The Use of Modeling and Simulation as an Instructional Strategy in High School Math and Science Classes

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Abstract – In May, 2008 a Hampton Roads, Virginia school district approved a Modeling and Simulation Demonstration School Project at a district high school. The project incorporates modeling and simulation as an instructional strategy within math and science curricula. This project was undertaken on the recommendation of the Hampton Roads Modeling and Simulation Initiative organized by NASA Langley Research Center and was implemented in partnership with the National Institute of Aerospace. During the 2008 – 2009 school year a team of three math and three science teachers mapped math and science curricula, developed lessons incorporating modeling and simulation, and participated in on-going professional development. Teachers used open source and commercial modeling and simulation tools to develop the lessons. This paper provides an overview of the project; a description of work accomplished and lessons learned during the 2008 – 2009 school year; and the expansion of the project during the 2009 – 2010 school year.

Keywords: modeling, simulation, STEM, K-12, classroom

BACKGROUND

The importance of engaging students in science, technology, engineering, and mathematics (STEM) subjects cannot be understated. There is growing alarm in the business and government communities over the lack of young adults entering the fields of engineering, math, and science as evidenced by reports exemplified by *Rising Above the Gathering Storm.* [National Academy of Sciences, 6] In order to increase the number of students pursuing careers in math, science, and engineering it is important to engage them early, before they decide on what they will study in college.

Modeling and simulation is a promising approach to engage students. In simplest terms, a model is a representation of a physical object or system and a simulation is the operation of a model over a period of time. With the advent of relatively inexpensive but powerful computers, the use of modeling and simulation has grown and is used in many diverse fields across academia, business and industry, and the military. Modeling and simulation in K-12 education is one approach to developing student-centered instruction that can develop in students the key 21st Century skills of creativity and innovation; critical thinking and problem solving; and communication and collaboration [Partnership for 21st century Skills, 9].

Epstein suggested sixteen reasons other than prediction to build models [Epstein, 1]. Among these reasons were: to explain, to guide data collection, to illuminate core dynamics, to suggest dynamical analogies, and to promote scientific habits of mind. These reasons align with the national standards for science education [National Research Council, 8], the national mathematics standards as set forth by the National Council of Teachers of Mathematics [National Council of Teachers of Mathematics, 7], as well as supporting the general principles of K-12 engineering education as set forth by the National Academy of Engineering in their latest report on engineering in the K-12 curriculum [National Academy of Engineering, 5].

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The National Science Foundation grant project *Modeling Instruction in High School Physics* investigated the impact of the use of modeling on student achievement. This project ran from 1994-2000 and involved 300 teachers and 20,000 students. In the final report [Hestenes, 3], it was noted that student normalized gains on the Force Concept Inventory (a test designed to assess student knowledge of the concepts involved in forces) were typically double for students who were taught physics using models versus students who were taught using traditional physics instructional methods. In a follow-up study conducted at Carnegie Mellon University [Malone, 4], it was found that the students who learned using models had a more expert-like knowledge structure as compared to the students taught with traditional methods. Students' problem solving skills were also more expert-like and these students both made fewer errors when solving physics problems and also caught a higher percentage of their own mistakes.

Other research has centered on the modeling program STELLA. STELLA is a systems thinking software package which allows users to model the interrelationships between the different constituents of systems. One study was conducted using high school juniors and seniors and students at a community college, all of whom were studying economics. The control group learned about Gross Domestic Product by reading a narrative while the experimental group learned by reading a narrative that was supported with STELLA models of Gross Domestic Product. The students who learned aided by a model scored better on a post-test than those who simply read [Wheat, 10], although the statistical significance was not conclusive ($p < 0.08$).

The CoreModels Program in Maryland sought to integrate STELLA into the science curriculum [Friedman, 2]. In this project, teachers were given professional development in the use of STELLA to teach science concepts with the ultimate goal of engaging students using modeling to study and understand various scientific processes. This study showed that students who were exposed to modeling as an instructional method were better able to look at a model of a scientific process and explain it in relation to the physical system it represented.

Realizing the importance of modeling and simulation and the lack of awareness of its instructional use in the Hampton Roads area, NASA Langley Research Center spearheaded the formation of the Modeling and Simulation (MODSIM) Education and Training Advisory Committee in 2007. The committee adopted a two-pronged approach to implement MODSIM – awareness and demonstration. In collaboration with the National Institute of Aerospace (NIA), several professional development sessions were conducted for teachers in the use of MODSIM in the classroom. Content-specific sessions were held for algebra (February 2008), biology (April 2008), physics (June 2008), and middle school math and science (October 2008). A session on object-oriented programming using Scratch was also conducted (April 2008).

In May, 2008 a Hampton Roads school district approved the MODSIM Demonstration School Project at one of the school system's high schools. The site selected also houses a math and science academy in a "school-within-a-school" model. The purpose of this project is to use modeling and simulation as an instructional strategy within math and science instruction and to demonstrate ways to integrate math and science instruction through the use of models and simulations. Mark Clemente, NIA Educator in Residence and local area teacher, serves as project lead. A cadre of six teachers at the demonstration site was selected to participate in the project. This cadre consists of three math teachers representing Algebra 1, Algebra 2, and Precalculus; and three science teachers representing Earth Science, Biology, Chemistry, and Physics. Of the three science teachers, only one (Physics) teaches math and science academy courses. Two of the math teachers (Algebra 2 and Precalculus) teach a combination of math and science academy and general population courses and the third math teacher teaches only general population students. The key features of the project include:

- the use of a variety of commercial and open source modeling and simulation software packages.
- on-going professional development over the course of the school year to support the development of MODSIM-based lessons.
- paid summer curriculum development.

What follows is a review of the development of the project during the 2008 -2009 school year and a discussion of the vision for this project for the 2009 – 2010 school year and beyond.

PLANNING AND LESSON DEVELOPMENT

The project coordinator and participating teachers met for three days during the summer of 2008 to lay the foundation for year one. They began by informally mapping the curricula. A topic listing for each subject, organized by academic quarters, was developed. The teachers then correlated math and science topics looking for connections that could possibly lead to integrated math and science lessons.

The next step in the planning process was to review available MODSIM tools and identify a set of tools for year one. The coordinator had previously assembled a listing of available tools and web sites which served as the starting point for the review. The following software packages were selected:

- STELLA® - the demonstration site owns a site license for the software and two of the teachers had attended training during the awareness phase.
- Interactive Physics – the demonstration site owns a class set of licenses and the Physics and Precalculus teachers saw many avenues for common lesson planning using this software.
- Scratch – This is open source software and three of the teachers had attended training during the awareness phase.
- Excelets – This is open source software, has many modules already developed, is easy for students to manipulate, and only requires Microsoft Excel to run.
- ExploreLearning Gizmos – This subscription service has preconstructed modules with accompanying questions and quizzes, is easy to use (for teachers and students), and is correlated to standards.

The final step in the planning process was to begin outlining lessons that would incorporate MODSIM as the core instructional strategy within the lesson. The teachers spent time individually and in math/science pairs brainstorming ideas for lessons.

Over the course of the 2008 – 2009 school year, the project teachers submitted their MODSIM lesson materials to the project coordinator. They also submitted a lesson feedback form detailing the type of activity conducted and the level of inquiry associated with the lesson (see Appendix A for a copy of the form). A summary of some of the reporting information is included in Table 1.

Table 1. Summary of Data Reported on Lesson Feedback Form.

Number of lessons using MODSIM for	
Instruction	34
Formative Assessment	20
Summative Assessment	10
Number of lessons implementing MODSIM through	
Direct Instruction	8
Discussion Initiation	13
Guided Inquiry	29
Open Ended Assignment	12
Students Modifying an Existing Model	8
Students Creating a Model	4

To raise awareness of the project, the project coordinator posted the lesson to the Hampton Roads MODSIM Initiative's wiki, modsim.wikispaces.com. Over the course of Year 1, a total of 34 lessons were developed and 30 were posted to the wiki (9 mathematics, 19 science, and 2 joint math/science). Note that the totals for groupings of use exceeds 34 because the model was used in different manners over the course of the lesson.

Professional Development

The project teachers participated in four professional development (PD) days coordinated by NASA and NIA, one per quarter, over the course of the school year. The first PD day focused on STELLA®. To familiarize the teachers with the software, iseesystems, the developers of STELLA®, provided a set of high school level systems dynamics

workbooks and access to online tutorials prior to the PD day. On the PD day, a software engineer from iseesystems conducted training with the teachers via web conferencing. He introduced the teachers to the software the morning of the PD, gave the teachers time to work with the software, and reconnected with the teachers the afternoon of the PD to answer specific questions.

The subject of the second PD day was Excelets. Dr. Scott Sinex, a professor at Prince George's Community College in Maryland and creator of Excelets, conducted a web-based synchronous workshop introducing the teachers to Excelets and how to develop them.

The third PD day was devoted to collaboration, lesson plan development, and preparing for workshop presentations for the Virginia Society for Technology in Education (VSTE) conference.

A workshop on Scratch was conducted for the final PD day of the year. This workshop was conducted by Dr. Rasha Morsi of the Creative Gaming and Simulation Lab at Norfolk State University and funded by a grant from Opportunity, Inc. This workshop was open to area math and science teachers. Fourteen teachers attended this workshop.

RESEARCH

A research component was built into the project to validate the work that was being accomplished. Dr. Ginger Watson, Associate Professor of Instructional Design and Technology at Old Dominion University and Associate Professor - Research Faculty at the Virginia Modeling Analysis and Simulation Center worked with the projector coordinator to develop and conduct research in three areas: changes in student attitudes towards math and science when exposed to MODSIM as an instructional strategy; the effectiveness of using MODSIM as an instructional strategy; and the needs of teachers trying to implement MODSIM in the classroom. Below is a summary of each of the studies.

Student Attitudinal Survey

NIA, in conjunction with Old Dominion University, designed and implemented a student attitudinal survey in the fall of 2008. This survey was designed to track changes in students' attitudes toward math and science when exposed to modeling and simulation as an instructional strategy.

The survey was conducted at the end of October 2008 and again at the end of May 2009. The questions targeted attitudes in four distinct areas: Making Connections Between Math and Science, Math and Science Classes, Problem Solving, and Working with Others. The same group of students was asked to complete the survey both times. The survey was voluntary and fewer students chose to respond in the spring than in the fall. A summary of the survey results appears in Table 1.

Table 2. Changes in Students' Attitudes When Exposed to Modeling and Simulation.

	Fall 2008 N = 180	Spring 2009 N = 72
Making Connections Between Math and Science	3.80	3.99
Math and Science Classes	3.61	3.75
Problem Solving	3.81	4.05
Working with Others	4.13	4.38

1 = Strongly disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly Agree

When the data is disaggregated by enrollment in the academy program, the gains observed from fall to spring for the non-academy population are much greater than for the academy students. Most notable, in the category of Problem Solving, non-academy students' scores were actually higher than academy students in the spring survey. This data can be found in Table 2.

Table 3. Changes in Students' Attitudes Disaggregated by Academy Enrollment.

	Fall 2008		Spring 2009	
	Academy N = 95	Non-Academy N = 85	Academy N = 60	Non-Academy N = 12
Making Connections Between Math and Science	4.07	3.51	3.99	4.00
Math and Science Classes	3.79	3.40	3.94	3.65
Problem Solving	3.96	3.64	4.03	4.15
Working with Others	4.12	4.15	4.39	4.33

1 = Strongly disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly Agree

Effectiveness Study

A lesson-effectiveness study was conducted during the May/June 2009 time period. This study examined the unit test scores of two chemistry teachers teaching the Gas Laws unit, one using modeling and simulation the other using traditional direct instruction and laboratory experiments. There were 91 students/four sections in the modeling and simulation group and 66 students/three sections in the traditional group. Before instruction began, these teachers met and agreed on the specific objectives to be taught and developed a single unit test that both would use at the end of the unit. The analysis examined the short answer responses from a sampling of five students from each section in both groups. The short answer questions were classified as one of three types: directed (questions that had only one correct answer and did not require analysis by the student), convergent (questions that had one correct answer but required the student to analyze the question in order to determine the answer), and divergent (questions that had multiple approaches and required students to synthesize their knowledge to produce an answer). The test had six directed questions, four convergent questions, and three divergent questions. A summary of this analysis can be found in Table 3.

Table 4. Analysis of Student Short Answer Responses

	Modeling and Simulation N = 20	Traditional N = 15
Directed	2.03	1.46
Convergent	2.07	1.72
Divergent	0.81	0.82

0 = incorrect/no answer, 1 = partially correct, major inaccuracies, 2 = partially correct, minor inaccuracies, 3 = correct

Although the averages on the divergent questions are nearly identical overall, the students not exposed to modeling and simulation scored slightly higher on two of the questions while students exposed to modeling and simulation scored higher on one of the questions.

Teacher Needs Survey

A short survey of teacher needs was conducted in conjunction with the Scratch workshop held at the end of April. Teachers were asked about their use of Scratch as well as other MODSIM tools as part of instruction. The survey data was disaggregated to study the response of the teachers involved in the MODSIM Demonstration Project against teachers who were not involved in the project. These other teachers were not asked about their use of modeling and simulation tools, however attendance at the workshop was voluntary and thus indicates interest in at least exploring the use of these tools in classroom instruction. Overall, the attitudes of teachers, both those involved in the MODSIM Demonstration School project and those who were not, were positive toward the use and effectiveness of this approach. When the data was disaggregated, the responses of the teachers involved in the project were significantly higher than those who were not, except on the question of equipment availability, where both groups scored this item about the same. Of the eight statements that the teachers rated, five of them had at least a one point difference between teachers involved in the project and teachers not involved. These five statements appear in Table 4. It is interesting to note that all teachers attending the workshop reported having at least six years of teaching experience.

Table 5. Selected Teacher Responses

Question	All Teachers N = 12	MODSIM Teachers N = 4	Other Teachers N = 8
I will use Scratch in my classroom.	4.25	5.00	3.88
I will share the information I learned in this session with other teachers.	4.33	5.00	4.00
I am familiar with modeling and simulation tools that can be used to teach my curriculum.	3.67	4.50	3.25
I am comfortable using modeling and simulation tools in my classroom.	3.33	4.00	3.00
I plan on using modeling and simulation tools in my classroom.	4.25	5.00	4.25

LESSONS LEARNED

The six teachers participating in the program, as well as the building-level and central office administrators, felt that this was a worthwhile project and one that should be continued. At the end of the school year, the participating teachers met with the program coordinator to discuss lessons learned from the first year of the project. The most important lessons learned were:

- MODSIM lessons are inquiry-based and student driven. Knowledge of how to manage an inquiry-based classroom is essential for the lessons to be successful. Teachers should receive training in inquiry-based instruction as they enter the project.

- The focus for the first year of implementation should be on a small number of MODSIM tools that use pre-constructed models or simulations. More complex tools are easier to incorporate once teachers have a solid understanding of how MODSIM fits into their curricula.

- Teachers need the first year to determine the topics in their curricula that lend themselves to a MODSIM approach. Having a library or source of pre-constructed models and simulations allows teachers to spend more time on finding curricular connections rather than learning new software.

- The dedicated professional development days during the summer and school year are key to sustaining the project. These days serve to refocus and re-energize the teachers as well as to give them time to plan/collaborate.

2009 -2010 SCHOOL YEAR AND BEYOND

During the summer of 2009, the six teachers involved in the project had the opportunity to attend additional professional development activities. During the week of July 27 – 31, 2009 the teachers met and talked to researchers from NASA Langley Research Center who are using MODSIM in their work. The researchers discussed their specific field, how they use MODSIM, and the high school level math and science connections they saw in their work. The teachers had the opportunity to ask specific questions of the researchers with the hope that the teachers could use this information to connect their content to real-world applications.

The teachers met again on August 24, 25, and 27 to plan for the 2009 – 2010 school year. The first day was dedicated to training on how to write and implement guided inquiry lessons in the classroom.

The 2009 – 2010 school year will also test the replicability of the Demonstration School project. During this school year, both Portsmouth Public Schools and Franklin City Public Schools will implement a Demonstration School site. Portsmouth plans on implementing the project at Churchland High School following the three math/three science teachers model of Ocean Lakes High School. Churchland follows a “four by four” block schedule and will implement the program at the beginning of the second semester. Franklin, a much smaller school system, has one math and one science teacher participating at Franklin High School. Representatives of both school divisions are currently working with the project coordinator to train and implement the project.

As other schools come on line, the challenge will be to coordinate all efforts and build collaboration and planning across buildings and school systems both synchronously and asynchronously. The project coordinator will work with all schools involved to set up a common professional development day to allow for synchronous collaboration, either face-to-face or via web conferencing. To facilitate asynchronous interaction, the project coordinator will set up a private Google Groups site for the teachers to post messages, questions, files, and comments.

As in Year One, there will be ongoing research built into the project. The project coordinator will continue developing research projects in the areas of student attitudes towards math and science and the effectiveness of MODSIM as an instructional strategy.

Beyond Year 2

A goal of the MODSIM project is to create a self-sustaining network of teachers to support each other and guide other teachers in implementing MODSIM strategies in the classroom. Although the Google Groups site will be used as a short-term answer to build this network, a more ambitious long-term solution is envisioned. This long term vision includes the use of a virtual world to nurture the self-sustaining MODSIM network.

The use of a virtual environment would give teachers more flexibility to form collaborative networks not constrained by geography or time. Professional development and training in MODSIM tools could be conducted in a more cost effective fashion. Teachers would be able to showcase lessons and demonstrate new software tools. It would also provide a place for student collaboration as well. Areas could be designated for students to work on projects, once again eliminating the constraints of geography and time. A virtual world lends itself nicely to the use of authentic assessment and allows for multiple forms of assessment.

Although the demonstration site is still in its infancy, early indications are that MODSIM is an effective way to engage students in content and, once established, can be implemented by teachers at little cost beyond supporting sustained, focused professional development over the course of the school year. With the active support of all partners involved, this project has the potential to serve as a model for authentic, best practice 21st century teaching and learning.

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Appendix A

MODSIM Lesson Feedback

Date: _____

Subject: ☐ Earth Science ☐ Biology ☐ Chemistry ☐ Physics
☐ Algebra 1 ☐ Algebra 2 ☐ Precalculus

Topic: _____

Number of students: _____ **Grade Level:** ☐ 9 ☐ 10 ☐ 11 ☐ 12
(check all that apply)

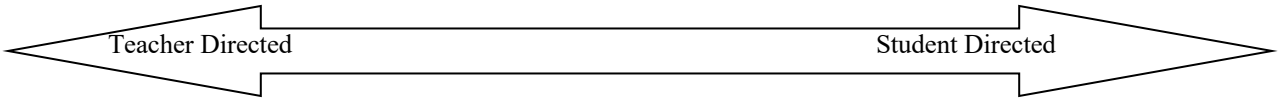
Summary of lesson:

Describe the role of Modeling and Simulation in the lesson. Include specific information about the model/simulation such as program used, web site address, etc.

Modeling/Simulation was used for (check all that apply):
☐ Instruction (Indicate the most appropriate level)
☐ Engage ☐ Explore ☐ Explain ☐ Extend
☐ Formative assessment
☐ Summative assessment

Indicate the use of modeling/simulation in this lesson using on the following continuum:

Teacher used MODSIM for direct instruction	Teacher used MODSIM to initiate classroom discussion	Students given guided assignment using preconstructed model/ simulation	Students given an open-ended assignment using preconstructed model/ simulation	Students modify a preconstructed model/simulation	Students design their own model/simulation
☐	☐	☐	☐	☐	☐



Modifications/Suggestions/Ideas to improve lesson:

Other comments:

Email completed evaluation forms to mark.clemente@nianet.org