impending hurricane. A real-time information source in the form of a simulated expert was available on the scene. The teams determined their information needs from the expert. In part two, the students were asked to develop a plan for strategically modeling disasters for proactive analysis at FEMA, with two concepts targeted: influence diagrams and Bayesian nets.

Concepts targeted: Decision trees; Bayesian decision nets

Ethical Issues: Appropriate amount of preparation for natural disasters

Implementation: MEA was implemented in a summer pilot MEA implementation course.

MEA Success Rating: High; very successful with students.

Hazardous Spill Response: This MEA followed a three-stage implementation strategy and was designed to motivate students in an Introductory Environmental Engineering course. Students are contracted to develop a model for rapid spill response to surface water bodies. During Stage 1 (outside of class) students are asked to brainstorm, research, and propose the information they will likely need to develop an effective spill response strategy that is universal to most small-scale domestic spills. Students are motivated and directed by recent news articles provided by the instructor to help focus their efforts on the potential water bodies and contaminants they may consider. During stage 2, students work in teams in class to develop a conceptual model that processes the information they feel most important from stage 1 and recommends an appropriate response (e.g., stop incoming streams and add aerators). This response is subject to the instructor's constraints. For example, the instructor may suggest that minimizing the time to cleanup is most important. During stage 3 students work in teams to mathematize their conceptual model (e.g., using Excel or Matlab) and make a prediction given specific input data. This later stage is also designed to allow for some conceptual extension, in which the instructor asks other questions that require students to extend their conceptual model and poses ethical questions regarding the selected spill response.

Concepts targeted: Conservation of mass, chemical kinetics, engineering economics.

Ethical Issues: During stage 3 students are asked how their proposed response for a given scenario will impact the local population, which is assumed to be wealthy and the downstream population, which is assumed to be impoverished, introducing environmental justice consequences.

Implementations: Stages 1 and 2 and part of stage 3 of this MEA were implemented in a single offering of the Introduction to Environmental Engineering course at the US Air Force Academy in Fall 08. The MEA will be implemented again in one section of the Spring 10 offering to permit a comparative analysis between two sections.

MEA Success Rating: Students generally identified the correct concepts and were able to apply conservation of mass principles and simple chemical kinetics. Students did exhibit some concern over the ill-defined nature of the problem. However, after a little coaxing from the instructor they proceeded superbly and often identified solutions that were much more creative than those developed by a group of faculty that participated in the MEA prior to its implementation in the course.

Wind Turbine Placement: This MEA is designed for 9th to 12th grade student teams; the client is the White Earth Tribal Council that wants to find a place on the reservation for a wind turbine. The teams must identify one or more sites on the reservation that could serve as potential sites and produce a procedure for identifying additional sites in other locations based on similar data. This will allow the tribal council to determine sites for any location in the future. Students must take into account environmental, geological, geographical, and human factors as they determine a location to place a wind turbine that has maximum power and minimal negative effects. They must: 1) use information from maps, tables, and charts to determine the best location for a community wind turbine; 2) tie together content knowledge from Earth Sciences, Biology and Ecology, and Physics to create a solution that accommodates the needs of the client, requirements of a mechanical system (the turbine), and environmental factors; 3) make decisions about whether or not a solution meets the needs of a client; and 4) communicate the solution clearly to the client.

Concepts Targeted: Matlab programming; basic statistics, land use planning

Industrial Engineering

Outsourcing (Gown Manufacturing): A U.S. company is planning to outsource its wedding gown manufacturing facility to one of three countries with the intent of also selling its dresses in that country. In addition to addressing the cost of outsourcing versus remaining in the U.S., the team also must recognize that adjustments may have to be made to their line of gowns according to the anthropometry measures of females in the selected country.

Concepts targeted: Decision to go offshore, deciding where to outsource; ethics of moving manufacturing offshore; potential use of child labor; protection of intellectual property (IP).

Ethical Issues: Embedded in this MEA are issues of the expected use of child labor in certain locations; preventing the selected offshore contractors from stealing the parent firm's designs.

Implementations: This MEA was implemented in a Human Factors course in Spring 2008.

MEA Success Rating: Students had difficulty with the story line; they did not recognize certain ethical issues embedded in the case.

Quality Process Control: A U.S. automobile parts manufacturer is about to sign a contract with a major Japanese car company that considers quality to be a high priority. However, first the manufacturer must conclusively demonstrate that it can produce the parts at the desired quality level. The manufacturer asks a consulting firm (student team) to provide a report documenting that the parts are of the desired quality. In part 1, students are introduced to the problem and requirements. They are given data to measure whether the manufacturer's current process produces parts of the required quality (using quality control charts). In the second part, the teams are provided with longitudinal data showing changes in the process over time. In a third part, students are asked to provide an overall report with their conclusion as to whether or not the process is indeed in control, and how to measure it in the future. They must link their recommendations to quality control procedures.

Concepts targeted: Understanding how to dynamically follow a quality control process, obtaining a manufacturing process that is *capable*

Ethical Issues: The team must deal with the implied pressure from a personal relationship to verify that the process is of the required quality. They must also address a hint of possible bribery to conclude that the process is in control.

Implementations: This MEA was implemented in a Quality Control course in Spring 2009.

MEA Success Rating: Students indicated that they benefited from working on this exercise and that it was better than working on a regular, textbook exercise.

Tires Reliability: This MEA requires students to determine if production runs of automobile tires meet the company's standard which is given as a distribution of time to failure data. Students are first asked to define reliability and to propose what a reliability plot might look like. Each team must then develop a general model for determining if a tire production run meets acceptable reliability and then apply that model to specific cases: three different grades of tires to determine if they are within a "gold" standard. Students must use the data set to determine the shape of the distribution, use probability plots and fully understand the concept of variance.

Concepts targeted: Data plotting, variation, histograms

Ethical issues: confidentiality of results. Students must propose when a tire recall should be implemented.

Implementations: This MEA has been used each semester for the past two years in an introductory engineering statistics course. It is used early in the course to introduce students to MEAs.

MEA Success Rating: High; it quickly allows instructor to see students' misconceptions of reliability or what the gold standard implies. Students have a chance to struggle with what to do with a large sample.

Campus Lighting: Which lighting proposal for a college campus is the least costly and best addresses the campus community's safety concerns? Students are given information about the current lighting system on campus: types of bulbs, their cost and amount of light produced. Students are asked to recommend to facilities management that lighting proposal which would not only work for the part of campus under study, but other parts of campus as well. Students are give recent statistics on campus crime.

Concepts targeted: Cost estimation; time value of money; comparing alternative investments.

Ethical Issues: Students are asked to think about how the lighting on the campus impacts the campus community. Campus safety concerns vs. cost of new lighting.

Implementations: This MEA has been used in an engineering economy course. It is used both as an introduction for the course (without requiring calculations) and then repeated later in the semester after the targeted concepts have been introduced.

MEA Success Rating: High – although students could often identify the important factors, they could not always tie-in the economic impact. Students also had difficulty in creating a general model using Excel spreadsheets.

Defibillator Leads: This MEA was motivated by a newspaper article about faulty implantable defibrillator leads. It is designed to introduce students to the central limit theorem and its assumptions. Students must do destructive sampling on a minimal set of leads to determine if the batch should be rejected. They are asked to determine what that sample size should be to enable the company to make the appropriate decision. They are also asked about recalling leads already implanted – when should this be done?

Concepts targeted: central limit theorem, sample size determination

Ethical issues: Cost of human life, what if a faulty test lead gets implanted? Students also must consider under which conditions to do a recall.

Implementations: This has been used several times in an introductory engineering statistics course.

MEA success rating: Medium - this MEA is more theoretical than other MEAs; students are challenged to think about this problem in ways that they are not comfortable doing.

SUV Rollover: This MEA was motivated by the Ford Explorer-Firestone Tire case. Ford Explorer SUVs with certain types of Firestone tires were susceptible to serious tire degradation and subsequent vehicle rollover, especially in hot climates. Despite a series of accidents in multiple countries, Ford implemented preventive measures in a piecemeal fashion, only instituting fixes in countries where required. The US was among the Nations where no fix was implemented even though the accident toll was rising. Eventually both Ford and Firestone were sued and found guilty of neglect, highlighting significant issues in both companies' engineering and management; both ignored evidence of faulty tire and vehicle design.

This MEA leads the student through a similar case: here a major insurance carrier has noticed a relatively large number of claims involving SUV roll-overs caused by tire tread separation. The carrier contacts an engineering testing firm (the student team) to design a series of potentially destructive tests on a combination of vehicles and tires in order to determine if a problem exists with either a vehicle model, a tire model, or a combination of both under various environmental conditions. Students are given the cost for conducting the test, the resale (if not destroyed) or salvage value of the car (if destroyed), a budget for the full experiment, and are then asked to provide an experimental design – i.e., specify each combination of vehicle and tire to test. A simulator is used to provide each team with a unique set of test results based on its design so that the team can then conduct a thorough statistical analysis. In the final report the team must address what it should do with the results (that the carrier has asked to be kept confidential). That is, they must consider at what point does public welfare trump non-disclosure?

Concepts targeted: Experimental design with a cost constraint; statistical decision making using ANOVA; public welfare vs. non-disclosure

Ethical Issues: Under what circumstances should the consulting firm disclose findings to protect the public interest if the client has requested confidentiality?

Implementations: This MEA was implemented as part of a second engineering statistics course in Spring 2008; it will be repeated in Spring 2010. Following completion of the MEAs, the instructor and research team members debriefed the students; students were also given a write-up of the actual Ford-Firestone case.

MEA Success Rating: High – a
student feedback was very positive; they liked the fact that the problem dealt with a real life situation. They also liked that the data was customized to their specifications; some teams came up with different results due to the points selected for analysis.

CNC Machine Replacement: This is a two part MEA. Here the Chief Engineer is interested in replacing an aging but quite functional CNC (computer numerical control) machine with a newer model. He views this as a significant opportunity, especially since the purchase would not come out of his operating budget. Consequently, the Chief Engineer requests that the consultants (student 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 strongest case for purchase (Part 1). 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, which is the most appropriate result), or provide more specific details if it found that the replacement is the better choice. (This stems from an actual situation one of the researchers found himself in as part of a summer internship.)

Concepts targeted: Statistical hypothesis testing; concepts of mean and variance, economic analysis, and sub-optimization. The ethical issue required dealing with pressure/intimidation from a supervisor who expected a particular result regardless of what the data indicated.

Ethical Issues: How should the engineering team deal with pressure placed upon them by their supervisor to come up with a specific answer? In fact, students are presented with the dilemma of whether to delete "outlier" data in order to meet the manager's demand.

Implementation: This MEA was implemented three times in an introductory engineering statistics course. It was repeated during the Fall 2009 semester.

MEA Success Rating: In two of the three trials the student teams used the targeted concepts; in the third they did not. The reason for the poor result in the third trial was attributed to the lack of guidance provided by both the instructor and the teaching assistant. There were six teams in that class, and all went off in inappropriate directions. (The research team learned an important lesson from this implementation relative to both instructor guidance and feed-back.) The following year, the instructor provided the appropriate feedback and the MEA was judged to be much more successful.

Condo Pricing: As part of a business plan for a construction company, the engineering team is asked to develop a model to price the units of a new condominium based on various features. A dataset consisting of features, both numerical and categorical, as well as prices of units in a nearby condos was provided. Multiple linear regression was the anticipated solution method. Students were asked to identify other applications for reuse of their models by the company.

Concepts targeted: linear regression

Implementation: This MEA was originally developed at Purdue for freshmen engineering students; it was modified for use with upper level industrial engineering students.

MEA Success Rating: Worked very effectively; students reacted positively.

Quality Improvement: A manufacturing client is faced with high scrap and variation. The team is the given diameter measurements from two shifts and asked to formulate an investigation plan. In part two, the team is challenged to develop a comprehensive improvement plan that also addresses customer complaints. The diameter and color, an accept/reject feature, are not meeting requirements. The plan is to be generally applicable across products and graphically depict time-ordered steps and tool application. Flow charting, process capability, and pre-control are targeted tools. An area for exploration is "prepping" students. As preparation for this MIA, students explored process capability and pre-control. This was intended to lead them to SPC and control charting, the targeted technique in part one. A creative, solid solution to part two would include the three techniques in specific order (control charting, process capability and then pre-control).

Concepts targeted: Control charting and root cause analysis were targeted concepts.

Implementation: This MEA was originally developed at Purdue for freshmen engineering students; it was modified for use with upper level industrial engineering students.

MEA Success Rating: Successful MEA; positive student reaction.

Compressor Reliability: The client requests a procedure for calculating the probability of interest, based on a non-normal dataset. In part two, to uncover the failure characteristics, the team must develop a procedure to statistically determine the failure type (burn in vs. wear out), using samples provided. The underlying distribution is a Weibull; fitting using a chi square fit test is targeted.

Concepts targeted: use of the Central Limit Theorem for failure-time data

Implementation: This MEA was originally developed at Purdue for freshmen engineering students; it was modified for use with upper level industrial engineering students.

MEA Success Rating: High; students very positively disposed towards this MEA.

Volleyball: The engineering team has to synthesize multiple player attributes characterized by continuous, categorical, and qualitative data to build three equitable teams. Although a small dataset is provided, the camp organizers requested a plan for handling 1,000 or more players for next summer. The team was asked to consider changes or resources needed to efficiently implement a similar procedure for a large number of players.

Concepts targeted: Categorical data analysis

Implementation: This MEA was originally developed at Purdue for pre-college students; it was modified for use with upper level industrial engineering students.

MEA Success Rating: High; positively received by students.

CD Compilation: The team must develop a procedure to create music CDs considering cost, time, and genre. A heuristic approach is anticipated. In part two, the MEA targeted 0-1 integer linear programming (that was covered in the students' junior year). A procedure incorporating specific constraints and the objective indicated is also requested.

Concepts targeted: 0-1 Integer/linear programming

MEA Success Rating: High; students reacted favorably to MEA.

Trike "Speedy Delivery!": This MEA focuses on utilization of an industrial tricycle for a realistic purpose: delivering groceries, wood, people, wild rice, maple syrup or pickup and delivery of mail, quilts, misc. packages, etc. on a remote Indian Reservation. Student teams will be introduced to this MEA, Speedy Delivery! Delivery scenarios will be presented with maps of the community and where specific items are located, where items need to go, and where the start and finish is to be. Student teams will be given 2-3 fictitious manifests which they are to create a decision model to help them progress through the manifest in a manner which is as efficient as possible. Test runs will be allowed to gain a greater sense of community logistics which may or may not have been considered prior to this activity, i.e. hills, distance, road surfaces, etc.

Implementation: This MEA is currently underdevelopment.

Materials Science

Wind Turbine Blade Fatigue: This MEA asks the student team to provide an Excel program to help a small company design the length of its turbine blades. The primary concern was over fatigue damage caused by a combination of different mean and alternating amplitude wind speeds. Students were provided a table of actual wind data collected over one year; rainflow analysis was used to count the number of cycles for a variety of mean and alternating speeds. The students needed to calculate lift and drag forces due to the wind speeds, and then determine the stresses at the root of the blade. During the class, we had covered how to determine the number of cycles to failure for a single loading pattern (eg, σ_{mean}= 1000 psi and $\sigma_{alternating}$ = 250 psi), but not how to determine cumulative damage from a variety of different loads. There were a variety of techniques that the students used; some just looked at each individual loading pattern and marked it as pass-fail (not a good solution), while others attempted to find an overall average wind loading by using a weighting algorithm. The following day in class, we covered Miner's Rule, which is one of the classic approaches to handling cumulative fatigue damage. For each load pattern, the number of cycles seen by the part is divided by the total number that would be required for failure. These are all added up, and if the number is greater than one, failure occurs (in equation form, $D= \Sigma\, n_i/N_i$, where D is the damage coefficient, n is the number of cycles the part undergoes, and N is the number of cycles to failure at that load pattern). One group out of the 18 came up with a form of Miner's Rule on their own. A short pre-read and initial force calculation were assigned before the lab period, then three hours were given to complete the assignment.

Concepts targeted: Combined loading, fatigue, cumulative damage.

Implementation: This MEA was implemented once in an introductory junior level mechanical engineering design course.

MEA Success Rating: Some students struggled with the Excel component, but all of the groups were able to come up with some type of solution (although if we do it again we will probably assign more work in calculating stresses before the lab period). When Miner's Rule was introduced in class, students seemed to understand it much more after having grappled with how to handle the cumulative fatigue problem in the lab.

Diamond Grading: This MEA requires students to create a procedure to develop a pricing model for one of the best trend-setting jewelry stores in the U.S. The store needs to use a grading system to accurately evaluate the quality of their diamonds and to provide great prices to their customers. The store has worked with various labs such as GIA, AGS, and EGL to certify their diamonds. However, this process increases the cost of each diamond. Thus, the company decided to create a reliable and consisted grading system to certify their diamonds to be able to offer lower prices to customers. The store has built its success on quality, service, and integrity. The new grading system will allow them to continue their success as they offer top quality diamonds at excellent prices.

Implementation: This MEA is currently under development

Mechanical Engineering

Accident Reconstruction: This MEA targets the principles of particle work-energy, impulse momentum, and impact in a sophomore-level dynamics class. A major concept that the MEA addresses is that mechanical energy is lost during an impact. Simple work-energy problems involving accidents are given as homework assignments prior to the MEA, and then a short pre-read provides background on some of the basics of accident reconstruction. For the MEA, the new Traffic Division in Sri Lanka has asked the student teams to develop a set of guidelines and procedures to use at an accident site. They provide two different accident cases to guide the students into creating their initial guidelines, then send an additional two scenarios so that the students can test and refine their procedures. The accident cases were obtained from an actual police department and contain a lot of extraneous information – students must make different simplifying assumptions, determine which information is relevant, and analyze each of the accidents to determine if the drivers were speeding. Additionally, they are required to make a recommendation if the driver should be prosecuted; this will bring in some decisions based on confidence in their calculations and how they think their assumptions affect the certainty of their results. It requires two class periods plus out-of-class work to complete model development and analysis. This MEA has been piloted over three different quarters and evaluated using subjective surveys and performance on the Dynamics Concept Inventory.

Concepts targeted: particle work-energy, impulse momentum, and impact

MEA Extensions: Misconceptions

Implementation: The Accident Reconstruction MEA has been implemented three times (multiple sections) in sophomore/junior year dynamics course (majors include Mechanical, Aerospace, Industrial, Civil, and Biomedical).

MEA Success rating: By the third implementation trial, almost all of the groups developed a procedure that could be applied to a wide variety of accident scenarios. Some provided very nice tables for the officers to use at the accident scene.

Catapult: 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 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). After completing their calculations, students tested them 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).

Concept Targeted: mass moment of inertia, rigid body work-energy, projectile motion

Implementation: The Catapult MEA has been implemented three times (multiple sections) in sophomore/junior year dynamics course (majors include Mechanical, Aerospace, Industrial, Civil, and Biomedical).

MEA Success Rating: This is a fairly time-intensive MEA towards the end of the quarter. Students appreciate having an actual physical object to analyze, and enjoy being outside on our actual launch day. This is our best example so far of a Physical MEA (P-MEA) where the assignment utilizes an experiment or hands-on activity to provide self assessment for the students.

Solar/Wind "No Grid, No Power, No Problem, Know Solution": This MEA presents students with an authentic situation where an alternative source of energy is required to sustain the objectives of a children?s home facility (Casa Monta Students will design a renewable power system which meets the energy needs of isolated structures within a facility at a remote locale in the high Chilean desert. Due to the remote location and the atmospheric conditions, it is both impossible to tie into existing power infrastructures and ideal, considering conditions, to explore solar and wind energy. The dynamic of the situation requires a self-contained energy module for each structure, therefore once one structure's power needs are met, the model developed for this purpose can be used for the remaining structures. It is important that the supplied power adequately meets the needs of each structure without over engineering the module to the detriment of cost effectiveness.

Implementation: This MEA is currently under development.

Wind Turbine Design: Student teams work for a research and design division of a company that sells and installs a wide variety of wind turbines to customers across North America. The teams must determine the appropriate motor design for specific wind conditions. They must propose one model for a specific wind condition and write a procedure for the company to use in the future to determine the proper design for any future site. This will enable the company to effectively market the appropriate design for customers with diverse needs.

Implementation: This MEA is currently under development.

Wind Farm Design: Student teams work for a research and design division of a company that sells and installs a wide variety of wind turbines to customers across North America. Student teams must determine the appropriate number of turbines to place in a site, deciding whether more power can be extracted from one single, larger turbine at a site, or multiple, smaller turbines. Student teams will write a procedure for determining the appropriate number of turbines for any site. In this way, the company can recommend different numbers of turbines for any given site to their customers in the future.

Implementation: This MEA is currently under development.

K-12 MEAs

International Foods Buffet - Reworked Thanksgiving Dinner: This MEA is designed for K12 students. Student teams work for a catering company to develop the most efficient schedule based on a series of recipes, including the cooking and pan size requirements given specific kitchen and appliance sizes. In the extension activity, students must then plan for the identical set of recipes if they are made in a catering kitchen, dividing up the work equally among five catering kitchens. For both activities, students must write a procedure for the catering company to use for other meal plans in the future for either scenario (in the client's kitchen or in the catering company kitchens).

Implementation: This MEA is currently under development.

Assessment

While a variety of assessment instruments have been tried, the three primary means of assessment have focused on the use of concept inventories pre- and post-MEA administration, the scoring of the resultant artifact, and the use of reflection tools. When triangulated in combination, these three provide insight into the solution process followed by the team, the degree that the students were able to work collaboratively, and the quality of the result. Specifically, we have used concept inventories to both establish a baseline for students before they begin the MEA and to identify those concepts with which they are having difficulty understanding. By establishing a baseline we are then able both computer the effect size given the post-MEA concept inventory results and compare the effect of the MEAs in a particular to comparable courses in which the MEAs were not used. To date we have used concept inventories previously developed for thermal sciences, mechanics, and statistics [11]. Where no concept inventory existed, as in the case of engineering economics, we have developed our own index.

We have used rubrics to score the resultant artifact (i.e., the student report typically written in memo form). By analyzing a relatively large sample of artifacts, we are able to deconstruct a given MEA, and then develop a flow chart that shows the various approaches (paths) and assumptions, both correct and incorrect, that the student teams have taken. By scoring each path, we can then use the flow chart as the basis for a rubric to score student artifacts. The flow chart also becomes a valuable tool for the instructor in that it clearly lays out how student teams may address the MEA, and, hence, where appropriate feedback would be desired to correct teams that have misconceptions, made poor assumptions, or have gone off on the wrong track.

Finally, the reflection tools are providing us with a very rich data set. Over the course of this project we have explored a variety of reflection tools. Our current tool has gone through three iterations before reaching a form that we consider stable. It asks the students to identify two points in the solution process that stand out and to then reflect on what happened at each of those points in terms of progress towards achieving the solution and team functioning. The tool also asks the student to identify the concepts he/she thought was embedded within the MEA, and to reflect on how well that concept was learned. (This later item is currently being correlated with results from the post concept inventory.) The student is also asked to reflect on his/her perception of how effectively the team functioned and whether or not his/her input was seriously considered. Finally the student is asked to assess how well he/she liked the exercise.

Acknowledgement

This research is supported in part by the National Science Foundation through DUE 070607 (California Poly San Luis Obispo), DUE 0717751 (Colorado School of Mines), DUE 0717529 (University of Minnesota), DUE 071780 (University of Pittsburgh), DUE 0717864 (U.S. Air Force Academy): "Collaborative Research: Improving Engineering Students' Learning Strategies through Models and Modeling."

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