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Using Computer Simulations to Support STEM Learning*

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In this study we investigated the implementation of a computer-based simulated Model Eliciting Activity (MEA). The sample included 30 students who completed a paper-based MEA and 60 students who completed a computer-based MEA. Results from both sets of students were compared using cognitive task analysis to determine if the MEA delivery format had an impact on how students: 1) defined the tasks, 2) determined appropriate variables to include in their analysis, 3) implemented correct mathematical analysis, and 4) communicated the results. It was found that students who used the computer-based MEA performed equally well on the first two factors but performed significantly better on the last two factors. Suggestions for improving the simulated MEA game are included.

Keywords: Model-Eliciting Activities; MEA, simulations; technology; problem-based learning; STEM

1. Introduction

Many U.S. students are not developing the mathematical skills generally and the problem solving skills specifically that are needed to succeed in school, become participating members of a 21st century society, and join the increasingly knowledge-oriented global workforce. America is currently experiencing a 'brain drain' in fields such as engineering. This situation is caused mainly by the lack of these basic mathematical proficiencies and problem solving skills [1]. To help reverse course, the National Academies' report, *Rising above the Gathering Storm*, detailed recommendations for enhancing the United States' science and technology enterprises. Of the four main recommendations, the first was to 'increase America's talent pool by vastly improving K-12 science and mathematics education' [2, p. 5]. Within this recommendation, the committee suggested that one way to strengthen the skills of K-12 mathematics and science teachers was to train and provide them with appropriate curricular materials modeled on real-world needs.

Jackson's emphasis on losing scientific and technical talent provides a poignant reminder of the urgency of this problem [3]. Jackson stresses the need to find ways to motivate U.S. students to enter careers in fields of science, technology, engineering, and mathematics, especially females and underrepresented groups. Furthermore, Jackson noted the need to prepare K-12 mathematics and science teachers who have the ability to foster higher student achievement and increase student interest in these fields. The National Commission on Mathematics and Science Teaching for the 21st Century noted that 'in an age now driven by the relentless necessity of scientific and technological advance, the current preparation that students in the United States receive in mathematics and science is, in a word, unacceptable' [4, p. 6]. If we fail to achieve these goals for mathematics and science, then engineering will consequently suffer.

The National Council of Teachers of Mathematics' (NCTM) *Principles and Standards for School Mathematics* [5] and the National Research Council's (NRC) *National Science Education Standards* [6] advocate principles for mathematics and science teaching and learning that focus on learning with understanding, assessment that supports the type of learning desired, and high expectations for students. As examples, the problem-solving strand in the NCTM Standards requires that students build new mathematical knowledge through solving problems that arise in mathematics and other contexts. The connections strand in the NCTM Standards requires students recognize and apply mathematics in contexts outside of mathematics. This focus on interdisciplinary views of science,

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technology, engineering, and mathematics (STEM) education is gaining traction in various states. In 2000, Massachusetts became the first state to include engineering in their K-12 curriculum frameworks [7]. Currently, other states including Minnesota, Oregon, and Texas have begun to integrate K-12 engineering standards into their academic standards [8–10]. It is important to note that Minnesota, Oregon, Texas, and Massachusetts have integrated engineering into their science standards rather than creating stand-alone engineering standards. While allowing for the inclusion of stand-alone engineering courses, the intent of these state policies is to integrate science and engineering.

The Nation's Report Card published by the Institute of Educational Sciences (IES) reported that between 1990 and 2005 the percentage of fourth graders and eighth graders performing at or above *basic* and *proficient* levels have increased [11, p. 1]. Although this report does indicate an upward trend, we must still heed the warning of the 1990, IES report, *The Underachieving Curriculum: Assessing U.S. School Mathematics from an International Perspective.* 'It is time we took the road toward a renewal of school mathematics and started on the way to becoming a nation of mathematics achievers. It is time to restructure and revitalize the mathematics curriculum' [12, p. 117]. IES found 'that children begin school with a keen interest in mathematics, but this interest declines significantly through the grades. Ways must be found to help children retain this excitement and nourish it' [13, p. 115].

One proven way to overcome this limitation of traditional mathematics classes is through problem-centered approaches [14]. Problem-Centered Learning (PCL) is a curriculum and instructional design approach that combines both school and real mathematics. Interest in PCL is increasing in fields that are heavy users of mathematics such as engineering [15]. Several positive outcomes have been associated with PCL instruction at the post-secondary level. Two meta-analyses from the medical education field found that students' attitudes were more positive toward PCL than traditional methods of instruction, and both groups performed equally well on clinical examinations and performance tests of scientific factual knowledge [16–17]. However, limited empirical research exists about the effectiveness of PCL as a curriculum and instructional approach in K-12 settings. Limited research studies exist that focus on teacher training and the implementation of PCL [18–19]. Despite the noted benefits of PCL, Lester and Kehle noted that 'to date, no school mathematics program has been developed in the United States that adequately addresses the issue of making problem solving the central focus of the curriculum. Thus, for students who are struggling to become better problem solvers, their difficulty due to the complexity of problem solving is compounded by the fact that many of them do not receive adequate instruction, in either quality or quantity' [20, p. 511].

The current study describes the development and implementation of a computer simulation problem-solving activity that elicits mathematical and engineering type thinking while students play within the problem space. The idea of 'play' as a way for students to interact with the system they are learning is not new. Dienes talked about both initial unstructured play followed by more structured play as necessary to enable students to grasp mathematical concepts [21]. This curricular tool in this study aims to provide students with a vehicle to play with the problem and to fill the curricular gap reported by Lester and Kehle [22]. This is done by creating supplementary problem-based learning student materials and engaging real-world simulations, as well as supporting teacher development by focusing on how to teach these much needed skills.

One specific approach to PCL is having students solve complex, client-driven problems through team-oriented activities called Model-Eliciting Activities (MEAs). Solutions to MEAs are generalizable models that reveal students' thought processes. The models created include procedures for solving problems and more importantly, metaphors for seeing or interpreting problems. The activities are such that student teams of three to four express their mathematical model, test it using sample data, and revise their procedure to meet the parameters of the problem. MEAs are based on models and modeling perspectives described by Lesh and Doerr [23] and are developed using six design principles as described in Table 1 [24–25]. The six principles are crucial in guiding the development of an MEA.

The format of a MEA is such that students are first introduced to the context through an advanced organizer. The organizer includes questions to help students individually begin to think about the situation in which they are being placed and assist them in organizing their mathematical understandings in a manner that will be advantageous to them as they work on the task [26–27]. MEAs are intended to be supplementary to the existing curriculum and are intended to be implemented anywhere from a few days to a few weeks.

The problem statement of the MEA introduces students to the activity. It is written so that students define for themselves the problem that needs to be solved. The students must assess the situation and create a plan of action to successfully meet the needs of the problem. The problem solving session re-

Table 1. Principles for guiding Model-Eliciting Activity development

Principle	Description
Model Construction	Ensures that the activity requires the construction of an explicit description, explanation, or procedure for a mathematically significant situation.
Generalizability	Also known as the *Model Share-Ability and Re-Useability Principle*. Requires students to produce solutions that are shareable with others and modifiable for other closely related mathematical situations.
Model Documentation	Ensures that the students are required to create some form of documentation that will reveal explicitly how they are thinking about the problem situation.
Reality	Requires the activity to be posed in a realistic mathematical context and to be designed so that the students can interpret the activity meaningfully from their different levels of mathematical ability and general knowledge.
Self-Assessment	Ensures that the activity contains criteria the students can identify and use to test and revise their current ways of thinking.
Effective Prototype	Ensures that the model produced will be as simple as possible, yet still mathematically significant for real life purposes.

quires a team of students to go through multiple iterations of testing and revising their solution to ensure that their procedure will meet the needs of the client. MEAs are thoughtfully crafted to provide students just enough information to make informed decisions to determine when the requirements have been met. One of the main differences between this type of task versus traditional mathematics problem-solving activities is the latter focus on the creation of a final answer to the question posed; whereas, MEAs focus on the development of mathematical (or STEM) models that represent an interpretation of one or more systems defined by the problem [28]. Having a rich stock of models that describe or simulate other systems promotes developing fluidity in mathematical thinking and learning to generalize in this manner is a foundational idea in all STEM disciplines.

Teaming during an MEA is necessary for two reasons. First, there is a time constraint. Students therefore cannot mull over the task for hours to think of things they may have missed. By requiring multiple perspectives, teams come to better solutions in less time [29]. Second, persons working in the fields of science, math, and engineering often must rely on the expertise of team members to complete assigned tasks. Being able to effectively work in teams is not a skill most people automatically possess. Therefore, it is necessary to put students in situations where it is essential to work in teams to develop these teaming skills [30].

When students see strong links between STEM disciplines and their real world experiences, students tend to: (1) be enthusiastic about learning mathematics and science [31–33]; (2) have better retention of mathematics and science knowledge, and for longer periods of time [34]; (3) be more engaged in mathematics and science [35–37]; (4) show sustained interest in mathematics and science [38]; and (5) develop greater self-direction and self-motivation towards mathematics and science. Instructional strategies such as MEAs provide an excellent context for students to learn mathematical problem solving.

With the implementation of the *No Child Left Behind Act*, it is imperative teachers understand what mathematics their students understand. Authentic assessments and PCL activities are key interventions to aid educators' understanding of students' learning. MEAs illustrate one such useful intervention. MEAs were created to be thought-revealing activities for teams of students that encourage the development of models that are frameworks for interpreting what the modelers see. This has two advantages beyond being an educational tool that helps students create conceptual understanding. First, MEAs can be used for research because they inherently allow others to see how students are thinking about a system. Second, MEAs are designed to document thinking. They are a proven mechanism to assess the knowledge and abilities that are expressed. Because MEAs are thought-revealing, teachers can assess whether or not students are thinking about the modeled system correctly.

2. The SimMath Project

The SimMath Project was funded by the Institute of Education Sciences (IES) under the Small Business Innovation Research Grant program granted to Seward Incorporated in Minneapolis, Minnesota. The project team was charged with creating an engaging computer simulation program that would support an existing MEA. Further details on the project can be found at simmath.com [39] The chosen MEA is known as the *Paper Airplane Contest*. In this MEA, students work in groups of three or four to develop judging criteria to determine which airplane should win various contests.

Students begin the task by first individually reading a newspaper article about the paper airplane

Table 2. Elements and description of the *Control Panel*

Element	Description
Grid	Turn on and off the coordinate grid on the ground.
Info	Display or hide the newpaper article detailing the airplane competition in a display panel.
Measuring	See a measuring tool that details the angle, distance from start, and distance from target for the last throw.
Path	Students choose to view no flight paths, last flight path, or all flight paths of a specific plane (maximim of 3 flight paths are visible at any time).
View	Change angle of view to: judges' view, top-down aerial view, or view from various points around the field. This function allows student to move around, explore the envronment, and see things from different angles.
Launch	Launch the next flight.
Relaunch	Launch the last flight again.
Flight Data	Display or hide all flight data flown displayed in a panel.
Scoreboard	See a close up of the scoreboard located on the playing field.
Chat	Use to chat with the teacher.
Help	Get help understanding the *Control Panel*. This panel also describes the purpose of the simulation in a display panel.
Lab	Move from the *Stadium* enviroment into the *Laboratory* environment. The *Lab* button is greyed out until all flights (N=36) are watched in the stadium.

competition and answering the following readiness questions: 1) What are the categories for which the airplanes should be judged?; 2) What types of measurements do you believe should be taken for each throw to judge the contest fairly?; 3) How should judges decide which airplane is the best floater?; and 4) How should judges decide which airplane is the most accurate? Students were put into teams and asked to write a brief message to the judges of the paper airplane contest to give the judges a procedure to determine which airplane wins in each category (see http://modelsandmodeling.net for a full copy of the task).

The paper-based version of the task is only what is reported above. The simulation version of the task has all of the information found in the paper-based version, except that the data for the task is provided in the computer simulation itself. The simulation has two components: a *Stadium* and a *Laboratory*. The *Stadium* provides students with the same data as the paper-based task whereas the *Laboratory* allows for exploration beyond the paper-based task. This will be explained in detail in the paragraphs that follow. Both environments are consistently linked through the *Control Panel* that appears on the bottom of each screen. Students interact with the environments using this panel. Buttons on the *Control Panel* perform the actions described in Table 2.

The *Stadium* provides students with a display of the data collected from four planes in a practice competition. Three different pilots throw each of the four planes. Multiple pilots and plane types were

Fig. 1. Side view of the *Stadium* in the SimMath program.

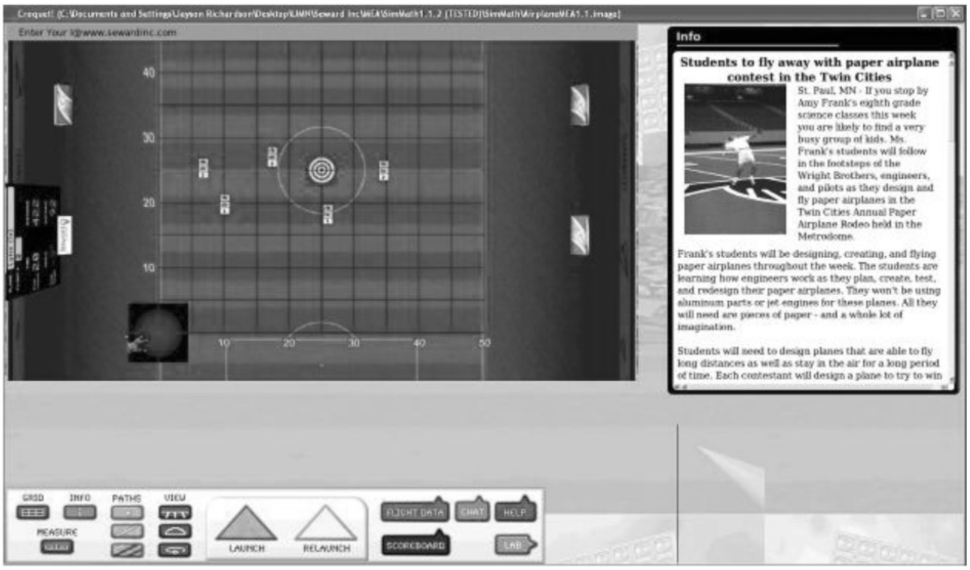

Fig. 2. Aerial view of *Stadium* with the Info panel displaying a newspaper article about the competition.

Fig. 3. Judges' view of *Stadium* with multiple paths displayed.

used because real paper airplanes fly differently when different pilots throw them. The judges need to factor out these effects and thus give awards to the best airplanes in each category—regardless of who flies them. Figs. 1, 2, and 3 display various aspects of the *Stadium* environment.

Once students have gone through the practice competition in the *Stadium*, they are taken into the *Laboratory* where they are given the opportunity to test different types of throws with the four planes to create judging criteria. In the *Laboratory*, students can select: plane type (Draco, Lynx, Hornet, Champ); height of throw (6 feet or 5 feet); force of throw (hard, medium, soft); and angle of throw (90, 60, 30, 15, 0, –15, –30). Figs. 4 and 5 display various aspects of the *Laboratory* environment.

3. Learning Objectives

The objectives of this research aimed to answer two key questions: (1) Does the method of delivery (simulation-based vs. paper-based) have an effect on teams' solutions to the *Paper Airplane Contest MEA*? (2) Do students and teachers using the simulations find them interesting and easy to use?

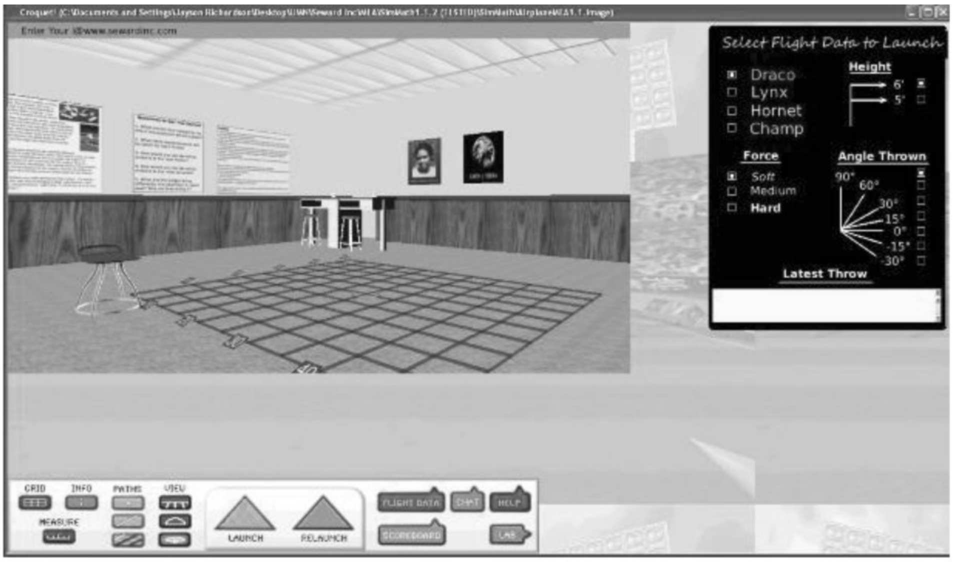

Fig. 4. *Laboratory* from judges' view displaying the *Select Flight Data to Launch* panel.

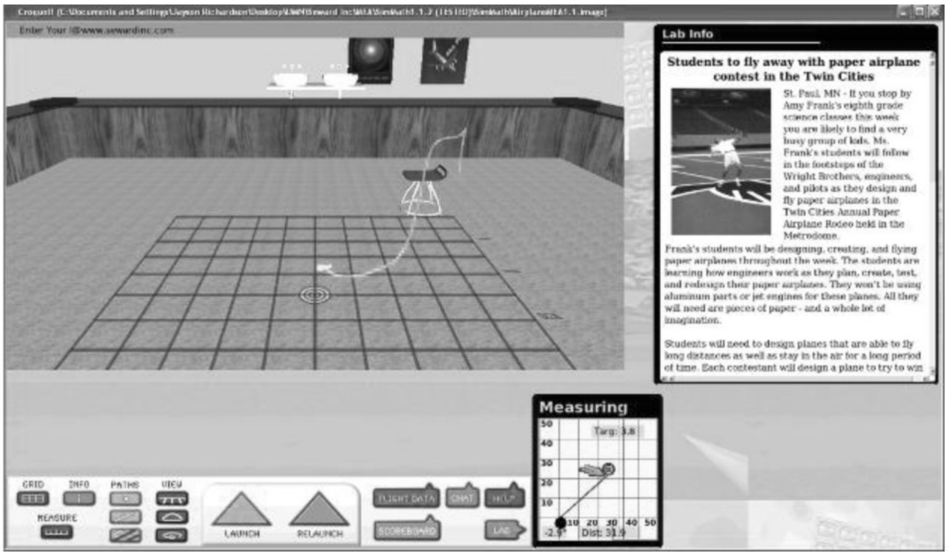

Fig. 5. Side view of *Laboratory* showing flight path (in green), *Lab Info* panel, and *Measuring* tool.

What follows is a description of the methodology followed by details of the data analysis.

4. Methodology

The study was conducted in fall 2008 within three second-year algebra classrooms (two different teachers) in a Midwestern high school. The MEA simulation was implemented in one section of each teacher's course. The paper version of the MEA without the computer simulation was implemented in a separate section of one of the teachers. The MEAs (simulated-based and paper-based) were completed over two consecutive days (75 minute class periods). The students in the sample were predominantly freshman, but included some sophomores and juniors. A breakdown of the research sample can be found in Table 3.

Two researchers and four graduate students were present during the entire testing phase. Data collected included video recordings of each session, audio recordings of each student group, surveys completed by each student, and unstructured interview questions of students and teachers throughout the testing.

Cognitive Task Analysis (CTA) was used to analyze team work products (i.e., team letters to the judges). CTA is a method of analyzing data that are related to 'knowledge, thought processes, and goal structures that underlie observable task performance' [40, p. 3]. While much of the published work using CTA has looked at individuals, it has

Table 3. Sample population

Class	Group	Teacher	Students
1	Simulation MEA	A	29
2	Paper-based MEA	B	30
3	Simulation MEA	B	31

been documented that an increasing number of studies are being done with teams as the unit of analysis [41], which is the case for the current study. CTA requires the development of a task model that describes subtasks necessary to complete a task successfully. Therefore, CTA is useful for interpreting the understandings and the ways of thinking of teams in the performance of a problem-solving task [42].

Based on the analysis of written work, audio recordings, video recordings, and researcher field notes, a task model was created to represent the subtasks for students' model development, which will be explained further in the results section. The development of the task model used the tools from Militello and Hutton's applied cognitive task analysis method [43]. We also drew on the work of Nathan and Koedinger who also developed task models of student work [44].

5. Results and discussion

The results below are organized by research question. The data were triangulated to better answer the questions. Since a major goal of this research was to inform the development of the future MEA computer simulations, the discussion also addresses this component.

> Question 1: Does the method of delivery (simulation-based vs. paper-based) have an effect on teams' process and solutions to the Paper Airplane Contest MEA?

One component of an MEA is model sharability (see Table 1). For this project, students presented their models to the class giving others the opportunity to test the model's generalizability. This also gave the teachers and the researchers a chance to understand model development and cognitive differences. Since Teacher B implemented the paper-based MEA and the simulation-based MEA, the researchers were only able to compare this teacher's perceptions between Class 2 and Class 3. Both Class 2 and Class 3 had eight student teams each.

A cognitive task model was created to analyze the team solutions to the problem. Four subtasks were identified as being necessary to solve this problem: (1) definition identification, (2) sampling strategies, (3) combination of statistical or mathematical analysis into a procedure, and (4) communication of the decision of a winner. Table 4 provides detailed descriptions of the subtasks. These subtasks were identified by analyzing the expert solutions to the task and then refined by analyzing student solutions. The subtasks were classified based on if a team's procedure within a subtask was a naïve, routine, or sophisticated strategy [45]. A rubric was created that described what constitutes each type of strategy. This rubric was developed first

Table 4. CTA subtasks and descriptions

Subtasks	Descriptions
Definition Identification	Having a clear definition of problem tasks is a good starting point in a complex problem-solving task. It may increase the possibility that students will evolve their problem-solving procedure effectively and efficiently. This subtask directly influences the following problem-solving processes because it works as a foundation stone. Based on their definitions of problem tasks, students select variables and determine how to combine them. In this subtask students bring their prior knowledge and experiences into the problem-solving tasks. Thus, it also provides teachers and researchers with a starting point to track students' misconceptions.
Sampling Strategies	This subtask includes variable selection and determining how much of the data are used. Students need to choose reasonable variables to reflect their definitions of the problem tasks. They determine what data is appropriate to describe or explain the given problem contexts based on their definitions. Beyond variable selection, students need to explore the nature of data so that the data for the variables they chose are required to test for a fair representativeness. A critical look at the data is required to avoid missing or distorting the solutions.
Combination of Statistical or mathematical Mnalysis into a Procedure	Students need to determine how to make a mathematical and statistical combination of data in order to describe or explain the given problem contexts. This is essential to create a model. Multiple attempts are made to combine the data that they selected and sorted. Students are required to consider all possibilities such as counterexamples because the models that they will develop should be reusable, sharable, and transportable. Students need to make clear justifications of their strategies. It strongly encourages students to bring their existing knowledge and experiences in mathematics and statistics to this subtask. Various misconceptions across several disciplines are revealed from students during this subtask.
Communication of the Decision of a Winner	Students need to clearly communicate their ideas in a group during MEAs. Multiple perspectives from group members should be welcomed, which may increase the possibility that a great model will be created. This subtask has strong influences on all preceding subtasks. Students also need to clearly communicate their ideas to the client. The models that they will develop should be reusable, sharable, and transportable by anyone who wants to use them including the client. Thus clear communication skill via writing is required with coherence in a logical way.

from looking at expert solutions to the problem, then looking at the range of student team solutions to the task.

Once the solutions were categorized as naïve, routine, or sophisticated for each subtask, these values were then translated into ordinal codes 0, 1, and 2 respectively. For each subtask, an independent sample Mann-Whitney U test, which is very much like a t-test when distribution of the means is unknown and the data are ordinal, was run on each subtask to see whether or not there were significant differences in the mean. Table 5 shows the means of subtask scoring for the simulation-based teams (N=16) versus the paper-based teams (N=16) and whether or not these differences are statistically significant.

We did see differences in two of the four subtasks. In the following paragraphs we describe the results seen and provide student team examples. For definition building and sampling, there were basically no differences found between the paper-based (PB) and the simulation-based (SB) teams. For definition identification, the means were exactly the same. All teams created a definition for floating and accuracy, but some made it explicit in the letter. Most teams, regardless of problem type, did not communicate their definitions explicitly in their solutions and were therefore coded with a naïve strategy. Team 1 (PB) and Team 2 (SB) were both coded as using a routine strategies for definition.

> Team 1 (PB): [The most accurate] planes will be thrown at a target.
> Team 2 (SB): The best floater is the plane that travels the furthest per second.

They each had an explicit definition for the constructs, but were not clear enough in their definition to allow for a sophisticated strategy rating.

Sampling strategies was another subtask where we saw no differences between the groups. Here the means were slightly different, but did not have statistical significance. Many teams were coded naïve for sampling because they used either unproductive or unclear sampling methods. The groups may have used some form of sampling but it would not have helped them to reach a sensible solution. Below are excerpts from Team 3 (PB) and Team 4 (SB). Both of these were coded as naïve strategies for sampling and developing explanations as to why this was the case.

> Team 3 (PB)—best floater: 'we think that to find the best floater you should find the average of the distance from start, time in flight, distance to the target, and angle from target.'

Using all of the variables and all of the data in Team 3's case is not a productive sampling method in order to determine which plane is the best floater. There is no rationale given for how all four variables could be used effectively.

> Team 4 (SB)—most accurate: 'You will judge the most accurate by averaging out all distance from target measurements from each plane thrown by each different pilot.'

This team's explanation was not clear. The phrase 'averaging out' is the main problem for this group. If they had phrased that they wanted to find the average of all distance from target measurements, it would have been understood easier. The way they worded this leaves room for doubt as to what they were trying to communicate.

The subtask *Combination of the Mathematical or Statistical Analysis into a Procedure* had a clear difference in the means of the groups and had statistical significance at the $p < 0.1$ level. Here the means were 0.25 and 0.56 for the paper-based vs. the simulation-based, respectively. In addition, the median codes were 0 and 1, respectively. A mathematical and statistical combination of data is essential to create a model. In this part, students needed to consider all possibilities for any contest. For example, students should consider counterexamples of their procedure to develop more reusable, sharable, and transportable models. Students also need to retest and revise their mathematical and statistical methods for a successful performance. This also provides more evidence of the claim that stu-

Table 5. Mann-Whitney U results of the simulation-based class versus the paper-based class on the subtasks of the problem

Subtask	Version of Problem	Means	U	N
Definition Identification	Paper-based	0.06	128	16
	Simulation-based	0.06		16
Sampling Strategies	Paper-based	0.63	120	16
	Simulation-based	0.69		16
Combination of the Mathematical or Statistical Analysis into a Procedure	Paper-based	0.25	88*	16
	Simulation-based	0.56		16
Communication of the Winner	Paper-based	0.25	104	16
	Simulation-based	0.44		16

* Significant at the $p<0.1$ level (two-tailed).

dents create useful mathematics when they see the need for it [46–47]. In the simulation-based classroom, students developed more useful models than students in the paper-based classroom. Team 5 (PB) and Team 6 (CB) are highlighted below.

> Team 5 (PB)—most accurate: 'For finding the most accurate plane, we found the averages of the angle from the target and distance from target. We think this formula can successfully determine the accuracy of planes.'

Team 5 was coded naïve for the combination subtask. Here, the team shows that they are using the mean of angle and distance from target, but they do not clearly state how they are going to combine these measures. They also state that this is a formula, but the communication of the formula is missing.

> Team 6 (SB)—best floater: 'To find the best floater, you need to find two averages. You need to find the average for the time in flight and the distance from the start. After you find the averages, you put the distance over time to find the distance per second. Whichever plane has the longest distance per second is the winner in this category.'

Team 6 was coded routine for the combination subtask. The team was detailed in their explanation of how to put the mathematical constructs together to build the procedure. They could have been clearer on whether or not to use all of the data for each variable. Not doing so prevented them from getting a sophisticated rating on this subtask.

In the paper-based classroom, only two of the eight teams received a routine or better rating for the combination subtask for either competition (best floater and most accurate); whereas in the simulation-based classroom, five of the eight teams received a routine or better rating for the combination subtask for either competition.

Finally, in the *Communication of the Winner* subtask we saw differences in the means between the two treatment groups; however, the differences did not show statistical significance. The means were 0.25 and 0.44 for the paper-based vs. the simulation-based, respectively. In addition, the median codes were 0 and 0.5, respectively. Here communication of the winner is making it clear how to use the information to make the final decision. As an example see the last sentence in the Team 6 (SB) above. Teams were coded naïve if their communication of a winner was unclear. For groups rated as routine, communication was relatively well done but still needed some adjustment to be clearer. The teams that were coded sophisticated had communication that could be understood by someone who was new to the problem task.

In general, we determined that the solutions developed by students in the simulation-based teams were significantly more advanced with regard to mathematical analysis as well as determining a winner, which was the end task. This indicates that the computer-based simulation was more effective at getting student to both use more advanced mathematical skills and communicating the results of using those skills. Additionally, it was determined that using the computer-based MEA was as effective as using a paper-based MEA with regard to getting students to accurately identify the problem and effectively choose variables to include in the analysis.

> Question 2: Do students and teachers using the simulations find them interesting and easy to use?

Data from students and teachers in all three classrooms were used to inform this question. Students and teachers overwhelmingly reported that the program was appealing and easy to use. Student comments included:

- 'It was realistic'
- 'It was an interesting and fun way to learn. It was more hands-on'
- 'It helped me to visualize the situation better'
- The simulation was 'very easy to use'
- 'It was easy to navigate'

The teacher made the following observations about the process of using the computer-based simulation while solving the MEA:

- The student conversations were much richer with the computer simulation group versus the paper MEA group.
- The simulation-based MEA allowed the teacher more time to work with individual groups since students were able to immediately use the simulation with little to no teacher direction.
- The simulation was engaging. It hooked students and got them started quickly.
- On a scale from 1–5 where five is highly engaged, the teacher rated student engagement as a five with the simulation compared to a three with the paper version.
- Student conversations and models included more complex variables with the simulation versus the paper version. For example, with the simulation-based MEA group, some students investigated the flight path and the angle from the target and included those measures in their model. In the paper-based MEA version, these components were not present in any student group.
- An unanticipated outcome came from the tea-

cher's observation of a child with Asperger's Syndrome. The teacher noted how this student was exceptionally engaged and challenged. It was noted that this student was able to work well within his group and even help his group members better understand the MEA.

The teachers also offered two recommendations regarding future implementations. First, teachers need to have formal training to both successfully navigate an MEA and make full use of the computer simulation. This training could be completed one-on-one or via a DVD. This training should include scenarios so teachers are better prepared to engage, probe, and move students through a computer-based simulated MEA. Second, teachers need a chance to play with the simulation to become familiar with its components. Thus, teachers need the opportunity to act as students and simply play.

Most of the challenges identified dealt with the MEA itself and not the simulation. This result was expected and is intended with MEAs. For instance, many students thought the task was very challenging and reported that it was hard to discover an appropriate solution. Nonetheless, software challenges included: (1) Lag times were evident on older and less powerful computers; and (2) Students could only see paths from flights thrown in the queue. Thus if the user is on throw 22, she cannot see the path for flight 5.

6. Conclusions

The drain of human capital out of the field of engineering can be partially attributed to the lack of adequate preparation in both mathematics and science. To aid the reversal of this and therefore provide more pathways for students to enter into STEM fields and engineering specifically, ways must be found to increase the mathematical, scientific, and problem-solving skills of our students; and we must start at a young age. Practically every professional mathematical and scientific organization lists problem-solving skills and higher-order thinking as a priority [48–49]. It is known that when students are engaged in meaningful, socially-oriented, hands-on activities, higher-order thinking is elicited. Model-Eliciting Activities are one way to help students achieve these goals. MEAs engage students with authentic, client-driven problems that entail the use of communication, reasoning, manipulating, predicting, and negotiating meaning. These go much farther and deeper than traditional textbook problems [50]. In addition to the benefit they provide students, the use of MEAs also creates a clearer window through which we can better gauge the problem-solving skills of students. Whether teachers use MEAs in a traditional classroom setting, or by use of computer simulation, the benefits for students are profound.

The computer simulation used for the MEA in the current study was an extremely useful tool in this emerging area of research. In this one school, students made larger strides toward successful problem solving when engaged in the simulation-based MEA versus those who were engaged in the paper-based version of the same MEA problem. This research should act as a catalyst for future research to determine if students who are allowed to 'play' in their context are more engaged and have better problem-solving practices. This line of research has great potential when developing future simulation-based MEAs.

The current study has numerous limitations with regard to replication. First, to conduct a simulation-based MEA, teachers and students need to have computer access and at least minimal proficiency with using computers, as well as a rudimentary willingness to engage in play. Due to the exploratory nature and robustness of MEAs in general, time may also be a limitation. However, classroom teachers who use the computer simulation and apply proper time constraints, this limitation can be somewhat abated.

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