Modeling Instruction in Physical Science: Effect on Student Achievement in Physical Science and Algebra I

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Abstract

This paper lays the foundation for an action research project concerning Modeling Instruction in a ninth grade Physical Science course, from inception of the research question through a preliminary literature review and ethical considerations. Modeling Instruction is a constructivist, student-centered approach to teaching science, where students perform experiments to collect data and create models--mathematical, graphical, and diagrammatic--that represent the data. Students then test their models with more experiments, refining their models for use in various situations. Research shows that student achievement in science is higher for students participating in courses with Modeling Instruction at any grade level, but few studies have been done to determine the effect of Modeling Instruction on student achievement in both Physical Science and Algebra I. This research has the potential to improve science education by showing the effects of Modeling Instruction on student achievement, thereby adding to the research base in science education.

Keywords: Modeling Instruction, STEM Education, action research, Physical Science

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Science, technology, engineering, mathematics: Together, these fields in education are combined into the acronym "STEM," which has become one of the most ubiquitous terms in education. A quick search of the term "STEM Education" returns "about 32,600,000 results" from the web tab and "about 9,750,000 results" from the news tab of Google (STEM Education, n.d.), and many of the results from the news tab reference articles describing multimillion dollar donations to many different organizations. From the sheer number and scope of these references, many groups have a vested interest in the quantity and quality of students who pursue careers in STEM fields. Further, due to the profound impact teachers have on students, these organizations have become very interested in teacher quality; for STEM education, the United States Department of Education alone has contributed 141.9 million dollars in 2013, 149.7 million dollars in 2014, and requested 319.7 million dollars for 2015 (U.S. Department of Education, 2014, p. 20).

With the rising interest in STEM education, all states have a coalition of organizations that work together to improve student achievement in STEM fields (State by State Initiatives, 2015). The state of South Carolina has the Coalition for Mathematics and Science, which "brings together advocates from business/industry, education, government and community organizations to catalyze action" (Mission & Vision, 2014). Many school districts, including Charleston County School District (CCSD), utilize curriculum designed by Project Lead the Way, "the nation's leading provider of K-12 STEM programs" (About PLTW, 2014). Laing Middle School in CCSD is a school that has utilized "aspects of STEM concepts in all academic curriculum since 2012," and "has been identified as one of the top middle schools in the nation for its interdisciplinary approach to teaching [STEM] subjects" (Kerr, 2015).

To determine the extent student achievement is impacted by the interventions, curricula, and instructional methods, organizations utilize research to answer questions about their programs and provide evidence about the efficacy of the programs. Research may happen on the national, state, district, school, or teacher levels, and have a scope from thousands of teachers and students to a single teacher and students in one class. Historically, "research has been conducted primarily by professionals whose principal education included training in the conduct of research studies," but "more and more research is being conducted by *practitioners*--people whose primary education and training is *not* in research methodology" (Mertler, 2014, p. 4). A specific "type of practitioner-based research, known as *action research*," can be

> defined as any systematic inquiry conducted by teachers, administrators, counselors, or others with a vested interest in the teaching and learning process. ... The basic process of conducting action research consists of four steps:
>
> 1. Identifying an area of focus
> 2. Collecting data
> 3. Analyzing and interpreting data
> 4. Developing a plan of action (Mills, 2011; Mertler, 2014, p. 4)

Once the plan of action has been implemented, the teacher-researcher will "make revisions and improvements to the project for future implementation, ... [and] the effectiveness of the revisions would be monitored and evaluated, with new improvements developed for the next phase of implementation" (Mertler, 2014, p. 37-38). The cyclical nature of action research gives power to the teacher-researcher, because they may build from previous research experience to make major changes and improvements for a particular course, department, or issue in a school.

I have been interested in all the parts of STEM for many years: As a high school student, taking all available upper-level STEM courses; as an undergraduate student, majoring in physics and performing research at several national laboratories and with professors at my institution; as a high school teacher, leading courses in physics, mathematics, and engineering; and as an employee of an engineering firm, helping to draft and design mechanical and electrical systems for buildings. I am now highly concerned with curriculum, instruction, and assessment in STEM courses, and my action research will focus on the instructional methods in a Physical Science course.

Evolution and Importance of Research Question

After starting coursework for the Doctor of Education program in January, I began a list of questions that could serve as a solid foundation for action research. The question "Should students take physical science?" arose from a conversation within CCSD about a good sequence of science courses, but this question was rejected due to a large scope and logistical difficulty. Another question, " Is there a way to incorporate data-taking into lower-level mathematics courses?" emerged as I considered ways to improve student achievement in mathematics, but this question was rejected because I lack in-depth knowledge of the curriculum and instruction for lower-level mathematics courses.

As a teacher of Physics and Physical Science, I have known of an instructional method called Modeling Instruction for several years. I became interested in implementing this method into my courses, but there were no opportunities to take a workshop about this method within a five-hour drive. As a result, I decided to host a workshop at Wando High School, and after the workshop I became convinced of the power of this instructional method. My action research questions became focused on Modeling Instruction, including "Is there a way to incorporate Project-Based Learning and Modeling Instruction?" This question was rejected because the Modeling Instruction materials would be heavily modified to include Project-Based Learning strategies, which would be a very large undertaking. Another question, "What is the effect of Modeling Instruction on student achievement in Physical Science?" may be implemented as action research, but I wanted to include student achievement in mathematics. Using the idea of student achievement in both Physical Science and mathematics through instructional methods in Physical Science produced my research question, and I hope to see positive effects on student achievement in both courses. This action research, whether there are positive effects or not, will play a part in furthering STEM education at Wando High, in CCSD, and potentially throughout South Carolina.

Research Question

What is the effect of Modeling Instruction in Physical Science on the achievement of ninth grade students in Physical Science and Algebra I? This question will be the focus of my research, and posing this question allows an opportunity to combine science and mathematics. There are very few studies to date that have a dual focus; most of the studies incorporating Modeling Instruction have only analyzed the effects of student achievement in the science course. Physical Science is currently the course that all ninth grade students take at Wando High School, and approximately three-fourths of the students take Algebra I as their mathematics course. With a ninth grade cohort of over 1,000 students, there should remain a large sample of eligible students after removing those students who are not taking Algebra I as their mathematics course. This research question will also serve as a pilot for the use of Modeling Instruction as the method of instruction in a Physical Science course. If the research shows positive student achievement in Physical Science and Algebra I, then there would be a strong case to incorporate Modeling Instruction into all Physical Science courses at Wando High School and throughout CCSD. The action research would continue with a larger set of students and teachers, providing valuable feedback to the STEM community of CCSD.

Review of Literature

Modeling Instruction

"Modeling Instruction is an evolving, research-based program for high school science education reform that was supported by the National Science Foundation (NSF) from 1989 to 2005" (Jackson, Dukerich, & Hestenes, 2008, p. 10). "When NSF funding for Modeling Instruction ran out in 2005, the teachers took over, creating a nonprofit organization of their own, the *American Modeling Teachers Association* (AMTA), to keep the program going" (Hestenes, 2015, p. 102). Modeling Instruction is based on the following:

Coherent instructional objectives

- To engage students in understanding the physical world by ***constructing and using scientific models*** to describe, to explain, to predict, to design and control physical phenomena.
- To provide students with ***basic conceptual tools*** for modeling physical objects and processes, especially mathematical, graphical and diagrammatic representations.
- To familiarize students with a small set of basic models as the ***content core*** of physics [and chemistry, biology, and physical science].

- To develop insight into the ***structure*** of scientific knowledge by examining how *models* fit into *theories*.
- To show how scientific knowledge is ***validated*** by engaging students in *evaluating* scientific models through comparisons with empirical data.
- To develop skill in all aspects of modeling as the ***procedural core*** of scientific knowledge.

Student-centered instructional design

- Instruction is organized into ***modeling cycles*** which engage students in all phases of model development, evaluation and application in concrete situations -- thus promoting an integrated understanding of modeling processes and acquisition of coordinated modeling skills.
- The teacher sets the stage for student activities, typically with a demonstration and class discussion to establish common understanding of a question to be asked of nature. Then, in small groups, students ***collaborate*** in planning and conducting experiments to answer or clarify the question.
- Students are required to present and justify their conclusions in oral and/or written form, including a ***formulation*** of models for the phenomena in question and ***evaluation*** of the models by comparison with data.
- Technical terms and representational tools are introduced by the teacher as they are needed to sharpen models, facilitate modeling activities and improve the quality of discourse.

- The teacher is prepared with a definite ***agenda*** for student progress and ***guides*** student inquiry and discussion in that direction with "Socratic" questioning and remarks.
- The teacher is equipped with a ***taxonomy*** of typical student misconceptions to be addressed as students are induced to articulate, analyze and justify their personal beliefs. (Wells, Hestenes, & Swackhamer, 1995, p. 614)

Modeling Instruction has been shown to produce positive gains for student achievement on many different assessments, but the earliest research focused on student achievement on the Force Concept Inventory (FCI). The questions on the FCI "are based on a detailed taxonomy of *common sense (CS) concepts of force and motion* derived from research," and "each question requires a forced choice between a Newtonian [the correct] concept and CS alternatives for best explanation in a common physical situation" (Hestenes, 2006, p. 17). Table 1 "summarizes data from a nationwide sample of 7500 high school physics students involved in the *Modeling Instruction Project* during 1995-98," and now there are "many examples of [modeling teachers] who consistently achieve posttest means from 80-90%" (Hestenes, 2006, p. 17).

Table 1

FCI Mean Scores Under Different Instruction Types

Instructional Type	FCI Mean Score (%) - Pre-test	FCI Mean Score (%) - Post-test	Difference of Post-test and Pre-test (%)
Traditional	26	42	16
Novice Modeling Teachers	26	52	26
Expert Modeling Teachers	29	69	40

Modeling Instruction in Ninth Grade

Modeling Instruction has typically been implemented in ninth grade within a Physics course, because some schools and districts throughout the United States are moving to a Physics-Chemistry-Biology course sequence. O'Brien and Thompson (2009) studied 321 students in 7 high schools in Maine; all the students were taking physics for the first time, with 216 in ninth grade and 105 in twelfth grade.

Table 2

Overall post-test scores and normalized gains (<g>) broken down by grade, course, and instructional method (O'Brien & Thompson, 2009, p. 237)

Subgroup			***N***	Pre-test Score (out of 27)	Post-test Score (out of 27)	<g>	*p*-value (post-test vs pre-test)
Grade	Honors (H/N)	Modeling (M/N)					
9	N	N	80	5.6	6.3	3%	0.072
9	N	M	32	5.0	8.9	18%	0.000
9	H	N	28	5.5	13.0	35%	0.000
9	H	M	76	4.9	12.5	35%	0.000
12	N	N	105	6.0	10.9	23%	0.000

"The use of Modeling Instruction appeared to have a large effect on the non-honors-level, ninth-grade students' performance on the post-test and their normalized gains," though "there was not a significant difference in the normalized gains of the two honors groups (Modeling vs. traditional)" (O'Brien & Thompson, 2009, p. 237).

Another study, conducted by Schuchardt et al. (n.d.) at an independent high school in Pittsburgh, Pennsylvania, compared ninth grade student performance in the areas of scientific reasoning and mathematical skills for students who completed one year of instruction in physics taught by a modeling-based instructional approach versus one year of instruction in biology taught by an inquiry-based instructional approach. The study found that "students who have completed one year of instruction in modeling-based physics scored significantly higher on scientific reasoning and mathematical skills test when compared to ... students who have completed one year of instruction in inquiry-based biology" (Schuchardt et al., n.d., p. 1). Results from these two studies show a positive impact on student achievement with Modeling Instruction, though more quantitative and qualitative studies need to be completed for a better understanding of the impact of Modeling Instruction with ninth grade students.

Modeling Instruction in Ninth Grade: Physical Science and Mathematics

One study, performed by JoAnn Deakin (2006), implemented "portions of the 1st semester modeling physics curriculum that originated in the Modeling Instruction Program (2006) for high school teachers at Arizona State University." The purpose of the study was "to annotate the effects of modeling based physical science with 1st year algebra, 9th grade physical science students on their mathematics achievement" (Deakin, 2006, p. 2). Deakin reasoned that

> if students are taught from a modeling science curriculum they will be applying and reinforcing the concepts learned in algebra 1 because modeling requires students to construct the mathematical models they need. This would undoubtedly lead to greater success in algebra. (Deakin, 2006, p. 2)

Deakin used the Math Concept Inventory (MCI) to determine student achievement in mathematics, and the MCI is a "23-question test which covers basic math concepts that include aspects of scientific and mathematical reasoning, proportional reasoning, variable identification, data analysis, graphical interpretation, slope of a line, equation of straight lines, direct variations, averaging, measuring, estimating, and calculating volume" (Deakin, 2006, p. 5). Deakin administered the MCI to 105 students as a pretest and 103 students as a posttest, and "all students tested were enrolled in algebra I and had a variety of different math teachers. No students were second year math students and no students were enrolled in honors algebra" (Deakin, 2006, p. 6).

Table 3

Average scores on MCI (Deakin, 2006, p. 6)

	MCI pretest Deakin	MCI pretest controls	MCI post-test Deakin	MCI post-test Controls	MCI post-test Deakin all-year	MCI post-test Deakin part-year
Average score	42.8%	41.7%	57.6%	44.8%	58.3%	55.2%

The pretest data shows no statistically significant differences between Deakin and the controls, but

> *students in the control group show a 3.1% gain while [Deakin's] students show a 15.5% gain overall*. ... This difference is due to the heavy emphasis on linear equations, slope, y-intercepts, etc. from the mechanics curriculum that students used in the second semester. (Deakin, 2006, p. 6)

This research by Deakin shows that ninth grade students are more successful in Algebra I when concurrently taking a Physical Science course that employs Modeling Instruction, and my research is an extension of this study. The Modeling Instruction for Physical Science has been expanded and updated since 2006, and my research will provide empirical data for Modeling Instruction on student achievement in Physical Science and Algebra I. In addition, my study will include data for a much larger number of students, providing the opportunity to perform a highly detailed level of analysis.

Ethical Considerations

When performing any research, ethical considerations must remain in focus during the stages of research. "Keeping caring, fairness, openness, and truth at the forefront of your work as a teacher-inquirer is critical to ethical work" (Dana & Yendol-Hoppey, 2014, p. 150). A major consideration for my proposal is privacy, because data about many students and teachers will be collected to use during analysis. Personal identification will never be associated with a particular student when collecting the data, and student data will be reported in the aggregate to further ensure students cannot be individually identified. Teacher data will likewise be protected; personal identification of teachers will be removed when data is collected and teacher's scores will also be reported in the aggregate. Charleston County School District explicitly provides an opportunity for students and employees to opt out of any research without penalty, and also protects students from "possible physical, psychological, legal or other risks" (Procedures, 2015).

Another area of concern is the instruction students will receive. I am proposing to use a teaching method with a group of students that is completely different from any of the current instructional methods, so there could be a disadvantage for those students who are in the classes of the teacher(s) who are using Modeling Instruction. However, in all the research I have studied, there is not a single case where students receiving Modeling Instruction have performed more poorly than the student receiving traditional or inquiry-based instruction. If this research shows positive effects on student achievement, the benefit to all future students outweighs any potential risks of this research.

Conclusion

This is an exciting time to be involved with STEM education, because there are many opportunities to affect student achievement and enjoyment of STEM courses and careers.

Modeling Instruction has already positively impacted many students, and has the potential to gain popularity and help more students understand science in a deep manner. My study will show any effects of Modeling Instruction on student achievement in Physical Science and Algebra I, adding to the research base in STEM education and Modeling Instruction.

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