MODELING INSTRUCTION IN PHYSICAL SCIENCE: EFFECT ON STUDENT ACHIEVEMENT IN PHYSICAL SCIENCE AND MATHEMATICS

by

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ABSTRACT

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. This review will discuss trends in science education from the early years of education in the United States to the present, providing context for this dissertation research. The theoretical base for Modeling Instruction comes from modeling theory, and this literature review will provide a background. Previous studies have shown that student achievement in science and mathematics is higher for students participating in courses with Modeling Instruction at any grade level, and this literature review will detail studies related to high school physics, ninth grade physics, and ninth grade physical science. Finally, keywords that have importance in Modeling Instruction will be defined.

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LIST OF ABBREVIATIONS

FCI ....Force Concept Inventory

MCI ....Math Concepts Inventory

NSF ....National Science Foundation

PER ....Physics Education Research

PSSC ....Physical Science Study Committee

SCIS ....Science Curriculum Improvement Study

SFCI ....Simplified Force Concept Inventory

Chapter 2

Mathematics and science classes have been an element in the course of study throughout the history of education in the United States, though mathematics and science classes gained special prominence after the launch of *Sputnik I* by the Soviet Union in 1957. Concerned that the United States was lagging behind the Soviet Union in scientific and technological research, the federal government began to pour large amounts of money into mathematics and science education. One organization to receive funds from the National Science Foundation (NSF) was the Physical Science Study Committee (PSSC), and this group was "led by [Massachusetts Institute of Technology's (MIT)] Jerrold Zacharias and Francis Friedman" (MIT Libraries, 2012). Ideas and materials from the PSSC were well-developed, and many have become embedded in modern concepts of science education. A modern method—with roots in the ideas developed by the PSSC and the ideas of Robert Karplus—in science education is Modeling Instruction, a hands-on, student-centered approach to teaching both the process and content of scientific disciplines. Modeling Instruction utilizes laboratory experiences to engage students in the science content to create a conceptual model, then students test and refine the conceptual model to determine its application and limits. This instructional technique and underlying pedagogy have been developed for physics, chemistry, biology, and physical science courses. Physical science is a combination course for ninth grade students, whereby students learn basic chemistry principles in the first half of the course and basic physics principles in the second half of the course. The problem of practice for this dissertation is utilizing Modeling Instruction as the instructional technique in physical science in an effort to improve student achievement in science and mathematics, and this literature review will discuss the problem of practice in the context of science education and previous research.

Historically at the high school where the research will be performed, physical science has been taught in a traditional manner: Information is presented to students through live or video lectures, students complete worksheets related to the information, students perform prescriptive laboratory experiments, and quizzes and tests are used to measure the amount of content students retain. These methods were productive when South Carolina employed an End-Of-Course (EOC) assessment in physical science, because the South Carolina Science Academic Standards (South Carolina Department of Education [SC DOE], 2005) contained too much information to allow time for more in-depth study of the topics. However, the SC DOE made two major changes in 2014: The EOC assessment was switched from physical science to biology; and, physical science was eliminated from the courses explicitly listed in the Academic Standards and Performance Indicators document (SC DOE, 2014). These changes from the SC DOE, coupled with a broader shift in science education towards more experiential learning methods, have altered expectations for teachers and students. Therefore, the purpose of this dissertation research is to determine the effect of Modeling Instruction in physical science by analyzing student achievement in physical science and mathematics. The research question follows the same idea: What is the effect of Modeling Instruction in physical science on the achievement of ninth grade students in physical science and mathematics? Previous studies have shown that student achievement in science and mathematics is higher for students participating in courses with Modeling Instruction at any grade level, and this literature review will detail studies related to physics courses for twelfth and ninth grade students and mathematics for ninth grade students. There are no available studies discussing the effect Modeling Instruction has on student achievement in physical science, so this dissertation research will generate new information for the research base. There are studies related to mathematics achievement and Modeling Instruction, and this dissertation research will extend and verify those studies.

Historical Context

Early science education in the United States. Prior to the mid-1800s, science and science education in the United States did not exist in a structured manner. However, "the public's interest in science and the scientific method increased in the late 19th century" (Bybee, 2010), partially due to scientific progress and technological advances associated with the industrial revolution. In addition, high school attendance increased drastically between 1890 and 1900, with enrollment more than doubling during this decade. In 1892, "the National Education Association formed the Committee of Ten on Secondary School Studies under the leadership of Harvard's president, Charles Eliot" (Spring, 2014). The final report from the Committee of Ten "established a general framework for discussion of the goals of secondary education" (Spring, 2014), and science education was included in the framework. "The report underscored the importance of science for all students, whether they intended to go to college or enter the workforce" (Bybee, 2010), and made explicit the need for laboratory work in a high school science curriculum. To further specify which type of scientific experiments were expected from secondary students, Eliot "asked the physics department at Harvard to develop an entrance requirement that emphasized the laboratory as part of high school physics courses" (Bybee, 2010). In 1889, these laboratories were compiled into a list and published as the *Harvard University Descriptive List of Elementary Physical Experiments*. The "list became the basis for a physics course and later for a national course in physics, ... [and] widespread acceptance of this report became the de facto first voluntary national standards for science" (Bybee, 2010).

Science education between 1900 and 1950. The era between 1900 and the end of World War II may be considered a time of scientific management in the American school system. In scientific management, "standardization became the magic word. [District and school] administrators were preoccupied with standardizing student forms, evaluations of teachers and students, attendance records, and hiring procedures" (Spring, 2014). During this quest for standardization, administrators became obsessed with cost-effectiveness; taking a cue from the business world, administrators began to approach every program with cost-benefit analysis. As a result of standardization, science--along with many other disciplines--became a set of facts to be memorized rather than experiences to be understood. This sterilization eliminates the process of science, and produces students who are unaware of the foundational meaning of the "facts." John Dewey, widely known for his progressive ideas about education, discussed the role of scientific process in an address at a meeting for the American Association for the Advancement of Science. Dewey (1910) argued that science "has been taught too much as an accumulation of ready-made material with which students are to be made familiar, not enough as a method of thinking, an attitude of mind, after a pattern of which mental habits are to be transformed." Further in the discussion, Dewey states that "surely if there is any knowledge which is of most worth it is knowledge of the ways by which anything is entitled to be called knowledge instead of being mere opinion or guess work or dogma" (Dewey, 1910). This sentiment of helping students understand the ways by which anything may be taken as "knowledge" was counter to standardization because it required experimentation and use of the scientific process. Laboratory work is often messy, intellectually and materially, whereas standardization strives for perfectly predictable results. In an ironic twist, Dewey's ideas about the scientific process as a method of inquiry about a topic were taken by those seeking standardization and changed into a rigid structure called the scientific method. "Soon the scientific method was included in textbooks, thus becoming part of the knowledge that students had to memorize" (Bybee, 2010). Even today, more than 100 years after Dewey's ideas, some textbooks begin with the scientific method and incorrectly tout this formal structure as the only way to perform the scientific process.

Science education and the Cold War. "After World War II, global events, particularly the Cold War between the United States and the Soviet Union, directly affected American schools" (Spring, 2014). Science education was greatly impacted because many were concerned the United States was falling behind the Soviet Union in engineering and technological advances. "The National Science Foundation (NSF) was established [in 1950] both to attract more students to science and engineering courses and to fund basic research" (Spring, 2014). One leader in the establishment of the NSF, Vannevar Bush, "believed that improvement of science teaching in high schools was imperative if latent talent was to be properly developed. He viewed as a great danger the prospect of high school science teachers failing to awaken interest or provide adequate instruction" (Spring, 2014). Although legislators United States Senate and House of Representatives were slow to provide federal funding to schools during the 1950s, their sentiments changed dramatically when the Soviet Union launched *Sputnik I*. In response, Congress passed the National Defense Education Act (NDEA), "which appropriate $70 million for each of the next four fiscal years to be used for equipment and materials and for the expansion and improvement of supervisory services in the public schools in science [and] mathematics" (Spring, 2014). One aspect of this funding was the creation of new curricula, and "money flowing from the NSF was used to develop curriculum materials and to train teachers" (Spring, 2014).

Influence of the Physical Science Study Committee. The Physical Science Study Committee (PSSC) was formed by Jerrold Zacharias, a physicist at MIT and member of the United States Office of Defense Mobilization's Science Advisory Committee. "At the urging of his colleagues on the Science Advisory Committee and officials at the National Science Foundation in July of 1956, Zacharias began to assemble the key players" (Rudolph, 2006). These individuals were scientists--primarily physicists--from major research universities and other important figures in education and technology, such as "MIT president James Killian, Polaroid founder Edwin Land, and Educational Testing Service president Henry Chauncey" (Rudolph, 2006). By the time *Sputnik I* was launched by the Soviet Union, work by the PSSC was well underway and on track to begin implementation in high school physics within five years. However, the "launch shocked the nation and brought even greater pressure for reform in all science subjects along the path set by PSSC" (Rudolph, 2006), and funds from the NSF poured into the project. The first draft of the materials was completed by 1958, and a full course was ready for high school science teachers by 1960.

Up to and during the 1950s, the vast majority of high school physics courses were delivered by textbooks. The most popular was *Modern Physics*, published by Holt, and "in the entire book there were no descriptions of experiments or graphs of results of experiments that would justify any of the book's many assertive statements" (Haber-Schaim, 2006). In addition, "there was no laboratory program to go with the textbook. ... For [students in these courses,] science was equated with vocabulary" (Haber-Schaim, 2006). Zacharias had a different perspective about the manner in which physics and chemistry should be taught, and his ideas led to a course that was unique. For Zacharias, "physics and chemistry [were to be presented] as a living discipline, not as a body of finished, codified facts to be memorized. In today's language, Zacharias wanted an inquiry-based approach" (Haber-Schaim, 2006). Instead of using a textbook as the primary learning aid, Zacharias envisioned the course using any set of materials that were useful for learning by the students. These materials included "films, slides, textbooks, laboratory apparatus for students and teachers, homework, and ancillary reading" (Haber-Schaim, 2006). While revolutionary at the time, the ideas of Zacharias have been broadly accepted and implemented at all levels by the science education community. The Next Generation Science Standards (NGSS) and many state science standards--including South Carolina--contain statements related to students acting as scientists and using laboratory materials, from Kindergarten to the upper-level secondary courses. One of the lasting effects of the PSSC is the mainstream implementation of the scientific process into science courses, and this legacy has been carried by other instructional approaches.

Another important aspect of the PSSC were the foundational principles on which the curriculum rested. One crucial point was that "science was to be presented as a human endeavor" (Haber-Schaim, 2006), which allowed students to understand that anyone can do science. Another major facet was the selection of topics, and the PSSC chose a set of five essential ideas about science:

- The unity of physical science.
- The observation of regularities leading to the formulation of laws.
- The prediction of phenomena from laws.
- The limitations of laws.
- The importance of models in the development of physics. (Haber-Schaim, 2006)

These foundational ideas are still used today, most recently in the *Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (National Academy of Sciences, 2012). This framework establishes three dimensions--scientific and engineering practices, crosscutting concepts, and disciplinary core ideas--for science education, and these dimensions echo the ideas of Zacharias and work by the PSSC.

Influence of Robert Karplus. In the 1960s and 1970s, science education continued to evolve. One of the leaders during this era was Robert Karplus, a theoretical physicist and head of the Science Curriculum Improvement Study (SCIS) at the University of California, Berkeley. Karplus developed a theoretical background for science education, and this "included the nature and development of children's intelligence, the nature and structure of science, and the implications of these two domains for designing science curricula" (Bybee, 2010). Karplus believed "the science curriculum had to provide students with experiences that differed from those they usually had, [and] the unique, unusual, and engaging experience afforded the opportunity for discovery" (Bybee, 2010). Utilizing psychological research from the work of Jean Piaget, Jerome Bruner, and others, Karplus and colleague Herb Thier created a practical program for students in grades K-6 through the SCIS. After performing work with the SCIS for a decade, Karplus solidified his ideas about science curriculum in a short talk titled *Three Guidelines for Elementary School Science* (1969). The first guideline was that

> two aspects of the teaching program should be distinguished from one another: the experiential--student experience with a wide variety of phenomena, including their acting on the materials involved; and the conceptual--introduction of the student to the approach which modern scientists find useful in thinking about the phenomena they study. (Karplus, 1969)

The second guideline stated that "major theories of intellectual development and learning should be drawn upon in curriculum construction" (Karplus, 1969), and the third guideline created a link between the first two.

> [SCIS has created] a learning cycle with three phases: *exploration,* which refers to self-directed, unstructured investigation; *invention*, which refers to the introduction of a new integrating concept by teacher or by learner; and *discovery*, which refers to applications of the same new concept in a variety of situations, partly self-directed, partly guided. (Karplus, 1969)

During the exploration phase, "the learner [is allowed] to impose his ideas and preconceptions on the subject matter to be investigated" (Karplus, 1969). This will often lead to conflict between the results of the experiment and preconceptions, and the teacher learns information about the students' understanding. In the invention phase, conceptual information is provided to the students to reconcile the differences between experimental results and preconceptions. Finally, the discovery phase allows students to resolve any lingering differences by "establishing a new feedback pattern for his actions and observations. Furthermore, repetition and practice occur at the conceptual level" (Karplus, 1969), leading to a deeper and more complete understanding of the phenomena. The idea of a "learning cycle continues to influence curriculum and instruction in science," and "it has substantial research support (Lawson, Abraham, and Renner 1989) and widespread application through textbooks on science teaching and learning (Lawson 1995; Marek and Cavallo 1997)" (Bybee, 2010).

Modeling Instruction. Modeling Instruction began in the early 1980s from a partnership between Malcolm Wells, a high school physics and chemistry teacher, and David Hestenes, a theoretical physicist and physics education researcher at Arizona State University. Wells began his teaching career "with a powerful boost from PSSC and Harvard Project Physics teacher workshops in the heyday of Sputnik space-race fever," (Wells, Hestenes, & Swackhamer, 1995) and these workshops positively influenced his view towards teaching. Wells became a "hands-on" teacher, "always eager to build his own apparatus, and always looking for simple demonstrations of deep physics" (Wells, Hestenes, & Swackhamer, 1995). The high school in which Wells taught was near Arizona State University, and Wells participated in many university science and education courses throughout his high school teaching career. Eventually, Wells decided to complete his doctoral degree in physics education, and his advisor was Hestenes. Wells wanted to perform research that would greatly contribute to the field of physics education, and Wells and Hestenes discussed possibilities for several years. During the time of these discussions, Hestenes was also advising Ibrahim Halloun, a graduate student performing work on a *Mechanics Diagnostic* test. "This test measures the difference between [scientifically accepted] Newtonian concepts and the students' personal beliefs about the physical world" (Wells, Hestenes, & Swackhamer, 1995). Studies throughout many years have shown "that this difference is large, and conventional introductory physics courses are not effective at reducing the gap. Further, the results are independent of the instructor's qualifications and teaching style" (Wells, Hestenes, & Swackhamer, 1995). After using the *Mechanics Diagnostic* test with his students, Wells was shocked by how poorly students had performed. "Confronted by the dismal scores of his students on the *Diagnostic*, [Wells] soon concluded that the fault was in his teaching and set about doing better" (Wells, Hestenes, & Swackhamer, 1995). The decision by Wells to improve his teaching practice launched his doctoral research, and ultimately led to the creation of Modeling Instruction.

Wells "had already abandoned the traditional lecture-demonstration method in favor a student-centered inquiry approach based on the *learning cycle* popularized by Robert Karplus" (Wells, Hestenes, & Swackhamer, 1995) when he administered the *Mechanics Diagnostic* test. Wells deeply understood all aspects of the learning cycle from a university course in methods of science teaching; however, faced with the poor scores, Wells determined something essential was missing from the learning cycle. After reviewing work by Hestenes "proposing a theory of physics instruction with modeling as the central theme, ... Wells mastered the details ... [and] implemented the theory" (Wells, Hestenes, & Swackhamer, 1995). Wells created a version of Modeling Instruction that

> is laboratory-based and adapted to scientific inquiry. It emphasizes the use of models to describe and explain physical phenomena rather than solve problems. It aims to teach modeling skills as the essential foundation for scientific inquiry. To accomplish this in a systematic fashion, [Wells] developed the *modeling cycle*. (Wells, Hestenes, & Swackhamer, 1995).

By the end of Wells' doctoral work, the modeling method could "be described as *cooperative inquiry with modeling* structure and emphasis" (Wells, Hestenes, & Swackhamer, 1995). After further refinement over several years, "the modeling cycle has two stages, involving the two general classes of modeling activities: Model development and model deployment" (Wells, Hestenes, & Swackhamer, 1995). As a rough comparison with Karplus' work, "model development encompasses the exploration and invention stages of the learning cycle, while model deployment corresponds to the discovery stage" (Wells, Hestenes, & Swackhamer, 1995).

After the completion of the doctoral work and further refinement of Modeling Instruction, Wells, Hestenes, and others created summer workshops for teachers interested in this methodology. From 1989 to 2005, these workshops were funded by grants from the NSF; after 2005, a non-profit known as the American Modeling Teachers Association (AMTA) was formed to continue offering summer workshops and further develop curriculum. Resources for Modeling Instruction have been created for physics, chemistry, biology, and physical science, and the newest offering is for students in grades 6 through 8 (AMTA, 2015). Hestenes has continued to develop the theoretical foundations of Modeling Instruction, utilizing information and methods from philosophy and cognitive psychology (Hestenes, 2006; Hestenes, 2010).

Theoretical Base

As scientists perform research on cognitive processes with increasingly sophisticated tools, the understanding of how humans learn continues to improve. Advances in the fields of neuroscience and cognitive psychology have provided relevant information for teachers and implications for curriculum design, and it seems that the best curricula will match the manner in which students learn. Hestenes has created a theoretical foundation for Modeling Instruction that matches modern cognitive theory, though the foundation of the theory began with a question: "Why don't [university scientists] evaluate their teaching practices with the same critical standards they apply to scientific research?" (Hestenes, 1987). For Hestenes,

> the ultimate goal of pedagogical research should be to establish a mature instructional theory which consolidates and organizes a nontrivial body of knowledge about teaching. Without such a theory, little pedagogical knowledge can be transmitted between generations of teachers, teachers cannot improve without repeating mistakes of their predecessors, and only the most capable and dedicated can progress to teaching with a moderate degree of insight and subtlety. (1987)

As pedagogical research has occurred in the field of Physics Education Research (PER), many groups have created instructional strategies to improve the understanding of students (Beichner, 2009). A principle concern of those in the PER community "has been to establish a scientific theory of instruction to guide research and practice" (Hestenes, 2006), and Hestenes has integrated philosophical, scientific, and cognitive theories to serve as a foundation for Modeling Instruction. The work of Hestenes has identified construction and use of conceptual models as central to scientific research and practice, so [Hestenes] adopted it as the thematic core for a MODELING THEORY of science instruction. From the beginning, it was clear that Modeling Theory had to address cognition and learning in everyday life as well as in science, so it required development of a model-based epistemology and philosophy of science. (Hestenes, 2006)

Modeling theory of scientific knowledge. To provide connections with modeling theory of cognition, modeling theory of scientific knowledge must have several key terms defined:

- System: A set of related objects. "Systems can be of any kind depending on the kind of object. … In a *conceptual system* the objects are *concepts*. In a *material system* the objects are material *things*" (Hestenes, 2006).
- Structure: "The set of relations among objects in the system" (Hestenes, 2006). In science, "all material systems have geometric, causal and temporal structure, and no other (metaphysical) properties are needed to account for their behavior" (Hestenes, 2006). As stated by modeling theory, "science comes to know objects in the real world not by direct observation, but by constructing conceptual models to interpret observations and represent the objects in the mind. This epistemological precept is called *Constructive Realism* by philosopher Ronald Giere" (Hestenes, 2006).
- Model: "A *representation of* ***structure*** in a material system, which may be real or imaginary" (Hestenes, 2006). Models exist in many different ways, depending on their function. "All models are idealizations, representing only

structure that is *relevant* to the purpose, not necessarily including all five types of structure" (Hestenes, 2006). Figure 1 provides a summary of the possible types of structure.

(a) **systemic structure**:
- ***composition*** (internal parts (objects) in the system)
- ***environment*** (external agents linked to the system)
- ***connections*** (external and internal links)

(b) **geometric structure:**
- ***position*** with respect to a reference frame (external)
- ***configuration*** (geometric relations among the parts)

(c) **object structure**:
- intrinsic properties of the parts

(d) **interaction structure:**
- properties of (causal) links

(e) **temporal (event) structure**:
- temporal change in structure of the system

Figure 1. Structures of a conceptual model in modeling theory of scientific knowledge. From "Notes for a Modeling Theory of Science, Cognition and Instruction" by D. Hestenes, 2006, *Proceedings of the 2006 GIREP Conference*. Copyright 2006 by David Hestenes. Reprinted with permission.

From these definitions many models may be created, and including two useful models for scientific knowledge: A mathematical model, representing the structure of a system by state and interaction variables; and, a process model, designating temporal structure as a change of state variables. These two models form the foundation of scientific theory, which is defined as "a system of general principles (or **Laws**) specifying a class of state variables, interactions and dynamics" (Hestenes, 2006). Scientific process is governed by general laws that define the domain and structure of a theory and specific laws defining models. "The *content* of a scientific theory is a population of validated models," and a "model is *validated to the degree* that the measured values (data) match predicted values determined by the model" (Hestenes, 2006).

Modeling theory of cognition. With the definitions of a conceptual model, a modeling theory of cognition may be created. Figure 2 provides information about the connection between the physical, mental, and conceptual worlds, and the theory rests on a "crucial distinction between mental models and conceptual models … Mental models are private constructions in the mind of an individual" (Hestenes, 2006).

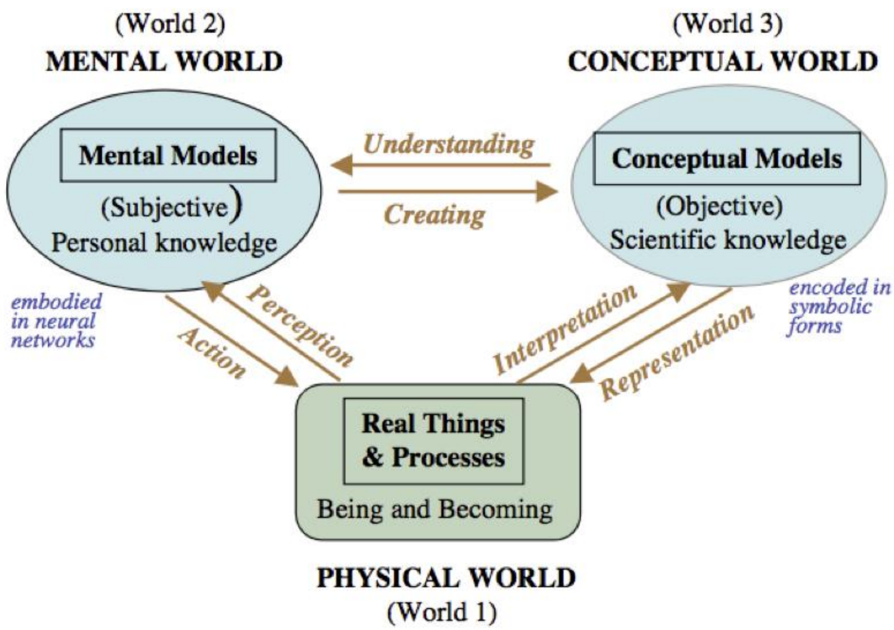

Figure 2. Relationships between the physical, mental, and conceptual worlds (Hestenes, 2006, p. 10). From "Notes for a Modeling Theory of Science, Cognition and Instruction" by D. Hestenes, 2006, *Proceedings of the 2006 GIREP Conference*. Copyright 2006 by David Hestenes. Reprinted with permission.

Conceptual models are an encoded "model structure in symbols that activate the individual's mental model and corresponding mental models in other minds" (Hestenes, 2006). Connections between the three worlds highlight the manner in which they interact, and an understanding of these relationships provide an opportunity to connect the modeling theory of cognition with the modeling theory of scientific knowledge. The combination of modeling theories of scientific knowledge and cognition is simply known as modeling theory. Figure 3 describes how modeling theory drives instructional design, which informs teaching practice.

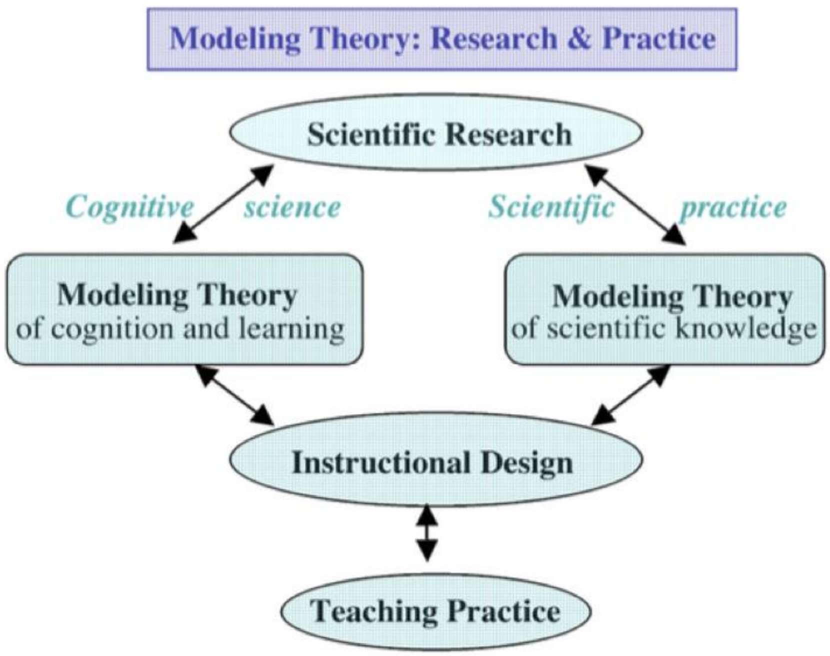

Figure 3. Relationships between modeling theory, cognition and learning, scientific knowledge, instructional design, and teaching practice. From "Notes for a Modeling Theory of Science, Cognition and Instruction" by D. Hestenes, 2006, *Proceedings of the 2006 GIREP Conference*. Copyright 2006 by David Hestenes. Reprinted with permission.

Modeling Instruction. As indicated by the arrows in Figure 3, Modeling Instruction—the combination of instructional design and teaching practice—arises from modeling theory. "Modeling Instruction produces students who engage intelligently in public discourse and debate about matters of scientific and technical concern … and students in modeling classrooms experience first-hand the richness and excitement of learning about the natural world" (Jackson, Dukerich, & Hestenes, 2008). Modeling Instruction is based on the coherent instructional objectives, which are:

- 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. (Wells, Hestenes, and Swackhamer, 1995)

Modeling Instruction also has a student-centered instructional design, whereby

- 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)

Modeling cycle. As a framework for organizing instruction, the modeling cycle is instrumental for students to develop appropriate models that accurately describe the phenomena they study. The modeling cycle has two distinct parts: Model development, in which students perform a paradigm laboratory and engage in discussions to create a mental and conceptual model related to the physical world; and model deployment, during which students manipulate and test the model to determine the limits and applicability of the model. Throughout model deployment, students utilize written and verbal, graphical, diagrammatic, and mathematical representations to test the model. Assessments in the form of whiteboarding, quizzes, and additional laboratories are used formatively, and the modeling cycle is completed with a laboratory practicum and summative unit assessment.

One major aspect that separates Modeling Instruction from other instructional varieties is whiteboarding. The whiteboards are 24” x 36” erasable pieces that students use during all parts of the modeling cycle, giving students the opportunity to make their thinking visible around scientific content and processes. When performing laboratories, students record, graph, and analyze data on their whiteboard for presentation during the post-lab discussion. Having visible information from all groups allows students to compare, contrast, and question data and analysis easily, creating a robust discussion about the results. As students solve problems, “small groups of students write up their results … [and] have to account for everything they do in solving a problem” (Jackson, Dukerich, & Hestenes, 2008). The students who are presenting are questioned by other students and the instructor to explicitly articulate their understanding, and any misconceptions are corrected through Socratic questioning.

Methodology

The research question for this study states: What is the effect of Modeling Instruction in physical science on the achievement of ninth grade students in physical science and mathematics? To collect data related to this question, the study will utilize both a one-group pretest-posttest design and one-shot case study. Grades and standardized assessment scores will be collected from eighth grade mathematics and science courses to provide a baseline for students, and several assessments will be used as a pretest and posttest. These assessments are the Simplified Force Concept Inventory (SFCI) and the seventh version of the Math Concept Inventory (MCI). The MCI will be given at the beginning of the course as a pretest and near the end of the course as a posttest, and the SFCI will be given at the beginning of the Physics section--approximately halfway through the course--as a pretest and near the end of the course as a posttest. For the one-shot case study, student scores on the physical science District

End-of-Course (DEOC) and algebra I End-of-Course (EOC) assessments will be collected and analyzed.

Use of the Simplified Force Concept Inventory (SFCI). The FCI and SFCI are 30-question qualitative assessments that "require a forced choice between [scientifically accepted] Newtonian concepts and commonsense alternatives" (Hestenes, Wells, & Swackhamer, 1992), and each set of answers contains only one Newtonian choice. The foundational research for the FCI comes from the work of Halloun on the *Mechanics Baseline* test, but the FCI extends the concept of force to six conceptual dimensions. The introduction of the FCI in 1992 was "a pivotal event in PER," though it was "difficult to convince [university and high school physics] faculty to give [the FCI] because they fear insulting their students' intelligence" (Beichner, 2009). However, after giving the FCI and seeing the results, the faculty "are usually shocked at the resulting low scores. This has been the start of many adoptions of PER-based instructional materials" (Beichner, 2009), and many papers have utilized the FCI to understand the impact of their academic intervention (Arseneault, 2014; Jackson, Dukerich, & Hestenes, 2008; Melendez & Wirth, 2001; Schuchardt, et al., n.d.; Wells, Hestenes, & Swackhamer, 1995).

Due to a "concern regarding the possibility that student FCI responses could be hindered by complex wording and unfamiliar contexts presented in some items," an adapataion of the FCI was developed to determine if "a linguistically simplified version of the FCI could be a viable option" (Osborn Popp & Jackson, 2009). Both the SFCI and FCI were given to students in the eleventh and twelth grades, and

> no significant difference was found between mean test scores. ... The common person equating results provide strong evident that the two instruments are

> measuing the same construct, at virtually the same level of difficulty, indicating that students did not receive an unfair advantage on the simplified version of the FCI. (Osborn Popp & Jackson, 2009)

Because the participants of this study are ninth grade students, the SFCI will be used to collect data on student perception of force. This will allow comparison between students in this study and the large number of students in previous studies that have taken the FCI, allowing this study to further contribute in science education research.

Use of the Math Concepts Inventory (MCI). This study will use the seventh version of the MCI to determine the extent to which Modeling Instruction has impacted student understanding of mathematics. The MCI "was based on an instrument developed by the Physics Underpinnings Action Research Team from Arizona State University" (Deakin, 2006) in 2000, and the first eight questions are from Lawson's *Classroom Test of Scientific Reasoning.* The remaining 15 questions are related to basic mathematics concepts and taken from released items of several widely-used standardized tests, and concepts 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). Specifically, questions ask about "graphing interpretation skills (#10-12, 19-23); relating linear equations to other representations (#9, 15, 18); estimating area (#13) and volume (#14); measurement (#16) and mean value (#17)" (Boyarsky, Bray, & Henrion, 2009). A study performed by researchers at Arizona State University showed "the MCI reliability estimate (Cronbach's alpha coefficient) [to be] 0.83" (Boyarsky, Bray, & Henrion, 2009). The typical threshold for drawing inferences from group level data is 0.80, and the MCI meets this criteria. Utilizing the MCI in this dissertation research will allow comparisons between these results and previous results, extending the body of knowledge on Modeling Instruction.

Previous Research Results

Modeling Instruction in physics. Modeling Instruction has been implemented most frequently in high school physics courses, with over 3,000 teachers participating in summer workshops from 1995 to the present. The FCI "has become the most widely used and influential instrument for assessing the effectiveness of introductory physics instruction" (Jackson, Dukerich, & Hestenes, 2008), and the aggregate of these scores shows a large effect of Modeling Instruction on the achievement of students in physics courses versus a much smaller effect of traditional instruction. Figure 4 "summarizes data from a nationwide sample of 7500 high school physics students involved in the *Modeling Instruction Project* during 1995-98" (Hestenes, 2006). The average pretest mean is

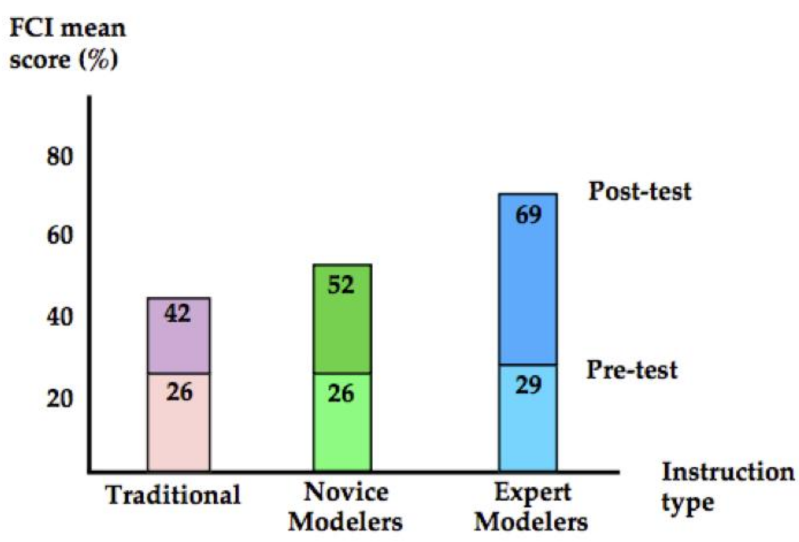

Figure 4. FCI mean pretest and posttest scores under different instruction types. From "Notes for a Modeling Theory of Science, Cognition and Instruction" by D. Hestenes, 2006, *Proceedings of the 2006 GIREP Conference*. Copyright 2006 by David Hestenes. Reprinted with permission.

slightly above a random guessing mean of 20%, and the data show that "traditional high school instruction (lecture, demonstration, and standard laboratory activities) has little impact on student beliefs" (Jackson, Dukerich, & Hestenes, 2008). Novice Modelers, defined as those in their first year teaching with Modeling Instruction, achieved a mean posttest FCI score of 51%. Those using Modeling Instruction for two or more years were defined as Expert Modelers, and their mean posttest FCI score was 69%. Teachers from other workshops have also given the FCI to their students, and there exists "many examples of [modeling teachers] who consistently achieve posttest means from 80-90%" (Hestenes, 2006).

The seminal study for Modeling Instruction is summarized by Wells, Hestenes, and Swackhamer (1995), and the research was performed by Malcolm Wells for his dissertation. Wells had established an inquiry course, whereby "70% of class time was devoted to lab activities, which were either developed by Malcolm or modified from the Harvard Project Physics handbook" (Wells, Hestenes, & Swackhamer, 1995). The other "30% of class time was devoted to in-class study groups utilizing the PSSC fourth-edition textbook," and "problems for class and homework were selected from the textbook or designed by Malcolm to reinforce and expand on concepts developed in the lab activities" (Wells, Hestenes, & Swackhamer, 1995). As Wells designed the modeling course, his class could "be described as cooperative inquiry with modeling structure and emphasis. ... The instructional difference [with the inquiry course] resided in the systematic emphasis on models and modeling," and "the net result was an increase in coherence of the whole course and its subject" (Wells, Hestenes, & Swackhamer, 1995). The inquiry course and modeling course became two of the groups in Wells' dissertation research, and the third course was led by a teacher who "was well matched to Malcolm in regard to age, experience, training and dedication" (Wells, Hestenes, & Swackhamer, 1995). This teacher used a typical textbook, and "his course consisted of lectures and demonstrations (80% of class time), with homework questions and problems selected to reinforce important concepts from lecture and to provide practice in problem solving" (Wells, Hestenes, & Swackhamer, 1995). In contrast to Wells, the traditional teacher devoted 20% of class time to laboratory activities; rather than allowing students to explore, these laboratory activities "were designed and/or selected to emphasize important concepts from lectures and/or to develop laboratory skills" (Wells, Hestenes, & Swackhamer, 1995).

For the study, "all three high school courses (inquiry, modeling, and traditional) were honors courses with about 24 students in each. By prior agreement between the teachers, all three covered the same topics in mechanics on nearly the same time line" (Wells, Hestenes, & Swackhamer, 1995). Using a pretest-posttest experimental design with the *Mechanics Diagnostic* as the test, Wells and the traditional teacher assessed their classes at the beginning and end of mechanics. The data in Table 1 "strongly supports the conclusions that Malcolm's modeling method is a considerable improvement over his cooperative inquiry method and clearly superior to the traditional method" (Wells, Hestenes, & Swackhamer, 1995) because the modeling course has a 34% increase between the pretest and posttest. This percent increase is almost three times the 13% increase of the traditional course and "is a large effect, because the standard deviation of student scores does not exceed 16% for any of the classes" (Wells, Hestenes, & Swackhamer, 1995).

Table 1

Comparison of Student Pretest and Posttest Mean Scores on the Mechanics Diagnostic

Course	Pretest Mean	Posttest Mean	Percent Increase
Traditional	44	57	13
Inquiry	31	53	22
Modeling	38	72	34

Note. Adapted from "A Modeling Method for High School Physics Instruction," by M. Wells, D. Hestenes, and G. Swackhamer, 1995, *American Journal of Physics*, *63*(7), p. 610. Copyright 1995 by David Hestenes. Reproduced with permission.

A recent study on the effect of Modeling Instruction in a Louisiana high school classroom was conducted by Mark Arseneault (2014). Arseneault taught two classes with traditional instruction and two classes with Modeling Instruction, and each instructional group contained one regular physics class and one honors class. The four classes received equal amounts of time on topics, and Arseneault utilized a pretest-posttest design with the FCI as the test. The traditional classes had a pretest mean of 24% and the Modeling Instruction classes had a pretest mean of 28%, both of which are slightly higher than the random mean of 20%. However, the traditional classes had a posttest mean of 34%, yielding an increase of 10% from the pretest to posttest. The Modeling Instruction classes had a posttest mean of 45%, giving an increase of 17% between the pretest and posttest. Whereas these results are not as impressive as those obtained by Wells, they are consistent with the results in Figure 4 from Novice Modelers. Overall, data from studies on Modeling Instruction have consistently shown a higher increase in student performance on the FCI and other assessments than other instructional methods. As a result, "a U.S. Department of Education Expert Panel in Science recognized the Modeling

Instruction Program as one of only two exemplary K-12 science programs out of 27 programs evaluated (U.S. Department of Education, 2001)" (Jackson, Dukerich, & Hestenes, 2008).

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. A 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 to one year of instruction in biology taught by an inquiry-based instructional approach. The study found that "students who took the physics first modeling course showed improvement in their performance on the ... Force Concepts Inventory as determined by both a comparison of the mean pre and posttest scores and by calculation of the mean normalized gain" (Schuchardt et al., n.d.). The 2005-2006 freshmen had a pretest mean of 22% and a posttest mean of 42%, yielding a 20% increase, whereas the 2006-2007 freshmen had a pretest mean of 22% and a posttest mean of 44% for a 20% increase.

A study by O'Brien and Thompson (2009) compared student achievement on an assessment for ninth grade students in a traditional course, twelfth grade students in a traditional course, and ninth grade students in a course using Modeling Instruction. "Seven high schools in Maine participated in this study, providing a total of 321 students. Three of the schools teach physics to ninth-graders and three teach physics to 12th-graders" (O'Brien & Thompson, 2009). Another participating school taught physics to ninth graders and a separate course for twelfth graders who had not previously taken a physics course. Because there the SFCI had yet to be developed, O'Brien and Thompson created an instrument from three well-established instruments: The FCI, the Force and Motion Conceptual Evaluation, and the Test for Understanding Graphs in Kinematics.

Whereas the use of their created assessment instead of the FCI presents a problem of full comparison with other studies, the results from O'Brien and Thompson are still instructive. They found "the honors-level ninth-graders had the highest post-test scores and normalized gains of any of the subgroups, even above that of the 12th-grade classes" (O'Brien & Thompson, 2009). However, "there was not a significant difference in the normalized gains of the two honors groups (modeling versus traditional). The honors groups outperformed the non-honors groups, regardless of the type of instruction" (O'Brien & Thompson, 2009).

Modeling Instruction in ninth grade physical science: Mathematics. A 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." Deakin noticed that the "freshmen algebra classes were experiencing close to 50% failure rates in first year algebra," and "hypothesized that *if modeling science were to be taught along with first year 9th grade algebra then many students would probably begin achieving in math and on standardized tests at higher levels*" (Deakin, 2006). Deakin had also noticed a difficulty in solving problems at higher cognitive levels, especially those related to creating and interpreting graphs. Deakin understood this information to mean "that *students had never really been asked to apply simple algebra I concepts in real situations*" (Deakin, 2006). Therefore, 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). Deakin reasoned that "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).

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). For a control group, Deakin used eight students who had transferred into her class at the beginning of the second semester, and "these students were from the other physical science classes" (Deakin, 2006). 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*" (Deakin, 2006). Deakin believes "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).

Another study utilizing a modeling approach was performed by Adrian Boyarsky, Russell Bray, and Mark Henrion in 2009. "The goal of this study is to investigate student conceptual and procedural understanding when proportional reasoning and interpretation of graphs are taught in a scientific modeling context as opposed to a traditional mathematics classroom" (Boyarsky, Bray, & Henrion, 2009). Data was collected with the seventh version of the MCI "before and after working through various labs and data collection lessons that emphasize proportional reasoning and interpretation and understanding of graphs" (Boyarsky, Bray, & Henrion, 2009). These researchers found "that students can learn mathematical reasoning skills by engaging the materially differently than in a traditional mathematics course, ... [and] the students' skills increase at a faster rate than in a traditional math class" (Boyarsky, Bray, & Henrion, 2009). The concepts of proportional reasoning and graphical analysis saw the most significant gains because the "prevalence of these concepts in the design of activities and labs that were used throughout the treatment" (Boyarsky, Bray, & Henrion, 2009).

Modeling Instruction and equity. Whereas there are no formally published studies that focus exclusively on Modeling Instruction and equity, many of the studies in this literature review provide information related to students in non-honors or lower-level courses. If the assumption is made that students in the non-honors courses had little success in science and mathematics throughout their academic career, then a goal of subsequent science and mathematics courses should be to provide opportunities for success. Through the student-centered and inquiry-based design, Modeling Instruction offers a different way to learn in a science course; many of the students in non-honors courses are more successful in courses that utilize non-traditional methods of instruction. In the study by Wells, Hestenes, & Swackhamer (1995), Wells and the traditional teacher had students in both non-honors and honors courses. On the FCI, the non-honors course for the traditional teacher had a pretest mean of 27% and a posttest mean of 48% for a 21% increase. However, non-honors course for Wells had a pretest mean of 28% and a posttest mean of 64% for a 36% increase. This posttest mean of 64% also outperformed the traditional teacher's posttest mean of 56%, showing that Modeling Instruction greatly impacts student performance regardless of previous performance by students.

Results from the study by O'Brien and Thompson (2009) also show differences between ninth grade students in honors and non-honors courses. The major difference was between the two sets of non-honors ninth grade students, with the students receiving Modeling Instruction had a normalized gain of 18% whereas the students in traditional classes had a gain of 3%. The results of the non-honors ninth grade students led O'Brien and Thompson to this conclusion:

> Schools and teachers considering teaching physics to [ninth grade] students need to carefully consider how the course will be taught. These results suggest in order for these students to be able to understand the basic kinematic and mechanics concepts that are typically taught in an introductory high school physics course, teacher need to employ a more student-centered approach rather than the traditional approach that is employed in most 12th-grade courses. (2009)

In an unpublished study, Javier Melendez and David Wirth implemented Modeling Instruction in an integrated algebra and physics course "to 9th grade Hispanic and black students at Tolleson High School, a largely minority public school in urban Phoenix [Arizona]" (Melendez & Wirth, 2001). The students in this course had two 90-minute blocks daily, and "the teachers identified the use of Modeling Instruction, the integrated approach, and the extended time (thus enabling the students to become a learning community) as the three most important factors in their success" (Melendez & Wirth, 2001). Two evaluations were used: A district end of year achievement test and the FCI. On the district end of year test, students in this class scored higher than students in a traditional honors ninth grade algebra class. On the FCI, the students' posttest mean was 61%; this value is slightly above the Newtonian threshold and comparable to Modeling Instruction honors physics courses for seniors. Results from these three studies show promise for the use of Modeling Instruction with students having lower background science and mathematics knowledge.

Conclusion. Modeling theory provides a foundation for how humans learn scientific concepts, leading to the manner in which science should be taught. Modeling Instruction has been created to align curriculum, instruction, and assessment with modeling theory, supplying a way to address student misconceptions and create accurate learning for each student. Because science and mathematics are intimately connected, Modeling Instruction has been shown increase the ability of students in mathematics..

The documents selected for this literature review have been chosen to provide context for the problem of practice and research question. This study is part of the broader movement to improve science education, and extends the research base in Modeling Instruction, PER, and action research. There are no available studies that examine the impact of Modeling Instruction on ninth grade students in physical science, so this study will make a unique contribution to the field. There have been studies related to ninth grade students in mathematics, and this study will provide more data for comparison and a direction for further research.

Keywords

Conceptual model: An encoded “model structure in symbols that activate the individual’s mental model and corresponding mental models in other minds” (Hestenes, 2006).

Force Concept Inventory (FCI): 30-question assessment that determines the conceptual understanding on the topic of force (Hestenes, Wells, & Swackhamer, 1992).

Learning cycle: A method of curriculum design that was aligned with cognitive research and popularized by Robert Karplus and the SCIS (Karplus, 1969); the three parts of the learning cycle are exploration, invention, and discovery.

Math Concepts Inventory (MCI) - 23-question assessment that determines student understanding of math concepts (Deakin, 2006; Boyarsky, Bray, & Henrion, 2009)

Mathematical model: A way of representing the structure of a system by state and interaction variables (Hestenes, 2006).

Mental models: Private constructions in the mind of an individual (Hestenes, 2006).

Model: "A representation of structure in a material system, which may be real or imaginary" (Hestenes, 2006).

Modeler: Informal term for person who uses Modeling Instruction.

Modeling cycle: A method of curriculum design that is aligned with cognitive research and used in Modeling Instruction (Jackson, Dukerich, & Hestenes, 2008); the two parts of the modeling cycle are model development and model deployment.

Modeling Instruction: Combination of modeling theory and instructional practices that create a coherent conceptual understanding for students; process by which science is performed and understood.

Normalized gain: Mathematical equation that describes the growth of an individual student on an assessment; $< g > = \frac{(posttest\ score - pretest\ score)}{(perfect\ score - pretest\ score)}$ (Hake, 1998).

Pedagogy: Method and practice of teaching.

Physics Education Research: Set of researchers working towards a coherent pedagogy of physics instruction (Beichner, 2009).

Process model: A way of designating temporal structure as a change of state variables (Hestenes, 2006).

Scientific process: Method by which science is constructed; this process is governed by general laws that define the domain and structure of a theory and specific laws defining models (Hestenes, 2006).

Structure: “The set of relations among objects in the system” (Hestenes, 2006).

System: A set of related objects; “systems can be of any kind depending on the kind of object. … In a conceptual system the objects are concepts. In a material system the objects are material things” (Hestenes, 2006).

References

American Modeling Teachers Association. (2015). Curriculum repository. Retrieved from http://modelinginstruction.org/teachers/resources/

Arseneault, M. (2014). *The effects of modeling instruction in a high school physics classroom* (Unpublished master's thesis). Louisiana State University, Baton Rouge, Louisiana.

Beichner, R. (2009). An introduction to physics education research. In C. Henderson & K. Harper (Eds.), *Getting started in PER*. Retrieved from http://www.per-central.org/items/detail.cfm?ID=8806

Boyarksy, A., Bray, R., & Henrion, M. (2009). *Effect of teaching mathematics concepts within a science context* (Unpublished master's thesis). Arizona State University, Tempe, Arizona.

Bybee, R. (2010). *The teaching of science: 21st century perspectives*. Arlington, Virginia: NSTA Press.

Dana, N., & Yendol-Hoppey, D. (2014). *The reflective educator's guide to classroom research: Learning to teach and teaching to learn through practitioner inquiry* (3rd ed.). Thousand Oaks, California: Corwin.

Deakin, J. (2006). Ninth grade physical science students' achievements in math using a modeling physical science curriculum. Retrieved from http://modeling.asu.edu/Projects-Resources.html

Dewey, J. (1910). Science as subject-matter and as method. *Science* 31: 121-127.

EBAPS. (n.d.). Retrieved from http://www2.physics.umd.edu/~elby/EBAPS/home.htm

Jackson, J., Dukerich, L., & Hestenes, D. (2008). Modeling instruction: An effective model for science education. *Science Educator, 17*(1), 10-17.

Haber-Schaim, U. (2006). PSSC physics: a personal perspective. Retrieved from http://www.compadre.org/portal/pssc/docs/Haber-Schaim.pdf

Hake, R. (1998). Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses. *American Journal of Physics*, *66*(1), 64-74. doi: 10.1119/1.18809.

Hestenes, D. (1987). Toward a modeling theory of physics instruction. *American Journal of Physics*, *55*(5), 440-454.

Hestenes, D., Wells, M., & Swackhamer, G. (1992). Force Concept Inventory. *The Physics Teacher*, *30*, 141-158.

Hestenes, D. (2006). Notes for a modeling theory of science, cognition and instruction. *Proceedings of the 2006 GIREP Conference*.

Hestenes, D. (2010). Modeling theory for math and science education. In R. Lesh, P. Galbraith, C. Haines, & A. Hurford (Eds.), *Modeling students' mathematical modeling competencies* (pp. 13-41). doi: 10.1007/978-1-4419-0561-1

Hestenes, D. (2015). A role for physicists in STEM education reform. *American Journal of Physics, 83*(2), 101-103. doi:10.1119/1.4904763
Jackson, J., Dukerich, L., & Hestenes, D. (2008). Modeling instruction: An effective model for science education. *Science Educator, 17*(1), 10-17.
Karplus, R. (1969). Three Guidelines for Elementary School Science. *Curriculum Theory Network, 4*, 4-10. Retrieved from http://www.jstor.org/stable/1179305

Melendez, J. & Wirth, D. (2001). *Closing the achievement gap by integrating 9th grade algebra and physics using modeling instruction*. Unpublished manuscript. Retrieved from http://modeling.asu.edu/

Mertler, C. (2014). *Action research: Improving schools and empowering educators* (4th ed.). Thousand Oaks, California: Sage Publications.

MIT Libraries. (2012). Physical Science Study Committee, 1956. Retrieved from https://libraries.mit.edu/archives/exhibits/pssc/

National Academy of Sciences. (2012). *A framework for K-12 science education practices, crosscutting concepts, and core ideas*. Washington, D.C.: National Academies Press.

O'Brien, M., & Thompson, J. (2009). Effectiveness of ninth-grade physics in Maine: Conceptual understanding. *The Physics Teacher, 47*, 234-239. doi:10.1119/1.3098211

Osborn Popp, S. & Jackson, J. (2009, April). *Can assessment of student conceptions of force be enhanced through linguistic simplification? A Rasch model common person equation of the FCI and SFCI*. Paper presented at the meeting of American Educational Research Association, San Diego, California.

Rudolph, J. (2006). PSSC in historical context: science, national security, and American culture during the Cold War. Retrieved from http://www.compadre.org/portal/pssc/docs/Rudolph.pdf

Schuchardt, A., Malone, K., Diehl, W., Harless, K., McGinnis, R., & Parr, T. (n.d.). *A case study of student performance following a switch to a modeling-based physics* *first course sequence*. Retrieved from http://home.comcast.net/~physicsfirst/PFSMReas.pdf

South Carolina Department of Education. (2005). *South Carolina science academic standards.* Retrieved from https://ed.sc.gov/scdoe/assets/file/agency/ccr/Standards-Learning/documents/sciencestandardsnov182005_001.pdf

South Carolina Department of Education. (2014). *South Carolina academic standards and performance indicators for science.* Retrieved from https://ed.sc.gov/scdoe/assets/file/agency/ccr/Standards-Learning/documents/South_Carolina_Academic_Standards_and_Performance_Indicators_for_Science_2014.pdf

Spring, J. (2014). *The American school: a global context*. (9th ed.). New York: McGraw-Hill.

U.S. Department of Education. (2014). *Fiscal year 2015 budget and background information*. Retrieved from http://www2.ed.gov/about/overview/budget/budget15/summary/15summary.pdf

Wells, M., Hestenes, D., & Swackhamer, G. (1995). A modeling method for high school physics instruction. *American Journal of Physics, 63*(7), 606-619.