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Exploring the Effectiveness of Model-Based Instruction to Improve Sixth-Grade Students' Science Content Knowledge

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EXPLORING THE EFFECTIVENESS OF MODEL-BASED INSTRUCTION TO IMPROVE SIXTH-GRADE STUDENTS' SCIENCE CONTENT KNOWLEDGE

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Abstract

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The economy of tomorrow is uncertain, so students today need to be prepared for the known and unknown careers that lie ahead. Currently, not all students are expected to have equal career opportunities based on evidence from dropout and testing data (Brown & Brown, 2007; Kirsch, Braun, Yamamoto, & Sum, 2007), so educators should consider different methods of helping all students reach their potential. Modeling instruction is one method that might help diverse learners improve their scientific understandings and allow them to pursue careers in technology-oriented fields. A quasi-experimental study was conducted with 128 sixth grade students as participants. A multiple choice assessment and modeling prompts were used to explore the effects of modeling instruction on student's science content knowledge. Findings from the study include (a) modeling instruction was effective in helping students of different abilities learn science content and (b) modeling instruction was more effective than regular instruction in helping students learn science content that was explicitly taught.

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Chapter 1: Introduction

Today's economy is becoming more technology-oriented, so students will need math and science skills to be competitive in the future workforce (Beede, Julian, Langdon, McKittrick, Khan, & Doms, 2011). There is some concern that students in the United States will not be competitive because of recent test score results. For example, results of the 2011 Trends in International Math and Science Study (TIMSS) showed that fourth-graders in the United States ranked seventh in the world in science and eighth-graders ranked ninth (Loveless, 2013). While some students (e.g., suburban) in the United States have science scores on the level of students in top countries like Singapore, there is a large gap amongst student scores in the United States when you consider socioeconomic status (Brown & Brown, 2007). Also related to economy, approximately 30% of students did not graduate from high school in 2007, and for minority students of low socioeconomic status this number may be closer to 50% (Kirsch, Braun, Yamamoto, & Sum, 2007). As a result, a majority of dropouts end up in low-skilled jobs (e.g., service) which pay less than one-third the wages of higher-skilled jobs (e.g., knowledge experts, managers), so their freedom of career choice and income are restricted (Kirsch et al., 2007). Over the years, policy makers and educational leaders have searched for ways to address these equity issues (e.g., achievement gaps, dropout rates). At the center of these issues is the vision of science education that leaders have in the United States.

Scientific Literacy

In a discussion of the vision of science education, Roberts and Bybee (2014) differentiated between science literacy (Vision I) and scientific literacy (Vision II). In Vision I, students are viewed as beginning scientists (science "looking in") and in Vision II, students examine how science impacts society ("science for all," science "looking out"). The authors note that there has been a recent trend away from Vision II towards Vision I. For example, the Benchmarks (National Research Council, 2012) focus more on theory and technology and less on personal and social issues. The authors argue that the definition of the two terms is important because policy and curriculum decisions are based on them. Over time, there have been shifts between the two visions, but both visions are important. To address both visions, the authors describe two ways to provide science education for students. The first way involves requiring a class for all students (Vision II), but allowing for additional classes for students who might seek professional careers in science (Vision I). The second way would incorporate Vision I and II throughout the curriculum. While there appears to be a distinction made between scientific insiders (career track) and outsiders (people who use science in everyday life), Roberts and Bybee (2014) discuss the possibility of developing "competent outsiders" – scientifically literate people who can make informed decisions. The authors conclude that there needs to be a balance between the two visions and that one should not be discarded for the other so that all students may benefit from science instruction.

The current study focuses on the "science for all" vision (Vision II) of science education because all sixth grade students learn the same set of science standards and take the same science classes. Modeling seeks to provide *equitable* instruction so that all students may improve their scientific understandings. Halloun (2004) describes equitable instruction as instruction that allows all students willing to put in the effort to gain an understanding of the basic models of a course, which is referred to as the *paradigmatic threshold*. Not all students would achieve at the same level, but all students would be able to meet this minimum competence level. Two groups of students who might struggle to reach this minimum competence include special needs students and English language learners. Several recommendations have been made to improve the scientific understandings of English Language Learners, such as (a) engaging students in hands-on learning, (b) integrate inquiry with literacy development, and (c) using student's' home language and culture to support instruction (Buxton & Lee, 2014). McGinnis and Kahn (2014) reported how special needs students can benefit by being in student-centered environments that give all students access and promotes participation. Modeling instruction might meet the needs of both of these student groups because of its hands-on, participatory nature.

There are many ways that science-for-all has been promoted in science education throughout the years. Some examples include the use of technologies, the promotion of activity-oriented approaches, and the implementation of co-taught classes and heterogeneous groupings. A variety of technologies have been used to promote learning for all students. Some examples of these technologies include simulations and virtual field trips. These technologies can help all students investigate real-world problems in a safe and inexpensive way. They can also provide access to the curriculum for students who may have a variety of disabilities, such as a virtual lab where a student can use a joystick to move tools and equipment around in a lab environment (Smedley & Higgins, 2005). An activity-oriented approach, where students can apply science, has also been found to help all students learn science. In such an approach, the use of the textbook and the focus on vocabulary acquisition is decreased; students can go into greater depth as they cover fewer topics (McGinnis & Kahn, 2014). Co-teaching, where a second teacher is involved in the instruction of a class, is a third strategy used in science classes to meet the needs of all learners (McGinnis & Kahn, 2014; Buxton & Lee, 2014). Finally, heterogeneous grouping is another method used by educators to meet the needs of all learners. The idea behind heterogeneous groups is to give all students the opportunity to share a wide range of ideas with each other so that all students experience learning gains (Watanabe, Nunes, Mebane, Scalise &

Claesgens, 2007). Some might argue that heterogeneous grouping might be detrimental to high-achieving students, but heterogeneous groupings did not appear to have a negative effect on the learning of high-achievers in a study of fifth-grade science students learning about convection (Carter, Jones & Rua, 2003). Homogeneous groups and classes have been criticized because low income learners and minorities often receive poor instruction and supports and all learners (including high achievers) lose out on diverse perspectives (Rubin, 2006). This is an important point, as discourse amongst students has shown to be an important factor in the cognitive development of students (Carter, Jones & Rua, 2003). Unfortunately, various factors (e.g., lack of materials and staffing) prevent many students from experiencing the benefits of these interventions, so other interventions must be sought.

Model-Based (Modeling) Instruction

Another way that science-for-all has been promoted is with model-based instruction (MBI), also referred to as modeling instruction. Reform documents in science education speak extensively about models and modeling. Science for All Americans describes a model as a simplified version of something that might help people understand science better (Rutherford & Ahlgren, 1990). Models come in a variety of forms; some common categories of models include physical (e.g., model car in a crash test), conceptual (e.g., analogies), and mathematical (e.g., formula for density). These concepts about models are what a scientifically literate person should understand. The three previous categories of models are echoed in the Benchmarks for Science Literacy (American Association for the Advancement of Science, 1994). Physical models are considered the easiest models to use, and can be used as early as the primary grades. Conceptual models are more complex, but teachers are encouraged to incorporate them in middle school curricula. The most complex of the models, mathematical models, can be introduced in the middle grades and elaborated on in high school. At the highest level, students would be able to create and use models in different ways, such as by making predictions. Models are considered to be one of the unifying concepts in science (National Research Council, 1996). As one of the unifying concepts, models can connect different science disciplines, be used as a tool in science, and be considered a fundamental part of the science discipline. The standards encourage teachers to help students understand that models can be created and tested, and are not just copies of real objects.

Finally, the Next Generation Science Standards are full of standards that require students to use or create models (National Research Council, 2013). The development and use of models is one of the science and engineering practices in the Next Generation Science Standards (National Research Council, 2013). According to the *Framework for K–12 science education,* "modeling can begin in the earliest grades, with students' models progressing from concrete 'pictures' and/or physical scale models (e.g., a toy car) to more abstract representations of relevant relationships in later grades, such as a diagram representing forces on a particular object in a system." (National Research Council, 2012, p. 58) Models highlight certain parts of the real world so that one can develop questions, test ideas, and share their ideas with others. Models are meant to be revised, as data collected from models are compared to the predictions that were made. Table 1 shows Practice 2 of the Science and Engineering Practices.

Table 1
Science and Engineering Practice: Developing and Using Models

Grades 6-8
Modeling in 6–8 builds on K–5 experiences and progresses to developing, using, and revising models to describe, test, and predict more abstract phenomena and design systems. • Evaluate limitations of a model for a proposed object or tool. • Develop or modify a model—based on evidence—to match what happens if a variable or component of a system is changed. • Use and/or develop a model of simple systems with uncertain and less predictable factors. • Develop and/or revise a model to show the relationships among variables, including those that are not observable but predict observable phenomena. • Develop and/or use a model to predict and/or describe phenomena. • Develop a model to describe unobservable mechanisms. • Develop and/or use a model to generate data to test ideas about phenomena in natural or designed systems, including those representing inputs and outputs and those at unobservable scales.

Note. The Science and Engineering Practice, Developing and Using Models, was taken from the Next Generation Science Standards (National Research Council, 2013).

Models are also one of the crosscutting concepts in the NGSS. According to the *Framework for K–12 science education,* "crosscutting concepts have value because they provide students with connections and intellectual tools that are related across the differing areas of disciplinary content and can enrich their application of practices and their understanding of core ideas." (National Research Council, 2012, p. 233) Appendix G of the NGSS explains that "systems and system models are useful in science and engineering because the world is complex, so it is helpful to isolate a single system and construct a simplified model of it" (National Research Council, 2013, Appendix G, p. 7). Table 2 shows the grades 6-8 portion of the learning progression of systems and system models.

Table 2
Crosscutting Concept: Systems and System Models

Grades 6-8
In grades 6-8, students can understand that systems may interact with other systems; they may have sub-systems and be a part of larger complex systems. They can use models to represent systems and their interactions—such as inputs, processes and outputs—and energy, matter, and information flows within systems. They can also learn that models are limited in that they only represent certain aspects of the system under study.

Note. The Crosscutting Concept, Systems and System Models, was taken from the Next Generation Science Standards (National Research Council, 2013).

Model-based (modeling) instruction is a method of teaching students science through the process of model-building, evaluation, and revision (Windschitl, Thompson, & Braaten, 2008). Modeling is an iterative process, as students may evaluate and modify their models many times until a scientifically-sophisticated working model is created. Model-based (modeling) instruction might be able to help students learn science content, such as the phases of matter, because most students have some sort of preconceptions about the world. Modeling starts with these preconceptions and provides the opportunity for students to either build on scientifically-appropriate preconceptions or correct misconceptions that they may have about science content. This modeling cycle (generating, evaluating, modifying) allows students to advance their scientific understandings of science concepts.

Purpose

Halloun (2004) stated that modeling instruction can help *all* student reach the paradigmatic threshold (level of basic models) of a given course if they put in the effort, so the current study seeks evidence to back this claim by examining the effectiveness of modeling instruction on the advancement of conceptual understandings of sixth-grade students at various levels (accelerated, regular, and co-taught). Accelerated classes have students who scored high on math and reading assessments, and the co-taught classes have a high percentage of special needs students (special education and English Language Learners). The current study also investigates the effectiveness of modeling instruction in contrast to regular instruction. Regular instruction includes activities developed by the local school district in alignment with the NGSS standards. A quasi-experimental design was used since the random assignment of students was not possible (existing classes will be used). Scores from assessments given at the beginning, middle, and the end of a unit on phases of matter were collected from students at a middle school in the southwestern United States to assess changes in scientific understanding as the result of modeling instruction.

Organization

Chapter Two is divided into two parts: the theoretical framework and the literature review. The theoretical framework used in the current study is modeling theory. The contributions of five authors were used to describe this theoretical lens. To begin, Halloun's (2004) version of modeling theory for upper level students in physics is described. An overview of Halloun's (2004) modeling theory is followed by a description of what he calls "paradigmatic evolution." Halloun's (2004) modeling program and learning cycles are also defined and described. Next, Clement and Rea-Ramirez's (2008) contribution to models based learning in areas such as human biology and electricity is summarized. In this part, a description of GEM (generate-evaluate-modification) cycles and model evolution levels are given. Following Clement and Rea-Ramirez (2008), Gilbert and Justi's (2016) model based teaching (for chemistry education) approach is described. The four phases of their modeling cycle are described, as well as contributions related to technology (for authentic inquiry) by Jonassen (2005; 2006; 2012) and model engagement (Jonassen, 2005; Chi & Wylie, 2014). The first part concludes with a description of the key elements of modeling theory that were found throughout the work of the five authors. The key elements include: (a) modeling instruction advances the scientific understandings of all learners, (b) modeling instruction is student-centered and teacher mediated, (c) modeling is an iterative process where students both construct and revise models, and (d) modeling instruction is equitable.

The second part of the chapter examines the literature related to modeling in science education. The review of literature is divided into four parts, each one aligned with one of the four key elements identified in modeling theory. For the first key element (modeling instruction advances the scientific understandings of all learners), the literature is divided by education level. Examples of learners advancing their scientific understandings at the elementary, middle, school, high school, college, multiple levels, and teacher education are given. For the second key element (modeling instruction is student-centered and teacher mediated), the literature is divided based upon the level of student-centeredness and amount of teacher mediation that was described. The first section includes literature that illustrates "complete" student-centered, teacher mediated environments. These studies describe learning environments that include student working in groups, students talking to each other and the teacher, students receiving feedback from various sources, and some level of teacher mediation. The second section includes literature that illustrates "partial" student-centered, teacher mediated environments, such as interventions where students talked and worked together in groups and experienced some teacher mediation, but didn't receive any feedback. The next two sections include literature that describes learning environments with either student-centered elements without teacher mediation or teacher mediation without student-centered elements. The fifth section contains literature that compares a student centered approach versus a teacher mediated approach. Finally, literature which did not have any evidence of a student-centered or teacher mediated learning environment are discussed.

For the third key element (modeling is an iterative process where students both construct and revise models), the literature is divided into three main sections. The first section describes ways that models have been used in science education, and the second section describes ways that models are constructed. The third section includes literature where students were able to both construct and revise models in an iterative fashion during an intervention. This section was broken down further by the mode of representation used: drawings, technology-based, and multiple models. For the final key element (modeling instruction is equitable), the literature was examined in four characteristics related to the participants: gender, socioeconomic status, ethnicity, and special needs (special education and English language learners). At the end of the literature review, a gap in the literature is identified and research questions and hypotheses are given to address this gap.

Chapter Three describes the methods for the current study. The first part of the chapter is a description of the participants and setting for the study. The second part of the chapter describes the design and instruments for the study. This section of the chapter starts with a description of the quasi-experimental design followed by two subsections. The first subsection describes the quantitative data collection instruments: the AAAS assessment and the modeling prompt. Threats to validity are also addressed in this subsection. The second subsection describes the quantitative data analysis procedures for the study (parametric and nonparametric testing). The third part of the chapter describes the procedures of the study. The NGSS standard that is addressed in the intervention is stated, and the differences between the two groups (treatment and comparison) are briefly explained. After the knowledge and performance targets are listed, the classroom activities that address each target are described.

Chapter Four begins with an overview of how the data from the study will be presented. Next, the assumptions testing for the first research question are described, as well as the justification for the types of tests that were used (parametric vs. nonparametric). The following section provides a record of the results related to the testing for research question 1. A summary table for all of the tests and results for the first question conclude this section. The last two sections of Chapter Four are similar to the previous two, except the assumptions testing, results, and summary table all relate to research question 2.

Chapter Five begins with a brief description of how the chapter is organized. After the purpose of the study is restated, a discussion of the results for the two research questions is provided. At the end of the chapter, educational implications, areas for future research, and limitations of the study are discussed.

Chapter 2: Theory and Literature

Theoretical Framework

The theory that is used to inform this study is modeling theory. Several researchers have contributed to modeling theory, but this section focuses on the work of five authors. Halloun (2004) developed a version of modeling theory for upper level students in physics. Clement and Rea-Ramirez (2008) contributed to models based learning in areas such as human biology and electricity. Finally, Gilbert and Justi (2016) focused on model based teaching in chemistry education.

Halloun's Modeling Theory. Modeling theory, according to Halloun (2004), is a pedagogical theory in science education. It states that models are at the center of any theory and the central part of a curriculum. Modeling theory in science education helps students to go through paradigmatic evolution, where student ideas evolve from naive realism towards scientific realism. Naive ideas are transformed, viable ideas are reinforced, and new knowledge is formed through this evolution. Modeling instruction incorporates student-centered activities, experiential knowledge, and equitable learning experiences that are mediated by the teacher in learning cycles. "Student-centered" refers to the active engagement of students in their learning, but making sure they receive some guidance (Halloun, 2011). Mediation (e.g., moderation, arbitration, scaffolding) refers to the main role of teachers in modeling instruction and is necessary because most students would not be able to learn on their own.

Halloun's (2004) modeling theory differentiates the physical universe (real world/empirical world) from the human mind (mental world/rational world) and focuses on the conceptual (rational) world. This conceptual world includes conceptions and tools (e.g., language, pictures, math). According to modeling theory, *paradigms* are conceptual systems that control a person's conscious experience as they experience everyday life. Paradigms are necessary in order to perceive the world, and people have a number of paradigms of various types. For example, a scientific paradigm is a paradigm that is shared by members of a certain scientific community. A paradigm may include several related theories, which provide the content of the paradigm. A scientific *theory* consists of a set of models and rules that guide model construction and deployment. Scientific *models,* according to Halloun (2004), are conceptual systems that are mapped onto real-world patterns, and may be exploratory (pattern description, explanation, prediction) or inventive (pattern reification: making something real/concrete). Models are at the center of a middle-out structure of theory, with theory being superordinate and concepts being subordinate. The level of models can be further divided into three sublevels: *basic* models (the middle level - they are comprehensive models), emergent models (superordinate level - a combination of two or more basic models), and *subsidiary* models (subordinate level - simplified version of a basic model). Models are the building blocks of knowledge because they provide meaning (e.g., atoms, the model - not elementary particles, the concept - gives meaning to matter).

A scientific model fits into a theory via a *schema* (Halloun, 2004). The definition for a schema is different in modeling theory than in cognition. In cognition, schema refers to a unit of knowledge (e.g., p-prims), but in modeling theory, schema refers to "a generic tool for explicitly organizing and deploying a particular class of conceptions," a "conceptual template with no specific content," and focuses on a pattern amongst many physical realities (Halloun, 2004, p. 40). Students must use these schemata (mainly model and concept schemata) to construct their conceptions. A model schema, which is used for model construction and deployment of a scientific model, is the most important schema in modeling theory and consists of four dimensions. *Composition* (conceptions) and *structure* (relationships between parts of a pattern) set the ontology and function of the model, and *domain* (all physical realities that exhibit a pattern) and *organization* (links models in a theory to each other) set its scope (the theory it belongs to, correspondence to pattern). Models are constructed, deployed, and continuously evaluated under the theory it belongs to, and correspond to physical realities exhibiting the pattern that the model represents. According to Halloun's (2004) modeling theory, the viability of a paradigm (or theory) depends on the way models are constructed, corroborated, and deployed. Model viability is not about if a model is true/false, but rather how well the model represents a pattern in the real world and how useful it is for answering questions about certain physical realities. Viability relies on corroboration, both empirically and rationally, since a model may have data to support it but still be faulty (e.g., Ptolemy's planetary model).

***Paradigmatic Evolution*.** Halloun (2004) identified three issues with students' natural paradigms in relation to knowledge evolution in science education: (a) students' conceptions of physical realities are often a mix of beliefs and knowledge rather than viable knowledge, (b) traditional science education does little to improve this situation, and (c) students may not get much out of lectures/traditional instruction because it does not relate to their natural paradigms. In the third case, science has been mostly presented as ready-made knowledge rather than scientific habits of mind, where mental habits are transformed. Modeling theory, however, promotes *paradigmatic evolution*: the transformation of student's natural paradigms (naive realism/common sense) to the realm of science (scientific paradigms).

According to Bachelard (1940), every conception is spread through an inferred epistemological profile. Subjective Concretism (SC) is the level of naive realism, where students focus on objects, not phenomena (e.g., students think bigger objects have more mass). Positivist

Empiricism (PE) is the level of clear and positivist empiricism where concepts become more precise (e.g., there is a scale for mass). Classical Rationalism (CR) is the level where conceptual systems have predictive power (e.g., mass considered a ratio of 2 concepts). Relativistic Rationalism (RR) is the level of complete rationalism, where there are no more absolute concepts (e.g., mass is a function of speed). Finally, Dialectical Idealism (DI) is the level of open and discursive rationalism, where reality is put aside (e.g., idea of negative mass considered).

Halloun (2004) extended this profile (pertaining to a single conception) to conceptions and all natural paradigms a person may have. These paradigms compose an individual's *paradigmatic profile* (PP) and are discussed later. Halloun (2004) created a modified scheme, based on Bachelard's (1940) work, that included three paradigmatic *dimensions*: (a) Naive Realism (NR) incorporates SC and PE of Bachelard's (1940) profile and is where an individual's ideas are inconsistent (and even contradictory), (b) Classical Scientific Realism (CR) incorporates CR and is where ideas are relatively viable, and (c) Modern Scientific Realism (MR) incorporates RR and DI and is where ideas are scientifically viable. Although the three dimensions appear side by side in the continuum, NR is significantly different than CR and MR. From this modified profile, the author identified two paradigmatic profiles that most students have: (a) a *naive profile*, which is a mix of NR and CR, but dominated by NR (a naive realist), and (b) a *common sense profile*, which exhibits some balance between NR and CR.

Naive profiles affect the learning of science, so they must be addressed (Halloun, 2004). For example, naive realists incorrectly think that: (a) scientists do not admit to the existence of a physical reality unless it can be perceived, (b) one should observe without prior knowledge (to be unbiased/objective), (c) scientists collect/analyze data without hypotheses, in an inductive manner, (d) the structure/behavior of physical realities are governed locally (not universally), and

(e) knowledge mirrors the world. The models that naive realists develop are incompatible with scientific models externally and internally, are narrower in scope and less viable, and are a loose collection of concepts that are confused with each other (e.g., velocity and acceleration). On the other hand, students with common sense profiles develop models that are somewhat compatible with scientific models (internally and externally), but are not as coherent, thorough, or viable. Naive realists usually don't understand the limitations of their models because they don't evaluate their models internally or externally.

The goal of modeling theory is to transform the paradigmatic profiles (not paradigms) of students from naive and common sense towards scientific dimensions, which is the level of *basic model* (the *paradigmatic threshold*) (Halloun, 2004). Halloun (2004) defines the paradigmatic threshold as the level where basic models are developed and successfully deployed (in the theories) in a science course. The paradigmatic threshold is the minimum competence required in a course. Halloun (2004) argues that this minimum competence is attainable for all students willing to make the effort (although individual differences and affective factors play a role), so modeling theory is both efficient and equitable. In this vision of equitable instruction, there would be no bell curve and all students would have the ability to reach and/or exceed the threshold.

Modeling theory seeks to have students develop scientific knowledge that is personally relevant (Halloun, 2004). This development, or paradigmatic evolution, "involves transformation of existing constituents of a person's initial paradigmatic profile, as well as formation of the new paradigmatic constituents. Transformation extends from the refinement to the rejection and replacement of existing conceptual structures and processes." (Halloun, 2004, p. 113) There are six types of components in a student's paradigmatic profile (PP): (a) naive belief, which is the uncorroborated part of a naive paradigm at odds with science (e.g., naive realist believes that scientists only accept the existence of something after it's been observed or measured), (b) naive knowledge, which is knowledge that is at odds with science based on unreliable evidence or misinterpretation (e.g., object fall because air pushes it down), (c) viable belief:, which is the an uncorroborated idea that is largely aligned with science (needs *evidence*), (d) viable knowledge, which is largely aligned with science (backed with evidence), (e), missing, derivable knowledge, which is scientific knowledge that students lack but can be developed using pre-existing viable ideas (e.g., learning acceleration using velocity and time), and (f) missing, prime knowledge, which is scientific knowledge that students lack and cannot be developed using pre-existing viable ideas (e.g., learning quantum mechanics). Naive knowledge is often called a misconception and needs to be replaced, whereas reliable knowledge needs to be refined. These six forms can be divided into three categories, naive ideas, viable ideas, and missing knowledge, and each category has different ways to be addressed in science education. According to Halloun (2004), the transformation and/or development of these ideas is similar to Kuhn's (1970) scientific revolutions and normal science.

While the proportion of naive to viable knowledge students have varies from course to course, the level of naive realism across student populations is relatively homogeneous (Halloun, 2004). According to Halloun (2004), this homogeneity allows teachers to help all students succeed in reaching the paradigmatic threshold by creating a course with basic models as the main content, considering students' initial paradigmatic profiles, engaging students in empirical-rational dialectics, and structuring the learning experiences to keep students on track. Teachers expose students to rational and/or empirical situations (e.g., discrepant events) that bring them to conflict (cognitive disequilibrium) so that they will reconsider their ideas. Paradigmatic profile evolution may involve fine tuning ideas, forming new ideas, or radically changing ideas. Students' paradigmatic profiles need to be assessed through regulatory dialectics in three ways: coherence (intrinsic, rational), correspondence (extrinsic, empirical), and commensurability (extrinsic, rational). The end result of these negotiations may result in reinforcement, modification, and/or replacement of paradigmatic components. All three modes of assessment, however, may not be necessary. Coherence is useful for viable knowledge, but not for missing knowledge, and commensurability is a last resort for naive realists.

Learning science also depends on affective controls, such as interest, motivation, locus of control, and attitudes towards science (Halloun, 2004). Students who do poorly in science are often unmotivated, not interested, and in authority-driven environments. These students may think science is irrelevant in everyday life and talent is more important than effort in learning science. Affective factors need to be considered to help students learn science, so Halloun (2004) suggests that teachers change the locus of control so students can take an active role and see the "personal need" to go through paradigmatic evolution.

***Modeling Program*.** Modeling theory promotes paradigmatic profile evolution which helps students go from naive realism towards scientific realism (Halloun, 2004). Science courses, then, should be designed to help all students cross the paradigmatic thresholds (set of basic models in the theories) of the course. Modeling theory advocates for a program with a structured learning environment which revolves around model-centered content. Students would self-regulate their paradigmatic profiles through *learning cycles* (discussed later). A modeling program focuses on structuring scientific theory around basic models and creating activities that help students develop theory and skills through experiential knowledge. During modeling instruction, naive realism is not completely eliminated, but is limited as students reach/exceed the paradigmatic threshold (as determined by the basic models). Since students cannot learn science the same way scientists do (e.g., scientists have more resources), they must be guided by the teacher to reconstruct scientific theory that has gone through a cognitive transformation, or *didactic transposition* (transforming scientific knowledge so it is suitable for students to learn).

In traditional science, theory is broken-up so much that it loses structural/functional power, so students have random theoretical ideas (Halloun, 2004). Modeling theory sets the structure and function of courses (paradigmatic thresholds), whereby theory is developed/deployed in a middle-out approach centered on basic models. Basic models represent patterns in the real world; they are the core content of courses and pedagogical tools to help students develop theory. In modeling instruction, content is divided into models, not individual concepts. New conceptions may be progressively developed within the context of a model (e.g., Newton's second law gradually developed in uniformly accelerated particle model). To engage students in the modeling process, Halloun (2004) suggests that two conditions must be met: personal relevance (everyday life experiences) and necessity (cognitive equilibrium). Students should not be expected to develop new models on their own; some teacher interventions may include activities, providing data, lectures, and helping students test their models. Individual students should constantly reflect on their knowledge and profiles during activities. Teachers can pair groups with differing ideas to generate discussion (merits and limitations), not to identify a right or wrong answer. Teachers need to give immediate feedback and provide follow-up activities to students. Assessment in modeling theory is not an end in itself; it is for helping students regulate their profiles. Success of a modeling program is judged by how many students reach the basic threshold.

Learning Cycles. Halloun's (2004) modeling theory promotes *reflective inquiry*, where students focus on patterns in the real world and are guided to regularly reflect on their conceptual and paradigmatic profiles. His modeling theory uses learning cycles to help students learn through active engagement. Learning cycles in modeling theory have 5 stages: exploration, model adduction, model formulation, model deployment, and paradigmatic synthesis. Students evaluate their ideas empirically and rationally through the learning cycle. Students' ideas may be naive, viable, or missing, so reflective inquiry can lead to the construction of missing knowledge, the preservation of viable ideas, the modification of flawed ideas, or the replacement of naive ideas. Any new, reliable knowledge is integrated into the student's paradigm.

Karplus (1977) proposed that learning cycles be used for teaching concepts through constructivism. Karplus' cycle had three phases: exploration, concept introduction, and concept application. Variations of this cycle were developed by Clement (1989), Hestenes (1987), and White (1993). Halloun's (2004) modeling learning cycles (MLCs) align with modeling theory and have many characteristics, including: (a) a structured, five-phase cycle, (b) a realistic objective (help all students cross the critical paradigmatic threshold), (c) a middle-out, progressive cognition, (d) didactic transposition, (e) insightful, reflective dialectics (rational-empirical), (f) a change in locus of control (student-centered), and (g) teacher-mediated learning (through moderation, arbitration, and/or scaffolding) and timely feedback.

The first phase of the MLC, *exploration*, is intended to help students identify a pattern that requires a new model (Halloun, 2004). The exploration phase has two parts: *monstration* and *nominal model proposition.* In monstration, students complete one or more cognitive disequilibrium activities where students realize the inadequacy of existing knowledge for describing/explaining a pattern and the need to build a new model. Monstration activities may include demonstrations, case studies, thought experiments, or other activities. Teachers might begin a monstration exercise by showing a phenomenon and following up with some questions to make students compare the parts of the system and make predictions (e.g., what is this demo about, what phenomena are involved). Students may generate many subsidiary models in this phase. In nominal model proposition, the construction of new model begins, starting with subsidiary models (subordinate to basic models). Students are asked to make formal hypotheses and justify them using subsidiary models so that they can see that their models have flaws. Teachers moderate this model negotiation, and by the end of the stage students are left with no more than three candidate models to consider - the others have been eliminated.

In the second stage, *model adduction*, the remaining models from the exploration stage are analyzed by the students, so that by the end of the phase one model will be chosen for evaluation and formulation (Halloun, 2004). The teacher's role is more involved in this phase; rather than moderating, the teacher acts as an arbiter. Students plan empirical experiments and/or observations during adduction to assess the model so it can be refined in the next phase. The model adduction phase has two parts: *plausible model proposition* and i*nvestigative design*. In the plausible model proposition part, students try to eliminate any remaining secondary/naive elements and develop a single model. In the investigative design part, students plan experiments to determine the viability of their models. The experiments are designed to test the viability of a model, not to verify a model. Many different designs are proposed by the students, but through negotiation only one design is chosen.

The third stage, *model formulation*, has students perform the designed experiment and refine the model in light of the evidence and through rational analysis (Halloun, 2004). The teacher acts as a moderator initially, but then shifts to an arbiter later in the stage. Scaffolding from the teacher also becomes important in this stage. The two parts of this stage include *investigation and initial model formulation* and *rational model extrapolation*. In the first part, student groups do their experiments separately, but may periodically communicate with each other. The groups then share out their results and eventually refine the plausible model. In the second part, rational extrapolation takes place to refine the model (e.g., formulate missing laws from the data).

During *model deployment*, the fourth stage, a model becomes more significant by having the ability to describe, explain, and predict a variety of physical realities (Halloun, 2004). There are two parts of model deployment: *elementary deployment* and *paradigmatic deployment.* In elementary deployment, students do simple empirical and rational activities, similar to end-of-chapter exercises in textbooks, which focus on several things such as recognizing patterns, clarifying concepts and/or laws, and developing scientific discourse. In paradigmatic deployment, students use a model empirically (E) and rationally (R) so their paradigmatic profiles are able to evolve. Ultimately, students may be able to use the model solely in a rational sense without any empirical data. Halloun (2004) identified four categories of deployment activities; (a) application (the empirical world is matched with the rational world, E-R), (b) analogy (different empirical situations that show a similar pattern, E-E), (c) reification (deduction, to match a pattern in the real world, R-E), and (d) extrapolation (consider models without empirical data, R-R).

In the final stage, *paradigmatic synthesis*, the model is evaluated rationally (for internal and external consistency), empirically (mapping between model and pattern), and summatively (model-theory match), and students engage in self-evaluation and self-regulation to promote paradigmatic profile evolution throughout the learning cycle (Halloun, 2004). Halloun (2004) suggests that students keep a journal of what they learned throughout the cycle and occasionally restate the main points (recapitulation).

Clement & Rea-Ramirez's Model Evolution. Clement and Rea-Ramirez (2008) proposed that modeling instruction start with student's preconceptions and go through a process of model evolution. The models that are produced in this type of instruction would be qualitative explanatory models that are central to the scientific theories addressed in a particular course. These explanatory models describe non-observable processes, explain how a system works and its observable characteristics, and can provide a foundation for later models. During the modeling process, an initial model is created from student's preconceptions and then students make a series of revised, intermediate models until they develop the target model. Having students begin the modeling process with initial, naive ideas allows them to engage in scientific reasoning, make small revisions (so they don't become overwhelmed), and build a deeper understanding of nature. Multiple analogies are used throughout the modeling process because students sometimes have a mix of correct and incorrect ideas. The teacher can plan a series of activities to help them develop their intermediate models along a *learning pathway*. Formative assessments should be used to make sure students are being appropriately challenged along the way.

Clement (2017) later refined these ideas of model development by identifying four levels of modeling processes. The highest level (Level 4), Model Construction Modes, has alternating events of model evolution (improving a model) and model competition (models are compared) that take place over a larger time scale, such as days (Clement, 2017). Model evolution is driven by the GEM Cycle (Level 3), where students generate, evaluate, and modify their models in a smaller time scale, such as minutes or hours. This cycle occurs through various interactions, such as: (a) disconfirmation mode (teacher-student interactions where a model gets eliminated), (b) modification mode (teacher-student interactions where a model gets revised), and (c) accretion mode (teacher-student interactions where new parts get added to a model) (Nunez-Oviedo & Clement, 2017). Clement and Rea-Ramirez (2008) refer to this process as *co-construction*, since both students and the teacher contribute to the process of creating a sequence of intermediate models on the way to the target model. Argumentation plays an important role in the modeling process because students improve their models when they have to share and defend their intermediate models. Model-based co-construction integrates cognitive and social elements, having its roots in model-based learning/conceptual change theory (Piaget, Kuhn) and social learning theory (Vygotsky). The next level (Level 2), Nonformal Reasoning Processes, is where students may work with analogies or run their models during a GEM cycle (Williams & Clement, 2017). This level is typically on a timescale of minutes and can occur frequently during whole class discussions. The lowest level (Level 1), Underlying Imagistic Processes, is where students use imagery in some observable way in their modeling in a very short timescale (seconds). For example, students may say what they are thinking or use imagery to make a prediction (Stephens, Clement, Price, & Nunez-Oviendo, 2017).

Clement and Rea-Ramirez (2008) estimated that 85% of this curriculum is teacher-led, but only 40% of ideas are teacher-generated. Roles of a teacher include: (a) determining target models and learning pathways in the curriculum, (b) identifying student preconceptions, and (c) providing scaffolding for students as they progress along the pathway. Clement and Rea-Ramirez (2008) argue that all students may benefit from this step-by-step model evolution because it starts with the individual student's ideas, it can be used in a variety of contexts, and it helps students follow the reasoning as models are generated and modified.

Gilbert & Justi's Model of Modeling. Modeling is a process of creating, using, and manipulating models to create explanations, make predictions, share ideas, and help students learn (Gilbert & Justi, 2016). In Gilbert and Justi's (2016) modeling approach, mental models are produced, expressed, and tested in a cyclical, non-linear process, and the created model is evaluated to determine its limitations. They state that, while there is no recipe for modeling, there are basic stages that could be identified to guide students through the process. In stage 1 (creation/development of a proto-model) of their approach, students need to understand the purpose of the model to be created, have experience(s) with the phenomena related to the model, and use analogies or other tools to understand the experiences. In stage 2 (expression of a proto-model), students create a model to represent their proto-model. This representation may be a drawing, a 3D representation, mathematical, or take other forms. During stage 3 (testing the model), students conduct a series of empirical and mental tests of their model. These tests should challenge students to think about the data and may lead them to make modifications, have additional experiences, or a change a source (e.g., analogy). Finally, in stage 4 (evaluating the model), students try to apply the model in different contexts to test its limitations and convince others of their model's validity and applicability. Progress through each stage is guided by the use of four processes: analogies, imagistic representations, thought experiments, and argumentation.

Gilbert and Justi (2016) argue that concepts form through direct experience and evolve through direct intervention (e.g., instruction). In order for conceptual evolution to take place, ontological, epistemological, and representational conditions must be met; models-based teaching meets all three criteria (Gilbert and Justi, 2016). They also argue that a concept is treated as an object that can be given to someone (it is law-like) and a model is produced for the purpose of sharing with others. Simple ideas can be considered concepts and complex ideas (with several concepts) make up a model, so the meanings of *concept* and *model* converge. If this is the case, then according to Gilbert and Justi (2016), concept-based teaching and models-based teaching would be compatible. So if one speaks of model evolution in models-based teaching, then the concepts related to those models would also be changed.

Gilbert and Justi (2016) also argue that modeling should be made as authentic as possible. One element of authentic science education is an engaging, student-centered environment where learners can collaborate with each other in a community of practice. Gilbert and Justi (2016) argue that working in small groups would help students produce consensus models that can be discussed as a whole class. In such an environment, students would need access to experts, such as a teacher, scientist, or additional resources (e.g., technology). Students would also need to have a basic understanding of models in science, such as (a) models are not copies of reality, (b) models can be changed, and (c) models have many functions. In the modeling process, teachers would be expected to guide students throughout the modeling process (e.g., scaffolding), although their level of participation would vary depending on student's prior knowledge and skill levels.

One way that teachers could address the demands of authentic inquiry would be to provide computer technologies to assist students in their modeling inquiries (Gilbert and Justi, 2016). Jonassen (2005) suggested that technology-based modeling tools (e.g., Mindtools) could help students develop both quantitative and qualitative models to advance their scientific understandings. Some of the tools (Mindtools) that he suggested included databases, concept maps, spreadsheets, and visualization tools (Jonassen, 2006). According to Jonassen (2005), students often build models in their minds to solve everyday problems, but their models are frequently incomplete or incorrect. Building and using technology-based models, then, might help students restructure their ideas and advance their scientific understandings. Jonassen (2014) suggested that students should have opportunities to work in groups as they engage in modeling with technology so they can share their ideas with each other (e.g., comparing concept maps). The construction and revision of these computer models not only helps students *reify* their understandings but also provides artifacts which teachers can use to *assess* the students' understandings (e.g., observing changes in concept maps over time) (Jonassen, 2005).

Jonassen (2005) differentiated between model *construction* and model *use* and argued that model construction is more powerful for promoting student learning. The reason for this is that when students use models, they are unaware of the model's underlying mechanisms; students can only change variables and run tests with many of the existing computer models, but they cannot change the models themselves. When students create and revise their own models, their *own* thinking can be restructured since they are starting with their own ideas. The idea that model construction is more powerful than model usage alone is in alignment with the ICAP framework developed by Chi and Wylie (2014). According to the ICAP framework, *interactive* learning activities (I) are more engaging than *constructive* learning activities (C), which are more engaging than *active* learning activities (A), which are more engaging than *passive* learning activities (P). Developing models according to the methods previously described would be *interactive* because students would be generating and revising models in groups, building on each other's ideas, whereas using models would be *active* because students would be manipulating models to learn how they work. So, model construction would be more cognitively engaging than model use alone.

Modeling, according to Gilbert and Justi (2016), plays an important role in developing scientific literacy for all students. Scientific literacy has many definitions, but in this context it refers to the ability to address everyday problems (e.g., staying healthy). Gilbert and Justi (2016) argue that learning about modeling and gaining modeling skills will promote scientific literacy and prepare students for future careers in four ways. First, by focusing on a limited number of models in the curriculum, students will be able to deepen their understandings of science concepts and gain skills that might help them explore real life problems. Second, understanding the role of models and modeling in the development of science and technology will help students to interpret data and evaluate claims using the data. Third, modeling might help students improve their abilities to think about science, engineering, and technology and communicate their ideas effectively. Fourth, experiencing modeling will allow students to understand that scientific knowledge is developed through argument (as well as experience argument).

Key Elements of Modeling Theory. There are some differences in the modeling approaches that Halloun (2004), Clement and Rea-Ramirez (2008), and Gilbert and Justi (2016) proposed, but four common elements can be drawn from the three contributions to modeling theory. First, modeling promotes the evolution of student's ideas from naive to scientific (advancing scientific understandings). Halloun (2004) describes a modeling process which helps students go through paradigmatic evolution. Students gradually transform naive ideas, retain viable ideas, and generate new knowledge through this evolution. Clement and Rea-Ramirez's (2008) modeling evolution might occur at an accelerated pace compared to Halloun (2004) because it's broken down into smaller parts and the teacher has a more central role in the process. Through analogies, imagistic representations, thought experiments, and argumentation, students are able to transform their ideas in Gilbert and Justi's (2016) modeling intervention. In all three of these modeling interventions, students start with initial ideas (or shared experiences when initial ideas are not present) and go through a process of revision and modification so that student's ideas become more scientifically sophisticated.

Second, the modeling process is student-centered and teacher-mediated. Halloun (2004) emphasized the importance of engaging students actively through activities and discussions. Teacher mediation is also a key element, as students need various levels of support (moderation, arbitration, scaffolding) to keep them on track as they go through paradigmatic evolution. Clement and Rea-Ramirez (2008) envision the student and teacher working more closely together in a process of co-construction. Both parties contribute to the generation, evaluation, and modification of models in a course. Gilbert and Justi (2016), like Halloun, encourage student-centered activities in the classroom and assistance from teachers, although the contributions from teachers is not stated as explicitly. For the purposes of this study, *student-centered activities* will be identified as those which allow students to work collaboratively in small groups, allowing students to share ideas with one another, build on each other's ideas, and receive feedback from peers, and *teacher mediation* will refer to any significant effort by the teacher to guide students through the modeling process (moderation, arbitration, scaffolding).

Third, modeling is an iterative process where students both construct and revise models. Halloun's (2004) MLC explicitly lays out how models are transformed throughout the learning process, as well as how MLCs can build on one another in a course such as physics. Clement and Rea-Ramirez's (2008) learning pathways have many more iterations, as the changes to student models are usually addressed in smaller chunks while students and the teacher discuss the shortcomings of the models. Gilbert and Justi's (2016) Model of Modeling Diagram may have less iterations compared to Clement and Rea-Ramirez (2008), depending on the limitations and scope of the model, but may also produce models that can be built on (like Halloun, 2004).

Fourth, modeling advances scientific understandings for all students engaged in the program. Halloun (2004) argues that modeling is equitable in that all students who make the effort can reach the paradigmatic thresholds of a given science course. Halloun (2004) does acknowledge that affective factors play a part, but states that a modeling program would help students reach the thresholds because student populations are mostly homogeneous at the beginning (most students start as naive realists). Clement and Rea-Ramirez (2008) view modeling as equitable because the modeling process is scaffolded (e.g., teacher contributions), is broken into smaller parts, and helps students track their thinking. Gilbert and Justi (2016) argue that modeling is important for promoting scientific literacy for all students. Through modeling, all students might be able to learn science that is applicable to everyday life, as well as learn content and skills that can be used if they choose to pursue a career in the field of science.

The modeling approach used in this study most closely resembles the one used by Clement and Rea-Ramirez (2008), but has elements of all three approaches. Since the participants in this study are middle school students, the author felt that Clement and Rea-Ramirez's (2008) approach was the most appropriate because it provides the students more support from the teacher than the other two approaches. In the approach used in this study, the students and teacher (the author) will co-construct a model of the phases of matter along a learning pathway, but the process will not be as chunked as Clement and Rea-Ramirez's (2008) approach. For example, the teacher will ask probing questions as students discuss their model of solids, liquids, and gases, but the students will not make as many modifications to their models as in Clement and Rea-Ramirez's (2008) examples. Rather than making *piecemeal* changes throughout the discussion, the teacher will record the changes on a class chart in front of the room so that students can make *wholesale* changes to their models once the discussion is concluded (Windschitl & Thompson, 2013). The modeling process will focus on helping students reach the paradigmatic threshold (Halloun, 2004) as they engage in learning cycles (Halloun, 2004; Gilbert & Justi, 2016; Clement & Rea-Ramirez, 2008).

Literature Review

The literature reviewed for this study is divided into the four themes (key elements) that were previously identified in modeling theory. The first section highlights how modeling instruction advances the scientific understandings of learners of all ages and in a variety of science contexts. The second section illuminates how modeling instruction is student-centered and teacher mediated throughout the literature. The third section gives examples of how modeling is an iterative process where students both construct and revise models. Finally, the fourth section examines how equitable modeling instruction is amongst diverse learners.

Three sets of words, “model science education,” “modeling science education,” and “modeling school science” were used in Google Scholar and a search of seven scientific journals: Journal of Research in Science Teaching, Science Education, International Journal of Science Education, Journal of Science Teacher Education, Research in Science Education, Journal of Science Education and Technology, and Science & Education. This set of searches yielded 129 articles that met the criteria of being (a) peer-reviewed, (b) empirical-based, and (c) related to the topic models and modeling in science education. Articles for this review were chosen from this group because they are foundational and/or current in science education and related to some of the identified themes in modeling theory (advance scientific understandings, student-centered and teacher mediated, iterative, equitable).

1. Advance Scientific Understandings. Modeling instruction has been studied in a variety of content areas and at many different grade levels. The following section of the review is divided into sections: elementary school, middle school, high school, college, multiple levels, and teacher education.

***Elementary School*.** Models can be used to assess changes in conceptual knowledge, such as the shape of the earth, in elementary students (Vosniadou & Brewer, 1992). The authors interviewed 60 students from first, third, and fifth grade using 15 factual and generative questions to gather a wide range of ideas that students have about the shape of the earth. After the responses were scored, six mental models of earth were identified: sphere (most sophisticated), flattened sphere, hollow sphere (like a fish bowl), dual earth (humans are on flat ground, looking up at earth), disc earth (Frisbee), and rectangular earth (piece of paper; least sophisticated). The data showed that most first graders had either a dual earth or mixed model (characteristics of more than one model), most third graders had some form of a sphere model (e.g. hollow, flattened, regular), and most fifth graders had a sphere model of earth. This pattern of data implies that, as students gain more experience, they revise their models from synthetic ones (e.g., dual earth model) to more sophisticated ones (e.g., sphere model), gaining deeper conceptual understandings.

Students in the primary grades can benefit from modeling to change their conceptions of matter. In a study of twenty-four students, researchers discovered that third grade students were able to improve their understandings of the abstract concepts of properties of matter and changes in matter by working with models (Acher, Arcà, & Sanmartí, 2007). Students worked in groups with different materials: clay, sponge, water, stones, wood, and metal. Students created objects using their materials, drew what they imagined the inside looked like, and revised the drawings by sketching what the *parts* inside the object might look like. After being instructed to break their objects, the students had to draw a model of the broken object and discuss how tightly the parts were held together (bonding). Evidence of change in conceptions through modeling was illustrated in the transcribed interviews. An example of this was a boy building on explanations of an earlier model when he described what steam is. The sequence of drawings at the end of the process was effective in showing the growth in understandings of matter throughout the unit.

Modeling can also help students improve their understanding of natural variation (Lehrer & Schauble, 2004). In this study, 23 fifth graders learned about variation as they generated, evaluated, and revised models of plant growth. On Day 19 of the activity, students were asked to create a model that could show (a) the typical height of the plants and (b) the spread of the plant heights. From the seven groups, there were five different types of models created, and ultimately, the class settled on a modified stem-and-leaf plot as a consensus model because the intervals were maintained, giving a good representation of both typicality *and* spread. These graphical models were then used to help students make various predictions of what the plant heights might be at different stages of the growth cycle. By Day 30, most students were using the same representations and were conscious of making changes of their models, like the size of the intervals. New comments from students, such as expressions of worry about losing the spread of data when changing intervals, were evidence that the student's understandings were improving.

Modeling might help very young students experience change in their understandings of a variety of concepts. One such concept, the decomposition of matter, was investigated by Ero-Tolliver, Lucas, and Schauble (2013) in an urban first-grade classroom. The authors explored whether modeling activities could help students gain an understanding of the abstract concept of decomposition and understand the use of models in science. Twenty-two students participated in the investigation. During the fall semester, the students participated in a pre-instruction activity, collecting leaves. In the spring, the instructional sequence was introduced, consisting of six phases. For example, models of decay were created and observed in Phase 5. The authors concluded that the use of models enabled these first graders to gain the understanding of decay as a process rather than just as an end result. None of the students mentioned leaves "disappearing" in the post-assessment, and students had more sophisticated understandings of the composition of soil and organisms that live inside.

Science can be viewed as a series of models, so models and modeling play a central role. Louca, Zacharia, and Constantinou (2011) explored how discourse might affect the modeling processes in science education. This investigation involved 38 elementary students, ages 11-12, in Cyprus. The participants used a computer modeling tool, Stagecast Creator, to complete the physics activities in the study. The authors used a case study approach, where each case involved one class and one topic. A total of six cases (2 classes, 3 topics each) were used in this study. Three modeling (discourse) frames were identified in the data, and the authors noted that students were able to develop causal models as they progressed through the modeling frames. In a related study, Louca and Zacharia (2015) found that the students (from grades K to 6) created more advanced models throughout the intervention, however, the steps that they followed were somewhat different that the steps than older students go through.

Finally, Manz (2012) explored the impact of modeling instruction on third grade student's understandings of plant reproduction. Nineteen students participated in the study which focused on two driving questions: "How did plants get here?" and "Why are there different plants in different places?" (Manz, 2012, p. 1078) The author found that the modeling activities made the content visible to students, helping them understand the relationships between seed dispersal, seed structure, and the environment. Students began with a few viable ideas and were able to gain a deeper understanding of seeds and reproductive success as a result of the modeling intervention. The author argued that the use of multiple representations in the intervention (not just a single representation, such as a simulation) was important in promoting this conceptual development.

Middle School. Genetics is a key concept in biology, yet many high school students may lack fundamental understandings of this concept. Duncan, Freidenreich, Chinn, and Bausch (2011) studied whether introducing key genetics concepts in earlier grades (seventh grade) could develop conceptual understandings of students and lay the groundwork for further learning. The unit was taught by two different teachers; one teacher (A) completed the unit with their classes and then authors make revisions to the unit, and finally the second teacher (B) used the revised unit with their classes. Analysis of the data revealed that the second group of classes (B) clearly outperformed the first group (A), causing the authors to conclude that the revisions made an impact on student learning by affording the students more time to discuss the phenomena and develop a generalized model of genetics that aided them in their ability to transfer their knowledge to the new phenomena (sickle cell anemia). The researchers also inferred that the evidence of students' increased level of specificity in protein function at the tissue and cellular level suggested a more sophisticated understanding of the role of proteins in the body.

The transfer of learning is important in order for students to apply learning to new situations. Bamberger and Davis (2013) examined to what extent modeling performance and knowledge can be transferred through modeling experiences. The participants were 65 sixth-grade students in three classes, taught by the same science teacher. The teacher used a modeling-based curriculum to teach the students a unit on smell. The students were then assessed on their modeling abilities and content knowledge of smell (taught), evaporation (related to the smell unit), and friction (not taught). The authors found that the conceptual understandings of the students improved significantly for the smell and evaporation topics, but not friction. The authors inferred that the improved understandings of evaporation was evidence of a transfer of learning as a result of similarities between smell and evaporation concepts (particulate nature of matter), and the lack of improvements in understandings of friction was the result of differences in smell and friction concepts (little/no transfer).

The effectiveness of working with animations and simulations, as well as drawings, was studied in the context of smell diffusion with sixth grade students (Wilkerson-Jerde, Gravel, & Macrander, 2014). The study was conducted in an extended workshop with five sixth-grade student volunteers and used SAM Animation and StageCast Creator as technology supports. As students created models through drawings and animations, a modeling cycle they referred to as "messing around" emerged, followed by a second cycle, "digging in." The authors concluded that the use of multiple technologies in the cyclical process of drawing-animating-simulating during the modeling process engaged the learners in the modeling process and deepened their conceptual understandings of diffusion.

Students from the east and west coast of the United States participated in a study to investigate whether technologies could help them understand the nature of models, and if there was a relationship between students' epistemologies of models and the content they learned (Gobert & Pallant, 2004). Middle school students were paired up in actual (physical) classes, and then each dyad was paired with another dyad from the opposite coast. The students built and explained their models, evaluated and critiqued partner models (from the opposite coast), revised and justified models, visited several geology websites, used runnable models, and took reflection notes during the unit. Significant change from pre- to post-tests suggested that conceptual and epistemological change was promoted in the context of the geology unit.

In order to address global climate change (GCC), students need an understanding of the underlying mechanisms. Visintainer and Linn (2015) explored the impact of a unit on climate change using technology to improve student's understandings of climate change, the mechanisms involved, and their relationships to everyday use of energy. The GCC unit was completed by 186 sixth-grade students from three racially and socioeconomically diverse schools. From this group of participants, five students from three different classes (from two of the schools) participated in pre- and post-interviews. Case studies of two students with differing understandings of the content were developed using the data collected. The findings show that the students were able to develop four new ideas about mechanisms (3 natural, 1 anthropogenic) as a result of the intervention. Differences in student engagement with models led to differences in student success in connecting the core ideas with prior knowledge. Despite the improvements in student's ideas, misconceptions about ozone persisted throughout the unit.

Models, like the water cycle, may benefit from a multimodal approach according to Márquez, Izquierdo, and Espinet (2006). The authors videotaped 30 seventh grade students as they were taught five 55-minute lessons, of which two were later transcribed. The researchers focused on four distinct modes of communication the teacher used to help students make sense of the water cycle model: speech, gesture, visual language, and written text. The authors concluded that the use of multimodal communication by both students and teachers could help students develop models of the water cycle.

Lee and Kim (2014) sought to understand the ways students evaluated models in the context of blood circulation. A total of 34 eighth grade students worked in groups of three to four during the intervention. The participants completed a series of modeling activities, which concluded with the development of a diagram or table. Episodes of cognitive conflict and interactive scaffolding were observed in certain places throughout the intervention, leading to improved scientific understandings of concepts such as the direction of blood flow.

The effects of a combination of two strategies, conceptual change texts and animations, were investigated with sixth grade students in the context of the particulate nature of matter (Ozmen, 2011). Students in the experimental group read conceptual change texts and worked with computer animations (CCT-CA), while a control group received traditional instruction. The author found that the CCT-CA method of instruction helped students gain a better understanding of the particulate nature of matter and phase changes than the traditional instruction. Ozmen (2011) argued that the animations may have helped students better understand the concept of matter by enabling them to observe matter at the particle level.

High School. Harrison and Treagust (2000) investigated the use of models in Chemistry to help students improve their conceptual understandings of atoms, molecules, and chemical bonds. The goal of the study was to describe the process of model evolution, from naive models of particles to scientifically sophisticated models. The case study tracked the conceptual status of 10 high school chemistry students by looking at changes in dissatisfaction, intelligibility, plausibility, and fruitfulness as they experienced models throughout the year. Models of atoms from a previous study (Harrison & Treagust, 1996) were used to pre-assess students in this case study. One student, Alex, was selected as the focus of this study. Alex's conceptions of atoms changed throughout the year, as evidenced by his writings about atoms that showed a more sophisticated view (e.g. electron cloud model, use of Legos as a metaphor). However, his drawings of atoms showed little change (e.g. distance of electrons to the nucleus). Alex was able to use a variety of models to explain different aspects of atoms and his mental models were assessed as approaching fruitfulness because he could solve problems and make predictions.

Students often have naïve conceptions about science topics, including the topic of study in this paper: light. Light is a difficult topic for students to understand because of its dual nature. Light acts like particles and waves, so in order for students to understand light they must be able to understand and negotiate between two models. This study investigated the use of modeling to promote conceptual change in students learning about light (Hubber, 2006). The author found that, at the beginning of the study, many students incorrectly thought that rays were a part of light. During the year, the author discovered that three of the six students developed more sophisticated understandings of light (rays as representations, not reality). At the conclusion of the study, it was found that five of the six students developed models of light as having both wave and particle characteristics. The author also found that the students developed hybrid models of light (waves and particles), and cautioned that these models should be considered separately. Finally, the author noted that ontological issues (ray as a physical entity versus ray as a geometric construction) and prior experience might present challenges to conceptual understandings in the topic of light.

Ionic bonding was identified as a difficult topic to teach by Mendonça and Justi (2011) because of its abstract nature and the many alternative conceptions that students hold related to the topic. If alternative conceptions are not addressed, then students cannot develop more sophisticated understandings of ionic bonding. The authors examined how the use of modeling activities based on the Model of Modeling diagram might contribute to high school student's learning about the main characteristics of ionic bonds. The authors found that there were a few factors that influenced student learning of ionic bonds in this study, including the use of empirical evidence, connections to prior knowledge, opportunities for model revision, and the development of consensus models. The use of the Model of Modeling diagram was found to advance conceptual understandings in this context. For example, students began to favor an electrostatic model over an electron-sharing model when explaining sodium chloride. Mendonça & Justi (2013) later found that there were several argumentative situations throughout the modeling process which promoted learning, including: (a) producing and justifying initial models, (b) justifications for how mental models were expressed, (c) justifying how well models "fit" the data, (d) analysis of the consistency of models, and (e) examining the usefulness and limitations of models. Inter-argumentation (within oneself) and intrapersonal argumentations (amongst others) were also noted throughout the modeling processes, similar to the findings of Berland & Hammer (2012).

"Physics First" is an initiative which seeks to teach physics prior to chemistry and biology in high school. The belief is that a physics-first (PF) approach would provide a foundation for the latter two subjects. Liang, Fulmer, Majerich, Clevenstine, and Howanski (2012) examined the effects of a models-based physics course on conceptual understandings of high school students in a physics-first context and sought to identify specific teaching practices associated with the model-based approach that might improve students' conceptual learning. The authors found that there were significant differences between the modeling, PF and non-modeling, non-PF students as well as between the modeling, non-PF and non-modeling, non-PF students, with modeling students performing better on the physics assessment.

Students' alternative conceptions are often difficult to change, but must be changed in order for students to reach sophisticated understandings of science content. Seasonal change is one topic in science that has many misconceptions because students draw on their own experiences to make sense of the seasons when they are young. This study investigated a computer model-based approach to promoting conceptual change in their understandings of seasonal change (Hsu, 2008). The participants for this study were two classes of sophomore students in a public school in Taiwan. The two classes were taught using different instructional approaches, both in a technology-enhanced environment. One class developed their understandings about the seasons with a teacher-guided (TG) approach and the other with a student-centered (SC) approach. Concept maps were completed by the students at the beginning, middle, and end of the instructional sequence on seasons. A majority of the students held level 1 or 2 models of the reasons for the seasons in the first concept map. The post-instruction concept map scores were significantly higher for both groups (SC and TG), but the SC group performed significantly better than the TG group overall. The authors concluded that the computer simulations and animations helped students change their naive conceptions of the seasons.

Barak and Hussein-Farraj (2013) sought to understand the impact of MBLT (model-based teaching and learning) on (a) student's ability to transfer across different modes of molecular representations and levels of chemical understanding, (b) students' knowledge, understanding, and implementation of proteins' structure and function, and (c) the characteristics of web-based molecular model exploration. A representative sample of 175 high school seniors from twelve different schools participated in the study. The students were divided into three groups: Group A (student exploration of the new 3D model), Group B (teacher demonstrations of the new 3D model), and Group C (traditional textbook instruction – the control). The authors found that the student exploration group (Group A) performed significantly better than the other two groups (Groups B and C) on the questionnaire. The teacher demonstration group (Group B) performed significantly better than the traditional group (Group C), but not as well as Group A.

The authors also found that using the textbook (Group A) to learn about protein structure and function did not advance conceptual understandings like in the other two groups (Groups A and B). Group A was the only group to show significant improvements in their ability to transfer across the macroscopic, microscopic, symbolic, and process levels of chemical understanding. Group A also had significantly higher scores in relation to two of the three content-level assessments (they were the same as Group B in the other one). The authors concluded that the web-based models and animations improved students' ability to transfer across levels of chemical understandings and their conceptual understandings of protein structure and function.

Simulations have been studied in various contexts, but few have focused on how students' inquiry skills may be impacted by simulations in an authentic context. Lin, Hsu, and Yeh (2012) explored how students build the concept of geologic time while developing inquiry skills by using a simulation (FossilSim) in a lesson. The participants for this study were 58 ninth-grade students from a suburban area in Taiwan. Overall, the authors found that student's knowledge of geologic time and inquiry skills improved as a result of the FossilSim intervention. There was evidence that students were building on prior knowledge throughout the lesson by making multi-scale observations, using reasoning in their sequencing of geologic events, and applying appropriate geologic laws.

Discourse is another factor which may enhance student learning during modeling instruction. Identifying sequences of discursive modes during a Models-Based Inquiry (MBI) module was the subject of the study by Campbell, Oh, and Neilson (2012). The MBI module, electrostatic energy, was investigated in two high school physics classes taught by the same teacher. Although the first two sequences (exploring scientific phenomena/student ideas and retrieving) were mostly discourse, the next sequence (negotiating) provided many opportunities for argumentation. During this sequence, students challenged each other's models and sought to reach consensus on an improved model. Previously, Campbell, Zhang, Neilson (2011) investigated whether there was a difference in student learning in modeling-based instruction (MBI) and traditional demonstration and lecture (TDL) in the context of a high school physics course. While the TDL group learned the content through traditional methods, the MBI group worked in groups to develop a model of buoyancy. The authors found that both groups, MBI and TLD, showed improved scientific understandings based on the pre-, post, and delayed tests, although there was no significant difference between the two groups.

A final high school study examined the role of student discourse as they developed models of water molecules and forces (Ryu, Han, & Paik, 2015). Sixteen-tenth grade students completed three modeling activities related to intermolecular interactions, surface tension, and capillary action. The authors found that the student's discussions that took place during the modeling activities promoted epistemic and scientific understandings. Students also started thinking of models as having explanatory power rather than just descriptive power.

College. Technology can prove to be a useful assessment tool in the context of modeling practices. The following study investigated the question: what are the modeling practices of experts (Zhang, Liu, & Krajcik, 2006)? The idea behind this study was that expertise is *developed*, so if expert practices could be identified then researchers and educators could use the information to guide their practices (e.g. further research, scaffolds to assist learners) and develop learning progressions. The authors used five Ph.D. students as their "experts." Model-It, a computer-based modeling program, was explained and used by the subjects to build their models of water quality. The authors found that: (a) experts started modeling with a clear focus and went through the plan-build-test process in a linear fashion (little revision was done); (b) experts may use evidence-based reasoning, reducing time needed to revise and test; (c) experts cluster their factors, making their models highly specialized; (d) experts had difficulty with differentiating objects and factors; and (e) experts varied their processes and final products, suggesting that modeling be properly scaffolded. Implications for middle school teachers and students included: (a) Model-It might help middle school students learn water quality, even though it is an ill structured problem as a result of a lack of domain knowledge, because the program is designed to assist the user in switching between the phases of modeling easily, and (b) Model-It might improve students' modeling practices through evidence-based reasoning, metacognitive strategies, and scaffolding embedded in the program.

CosmosWorlds is a computer program which was used in an undergraduate astronomy course, the Virtual Solar System (VSS), to see whether building 3D models could help students understand concepts in astronomy (Keating, Barnett, Barab, & Hay, 2002). Eight students in the class formed three groups and completed three projects in relation to this study: construction a 3D model of (a) the Celestial Shpere, (b) the Earth-Moon-Sun system, and (c) the entire Solar System. From these models, the authors sought to understand if the students could gain a scientific understanding of eclipses, phases of the moon, and the reasons for the seasons. The data, from interviews, student work, and reflections, showed that students showed significant improvement in their understandings of eclipses and moon phases. Reasons for this improvement included the ability of the modeling program to make abstract concepts into concrete ones and the ability to change students' frame of reference in the model (e.g. moving from Earth to Sun to Moon) so that they could test and revise their models. There were also improvements in the students' understandings of the seasons, but not as dramatic as with the eclipses and moon phases. The authors argued that the 3D modeling technology advanced scientific understandings by giving students direct experiences, the ability to compare prior conceptions with those direct experiences, and the ability to test and revise their models. In a similar study, Barab, Hay, Squire, Barnett, Schmidt, Karrigan, Yamagata-Lynch, and Johnson (2000) found that the same technology (CosmosWorlds) helped students engage with their peers in the modeling process, but cautioned that using technology might negatively impact student learning because the students might spend more time learning the technology and less time learning the content.

Individual-based models (IBMs) are used in areas of science, such as biology, and mathematics to assign individuals their own characteristics so one can study the interactions amongst the individuals and their environment. Ginovart (2012) used the modeling environment, NetLogo, as the platform to study if IBMs could help first year undergraduate mathematics students gain an understanding of a predator-prey system. The author also wanted to compare the advantages and disadvantages of IBMs to a more traditional model, ordinary differential equations (ODEs), in a NetLogo environment. As a result of this learning sequence involving both modeling methods, students obtained more sophisticated understandings of models and population dynamics concepts (e.g. growth, stability, interaction).

Multiple Levels. Modeling and argumentation are two scientific processes that students frequently use in science. Pallant and Lee (2014) identified the topic of climate change as a timely and relevant one, so they conducted the current study in order to investigate how modeling practice and argumentation skills might be promoted in the context of this “hot topic.” Nine total teachers from two middle schools and six high schools (from six different states) taught the climate module in their classrooms. The authors found that 72% of students made correct claims in relation to the CO2 argument task, 83% of students made correct claims for the positive feedback task, and 70% of students made correct claims for the water vapor task. The use of evidence strengthened the students' arguments, however, the students gradually started to use evidence that showed simple causality. The authors also found that the students had improved their understandings of the factors which affect climate change.

Modeling is used in middle and high schools, but might not be as accessible to some elementary school students. Technology might be an appropriate scaffold to help these younger students use modeling, so van Joolingen, Aukes, Gijlers, Bollen (2015) developed a modeling system (SimSketch) to explore how effective such a system might be at helping elementary students create drawing-based models of the solar system. A total of 247 children, ages 7-15, participated in this study. All participants were visitors to a science center. The participants (eight at a time) received brief instructions, completed a pretest and SimSketch tutorial, worked on their computer model, and completed a post-test and questionnaires. The authors found that the scores for the subjects improved, though not significantly. It was noted, however, that the pre-tests scores were relatively high (roughly 75%), the intervention was short in duration (approximately 45 minutes), and there was no explicit instruction. Students of all ages were able to create adequate solar system models using SimSketch, although prior knowledge (in relation to age) was an indirect factor in the models.

Models can also be used to assess changes in conceptual knowledge, such the concept of phase transitions, in elementary, middle, and high school students (Chiu & Wu, 2013). The authors analyzed mental models from students in fourth through twelfth grade to determine if there was a development of mental models in the context of phase transitions. The authors found that the student's views of nature gradually shifted from a continuous view to a mixed view to a particulate view as they got older. These findings are similar to the study of Earth's shape by Vosniadou and Brewer (1992).

Teacher Education. Changing teachers' scientific understandings can benefit students, but only if those changes remain over extended periods of time. This is especially true for preservice teachers who may not teach students for several years. There is some evidence that preservice teachers' conceptual knowledge of moon phases was sustainable for long periods of time after instruction using psychomotor modeling (Trundle, Atwood, & Christopher, 2007). Twelve preservice teachers participated in this study, which was in the context of a physics course. The authors assessed the preservice teachers' understandings of moon phases before instruction, three weeks after instruction, and 6 or 13 months after instruction. Four patterns became apparent when analyzing the data. *Growth and stability* was evidenced in six students moving from alternative to scientific understandings (pre- to post-test) and maintaining their scientific understandings up to the 6/13 month final interview. *Continuous growth* was evidenced in two participants steadily increasing in moon phase understandings throughout the three interviews (alternative to scientific fragments to scientific understandings). There was one student who showed the pattern of *partial decay* because they increased from alternative explanations to scientific understandings, but then regressed to scientific fragments by the final interview. Finally, the remaining three students were classified as *full decay* because they went from alternative to scientific to alternative fragments on the three interviews. The authors were encouraged that all students increased from pre- to post-interview and that two-thirds still had scientific understandings one-half to one year after instruction. This evidence of advances in scientific understandings might be important for students who could go up to three months without any schooling (e.g. summer break). The study also showed evidence of the power of preconceptions and how some learners can revert to them after extended periods of time.

A case study of an in-service teacher (Emily) showed that conceptual change can occur when one creates and revises ("transforms") their model (Shen & Confrey, 2007). The teacher was one of fourteen who took part in a 15-week professional development astronomy course, Earth and Planetary Systems, for K-8 science teachers in the spring of 2005. Throughout the two selected lessons, the authors noted the change in Emily's conceptions of astronomy as she transformed her models. Emily made changes to her two-dimensional model of moon phases when errors were discovered, and when the teachers had to incorporate sun and moon rise into their model she created a three-dimensional model to share her thinking. The authors argued that the case of Emily shows the use of multiple models can increase active participation and drive "dissatisfied" learners to make transformations in their models. The transformation of Emily's models shows how her thinking changed over time and how new ideas built on top of older ones. While this is just one example of a teacher experiencing conceptual change, it illustrates the changes that might take place as learners actively manipulate their models.

Summary. As evidenced by the reviewed literature, modeling instruction is effective in advancing scientific understandings of learners of all ages. Students as early as the elementary and middle grades were able to learn about complex concepts such as decomposition of matter and genetics, to use a variety of technologies throughout the modeling process, and even transfer their learning to new situations (e.g., smell to evaporation). Modeling instruction was also effective in advancing understandings in a variety of scientific contexts such as matter, the water cycle, seasons, plant reproduction, geology, ionic bonding, and light.

2. Student-Centered (SC), Teacher Mediated (TM). Modeling instruction is student-centered (e.g., students working in groups) and teacher mediated. The following section of the review illustrates how different studies have implemented modeling instruction with differing levels of student-centeredness and teacher mediation.

Complete SC and TM. Many of the studies in this review provided instances of “complete” student-centered, teacher mediated environments, where students worked collaboratively on tasks in groups, talked with one another to build ideas, gave each other feedback, and whose activities were guided by the teacher. In Lehrer and Schauble’s (2004) study, the teacher asked the students questions, suggested next steps, and prompted students to make explanations. The students participated in small group and whole class activities throughout the unit. In the small groups, students usually discussed ideas with each other rather than with the teacher. Students groups generated graphs and shared them with another group for feedback. As students discussed each other’s representations, they started valuing the primary details and ignoring the parts that seemed “cool.” Students worked in groups to develop and critique models as the teacher guided the whole class model discussion in the Duncan, Freidenreich, Chinn, and Bausch (2011) study. The teacher focused the student discussions on the clarity of the models, how well the models represented the data, and other aspects. Shen and Confrey (2007) had participants work in groups of four to transform their models. The participants shared their models with each other and discussed some of the problems each model had (in representing the system). Active learning took place throughout the activities as participants discussed, transformed, and critiqued their models. The teachers of the course chose the models to be used in the course, although the students had freedom to explore the models in a variety of ways. The authors encouraged future teachers to have students make small revisions throughout the modeling process, use real-life situations to provide context for the models, and to have students share their models with each other.

Throughout the first Mendonca and Justi (2011) study, students interacted in a variety of ways during the modeling intervention, such as interpreting evidence, negotiating ideas, and using prior knowledge. Students were eventually able to develop a consensus model through their interactions with each other and the teacher. The teacher did not force a target model on students, but used the target to help students see the limitations of their models. The teacher's role in moderating student discussion was identified as a key feature of this modeling intervention. For example, the teacher in the study answered a student question about stability by explaining how bonds are broken and formed. During the second Mendonca and Justi (2013) study, students worked in groups to complete modeling activities and engaged in argumentation throughout the four phases of the modeling process. The authors identified several key roles that teachers play in the intervention, including: (a) proposing questions about student models, (b) providing information to be used in modeling discussions, (c) drawing out student preconceptions, (d) proposing additional explanations., and (e) promoting multiple modes of representation.

Liang, Fulmer, Majerich, Clevenstine, and Howanski (2012) placed students in small groups to plan and run investigations. Students also made class presentations and critiqued the work of their peers. A key role for teachers that was identified by the authors was scaffolding discourse. The authors recognized that training teachers to scaffold might need to be an ongoing process because of the difficulties in achieving teaching expertise in this area. In the Wilkerson-Jerde, Gravel, and Macrander (2014) study, the researchers took on the role of facilitator, asking the participants questions to elaborate on their thinking. The students engaged with the researchers and each other in group discussions, leading to consensus building and the co-

construction of a model. The students worked independently at times, such as drawing their initial models, and in groups, such as working with the animations.

Gobert and Pallant (2004) paired students up in physical classrooms and had each group create a model of plate tectonics, then had the pairs share their model with another pair from the opposite coast (electronically). The receiving pair then critiqued the model and sent feedback to the creators of the model. Using the feedback, the models were revised. The teacher/researcher role was to provide the prompting (e.g., reflection) and scaffolding online. These supports were meant to help students create and revise their models, evaluate the models of other students, reflect on their understandings, and apply their knowledge to new situations. For the Campbell, Oh, and Neilson (2012) intervention, students were also paired up to develop, test, and revise models of electrostatic energy. The student groups actively discussed scientific phenomena and ideas, prior knowledge, and then came to a consensus on the topic of discussion. The teacher introduced the purpose of models with the classes, then conducted demonstrations to introduce the topic of electrostatic electricity. Later, the teacher helped students gain a deeper understanding about the nature of models (their predictive nature), shared discrepant events, and guided their model revisions. The authors emphasized the importance of the teacher's role in classroom discourse during modeling, adding that it was important for teachers to shift to elaboration and reformulation when necessary.

During the Louca, Zacharia, and Constaninou (2011) study, the teacher provided guidance to the students, provided scaffolds when they got stuck, and facilitated the model evaluation discussions, but did not give the students a specific set of steps to follow when building their models. Students were allowed to change groups throughout the first part of the modeling activity until all the groups were able to work together effectively. The authors found that students discussed model elements and the processes involved in the models, shared prior knowledge, and critiqued each other's models. Lee and Kim (2014) had students working in groups of 3-4 to complete three activities during the intervention: a pump analogy activity, a pig heart dissection, and the creation of a circulatory system diagram. Student autonomy was developed through a student-centered format, model evaluation training, teacher scaffolding, and peer evaluation of models. The teacher helped students throughout the intervention, but guided the modeling activities directly in the third part. The authors suggested that teachers should take a greater role in the modeling process to help students reach Level 4 (the highest level of model evaluation).

In Ryu, Han, and Paik's (2015) investigation, students worked in groups throughout most of the intervention. The groups had several opportunities to share their ideas and models with the class, as well as visit other groups to get or give feedback. Technology was also available (e.g., discussion boards) to help students share their ideas with each other. All of the activities promoted argumentation, as the students discussed their observations, data, and models and attempted to make explanations. The role of the teacher (e.g., scaffolding) decreased and student-centered activities also increased throughout the intervention. Louca and Zacharia (2015) had the participants engage in student-centered discourse and observed active interactions between the students and the teacher. Students had access to a variety of modeling tools as they explored accelerated motion and plant parts. The teacher did not determine the direction of discourse, but provided time for students to share and debate their ideas. Since the participants were younger students, the teacher had to lead students to evaluate their models and guide their thinking. In Bamberger and Davis (2013), the teacher helped students reflect on the nature of models during class discussions as the students generated several models in a project-based science curriculum.

Finally, Barab, Hay, Squire, Barnett, Schmidt, Karrigan, Yamagata-Lynch, and Johnson (2000) had students working in groups, posing their own questions, asking other students questions about their models (e.g., to identify possible limitations), and periodically sharing ideas and with each other. For example, students would often gather at another group's computer to learn how that group solved a problem. The teacher facilitated activities in the class, gave impromptu mini-lessons to address student questions, and asked questions which made students think about the effectiveness of their models. The teacher also guided students in the modeling pathway and the whole-class discussions of models (usually Socratic in nature) to promote model modification.

Partial SC and TM. Several of the studies had evidence of students working in groups, students talking with each other about their ideas, and teacher participation, but a lack of feedback. In Acher, Arca, and Sanmarti (2007), a combination of small group and whole class talk was used with students as they shared their ideas. Students used drawings, body expressions, and their models to share with their peers. The teacher guided students as they developed their models (through activities, discussions, etc.). Mediation activities identified by the authors included: (a) helping students compare their ideas and (b) focusing students' attention on the main concepts being studied. In Trundle, Atwood, and Christopher (2007), students worked with the teacher to develop an explanation for the moon phases. Students worked in groups of 3-4 to discuss the activities. Once a week, the students engaged in a whole class discussion of the activities. During the Ero-Tolliver, Lucas, and Schauble (2013) intervention, students discussed ideas in groups of four and conducted several investigations related to decomposition, including an examination of soil and observations of decaying foods and a compost bin. The teacher led discussions, proposed questions, and guided students through the activities and model revisions.

Visintainer and Linn (2015) had students working in pairs to complete the unit, including the models. The authors suggested that students should receive guidance from the teacher to help them better understand the mechanisms in the model, such as prompting students to make predictions, having students describe the pathways of sunrays, guiding students to add details in their observations and to isolate variables, and encourage student reflection. Throughout the intervention in Campbell, Zhang, and Neilson's (2011) study, students in the modeling group worked in groups of 2-3 throughout the intervention to develop and revise a model of buoyancy, but the TLD (traditional lecture and demo) group did not work in groups throughout. The teacher had a more central role in the TLD group, but was more of a facilitator in the MBI group (e.g., guiding class discussions).

Two studies had students talking with each other and the teacher in whole class discussions, but lacked student group work and feedback. In the Ginovart (2013) study, the activities were designed for individual learners, but group discussions with the teacher were used occasionally. During the Manz (2012) intervention, the students were guided by the teacher at the beginning of the year, but soon students were sharing ideas about plants, such as how seeds are spread with the class. Through argumentation, students began to understand key aspects of seeds, such as its structure and function. The teacher had the most control of the activities at the beginning of the intervention.

SC Only (No TM). Several of the studies had evidence of a student centered environment but lacked teacher guidance throughout the modeling process. In Hubber (2006), students negotiated their models, but also created their own models based on their understandings of light. The role of the teacher was not explicitly stated. In the Harrison and Treagust (2000) study, there were student discussions throughout the year. During the Pallant and Lee (2014) intervention, students worked in small groups to complete several tasks such as exploring climate data, using a dynamic climate model, and and watching a video. The role of the teacher was also not mentioned, but the authors discussed the need for research into the teacher's role in developing a model-centered classroom. Lin, Hsu, and Yeh (2012) had students work in pairs to complete the models, but the authors mentioned that students may have struggled with the modeling because scaffolds were not in place in FossilSim. They suggested that teachers should modify the FossilSim tasks to provide the necessary scaffolding. Other than this, the teacher role in the intervention was not evident. Lastly, Keating, Barnett, Barab, and Hay (2002) had students work in groups of 2-3, but not much additional information was provided.

TM Only (No SC). One of the studies had evidence of teacher guidance, but not a student-centered environment. Teacher discourse was the focus of a study by Marquez, Izquierdo, Espinet (2006). The authors found that there were four modes of teacher communication during the intervention: speech, gestures, drawings, and written text. The purposes of speech were to pose questions, introduce new ideas, identify model elements, and answer questions. The purposes of gesture were to describe water movement, visualize interactions, and make the model dynamic. Finally the purposes of the drawing and text were to provide model elements, illustrate the cycle, visualize the cyclical process, and apply the model to real life situations. While student discourse was not the focus of this study, the authors recommended that students also should be given the opportunity to use multimodal communication as they engage in modeling.

SC vs. TM. Three of the studies compared the effects of a student centered versus a teacher centered learning environment. In Hsu (2008), students were either in a student-centered (SC) class or a teacher guided (TG) class, so none of the students benefitted from a mix of both.

During the intervention, students made connections to real life experiences, explored animations, created models (concept maps), and applied their model to a new situation. Students in both classes received the same content, assignments, and objectives. In the TG class, the teacher showed animations, performed demonstrations, and gave explanations. In the SC class, students completed the animation and simulation individually and created their own explanations. The author found that the SC approach was more effective than the TG approach in helping students develop scientifically appropriate understandings of seasonal change. In the Barak and Hussein-Farraj (2013) study, one group of students explored animations on their own, another group had the teacher demonstrating the animations, and a third group received traditional, teacher-led instruction. In certain lessons involving models and animations, students in the first group were able to work in groups of 2-3 to discuss their ideas and help each other with the technology. The authors concluded that students who were teacher-led could gain certain scientific knowledge, but to gain a deeper understanding of the concepts students should be allowed to manipulate models on their own. During the Ozmen (2011) intervention, students were passive learners in the control group (teacher-led), but took a more active role in the experimental group (texts and animations). The students did a variety of activities, such as reading and analyzing texts and exploring animations in groups of two. The teacher led most of the classroom activities (e.g., demonstrations) in the control group, whereas the teacher was more of a facilitator in the experimental group. The author found that students in the experimental group (student-centered) outperformed students in the teacher-led group on both the post and delayed tests.

None Evident. Four studies showed no evidence of either a student-centered or teacher guided approach. In Vosniadou and Brewer (1992) and Chiu and Wu (2013), model generation was done for assessment purposes. In the van Joolingen, Aukes, Gijlers, and Bollen's (2015) study, students worked individually without teachers support. Finally, while there was no evidence of either a student-centered or teacher mediated approach, Zhang, Liu, and Krajcik (2006) used the findings to make several recommendations to teachers (teacher mediation). First, teachers need to identify students' prior knowledge and then plan the modeling activities so that students can develop their understandings. Second, teachers need to provide scaffolding so that students can develop appropriate modeling skills, such as clustering concepts, and learn how to use modeling technologies effectively. Third, teachers should regularly probe students for explanations to assess their levels of understanding throughout the modeling process.

Summary. A majority of the modeling literature illustrated examples of learners working in a student-centered, teacher mediated environments. Many of the students were able to complete tasks in groups (sometimes even being given choices of tasks), talk with each other throughout the process, and give feedback to each other as well as to other groups. Most of the students also experienced modeling situations where the teacher guided them through their learning, such as teachers asking probing or clarifying questions, organizing groups and activities, and helping students develop consensus models.

3. Iterative; Construction and Revision. Modeling is an iterative process that allows students multiple opportunities to revise their models. The following section of the review illustrates the iterative process in a variety of science contexts.

Use.

Several studies illustrated the use of models to advance scientific understandings of learners. In one study, preservice teachers engaged in psychomotor modeling, where they actively manipulated models to gain a deeper understanding of moon phases (Trundle, Atwood, & Christopher, 2007). Five other studies used a variety of technologies to model the science content. In the first study, students used a climate model to investigate various factors, such as radiation, ocean surface temperature, CO_2 levels, water vapor, ice, and cloud cover (Pallant & Lee, 2014). In the next study, participants engaged in an iterative process of actively manipulating computer models of a predator-prey system by varying the initial values and conditions (Ginovart, 2013). Some students in the third study used animations to learn about protein structure and function, however, they did not have the opportunity to draw and revise their models (Barak & Hussein-Farraj, 2013). As a result, the authors observed that many students had a difficult time accurately drawing the models of molecules. The authors noted that students who could draw molecules correctly held sophisticated understandings of molecules, so it can be inferred that students should be given the opportunity to draw and revise their models as they complete the activities in class. In the fourth study, students could modify the given computer model, such as by adding/removing sunrays or greenhouse gases, but could not make their own models from scratch (Visintainer & Linn, 2015). In the final study, students in the experimental group completed an activity with conceptual change texts and worked with interactive animations to reinforce the texts, address the misconceptions, and explore particle behavior (Ozmen, 2011).

Construct.

Four instances of students constructing models (without revisions) were found in the literature. In Vosniadou and Brewer (1992), some of the models students drew were identified by the authors as initial models (drawn without the benefit of instruction). In looking at the models, from first to third to fifth grade, the authors inferred that students may have revised their models over the years, creating synthetic (intermediate) models as they gained more experience and included new knowledge into their ideas about the shape of the Earth. Similar findings were discussed by Chiu and Wu (2013) in their study of phase transitions with students in fourth to twelfth grade. In a third study by van Joolingen, Aukes, Gijlers, and Bollen (2015), students drew models of the solar system and then used SimSketch to create a digital version. Students were then able to divide their model into parts, assign behaviors to each part, run their models, and observe the interactions. An important note from this study is the authors were unclear if SimSketch had the capability of making modifications to the model, or if students were encouraged to make improvements to their model. In the final study, the modeling intervention included seven activities, and the activities varied from simple to more complex because of the age of the students (Manz, 2012). The students began by observing the schoolyard, posing questions, drawing plant parts, and reading about plants from books. The students examined each other's pictures to identify one that was most like the schoolyard. Around the same time, students grew plants, compared their growth to plants that grow outside, and built and tested models to understand seed dispersal. Later in the year, the students used ideas from the previous activities to design model systems to test growth conditions, such as trays where seeds could be spread out or crowded together. Again, students were asked to think about how their model might be similar to the schoolyard ecosystem. While this modeling intervention is not the same as the construct, deploy, and evaluate version, the author makes the case that this process has a similar effect in developing students' scientific understandings.

***Construct and Revise*.** The previous literature in this section highlighted examples of using models and constructing models. Modeling instruction, however, requires students to also construct and revise their own models. The following section illustrates how students have constructed and revised models during modeling instruction throughout the literature.

Drawings. There are many examples of students creating and revising drawings in an iterative manner in a variety of contexts throughout the literature. A model of matter was built-up through a series of activities with elementary students as they manipulated six materials during the unit: clay, sponge, water, stones, wood, and metal (Acher, Arca, & Sanmarti, 2007). Student drawings expressed what they thought their objects looked like (inside their material) throughout the unit. Several iterations occurred as students went through learning phases identified by the authors: “making discrete,” “quantity of parts,” bonds, and transformation/conversion. In another study, students performed a couple of iterations in the modeling process as student groups created a model (graph) of their plant growth data throughout the life cycles of their plants (Lehrer & Schauble, 2004). Students in a genetics study developed an initial model in small groups to explain the connection between genes and sickle cell anemia (Duncan, Freidenreich, Chinn, & Bausch, 2011). Several of the group models were critiqued in a whole class discussion, as students looked for things like correct labeling and how well the model connected with the evidence. After students received additional data, they revised their models. In a study involving high school student participants were given the chance to create and revise their drawings (or create new ones) of light (Hubber, 2006).

Middle school students created drawings of scientific concepts such as smell and evaporation (Bamberger & Davis, 2013). The students then evaluated each other’s models, made revisions to their models, and used their models to make explanations and predictions. Pairs of students in another study each created a drawing of plate tectonics, then revised the model using feedback from peers (Gobert & Pallant, 2004). These students also used runnable models (e.g., animations), but rather than revising their models the students were asked to complete a series of reflection activities. In a study by Marquez, Izquierdo, and Espinet (2006), students and the teacher co-constructed a water cycle model, so revisions were made progressively throughout the modeling activity. Finally, students in an experimental group created initial models (on paper) of buoyancy, revised their models, developed and performed investigations, and modified their models again to incorporate data from the investigations (Campbell, Zhang, & Neilson, 2011)

Technology. Several other examples of students iteratively creating and revising models using technology were also present in the literature. In a study by Zhang, Liu, and Krajcik (2006), participants generally moved from the "plan" to the "build" to the "test" stage in a linear process. There was some movement back and forth between the three stages, but the authors reasoned that this sparsity of movement was a result of the participants being "experts" and that middle and high school students would likely need to go back and forth many more times. The iterative process in Keating, Barnett, Barab, and Hay (2002) was similar to other studies that incorporated psychomotor modeling, except they developed and actively manipulated computer models rather than physical models (e.g., hula hoops). Other students engaged in an inquiry cycle throughout a geology intervention in another study (Lin, Hsu, & Yeh, 2012). Students answered questions and completed activities throughout the cycle and developed a model at the end of the cycle. The technology (FossilSim) allowed students to experience how trace fossils might form by observing crabs, photos, and a simulation. Students used FossilSim to generate a model of fossil formation (a sequence of events) and test their model. The authors pointed out that a limitation of FossilSim was that a student who wanted to modify and test again had to go through the whole process from the beginning. Several models were developed throughout a study on physical phenomena, such as accelerated motion, relative motion, and diffusion (Louca, Zacharia, & Constaninou, 2011). For each model, students typically started by discussing prior knowledge, followed by developing models in groups of 2-3 in a computer environment (StageCast Creator). The group models were then shared with the class so that they may be evaluated. Using the feedback, students went back to their computer models and made revisions. This process of evaluation and revision took place multiple times until students were satisfied with their models. Undergraduate students created models of the sun/earth-moon system and the entire solar system in a university astronomy course (Barab, Hay, Squire, Barnett, Schmidt, Karrigan, Yamagata-Lynch, & Johnson, 2000). They used technology (e.g., virtual environments) to design, build, evaluate, revise, and demonstrate their models. Two specific modeling stages were identified by the authors: enactment (planning and building models) and visualization (applying the models). At the end of each modeling project, the students compared their models with others and the actual solar system to deepen their modeling experience. The back and forth questioning between the teacher and students was a form of co-construction which strengthened the student models.

Multiple Models. Many times in the literature, students were given the opportunity to create and revise multiple models to learn the content. For example, students drew and revised diagrams of atoms, as well as manipulated an organic modeling set throughout the year in one study (Harrison & Treagust, 2000). The teacher-participant in another study created and made several revisions to models related to astronomy (Shen & Confrey, 2007). To start, the participant revised a data model (table) to better represent the moon cycle. Next, she transformed the data model to a 2-dimensional model of the sun-Earth-moon system. To clarify her model, the participant added two additional features to her model, and through a conversation with a peer, further refined the model. In order to incorporate sunrise and sunset into her model, the participant created a new model using a hula hoop. The authors argued that the transformation of the prior model led to the formation of this new model. Students in Mendonca and Justi (2011) and Mendonca and Justi (2013) used the Model of Modeling Diagram (MMD) to guide them through the modeling process. In the MMD sequence, students moved amongst the stages of model generation, model expression, model testing, and model evaluation. The MMD process allowed students to engage in modeling in a nonlinear, multidirectional process, enabling the students to go through several cycles. The students created and revised 2-dimensional models (drawings) as well as 3-dimensional models (e.g., ball and stick figures).

Some high school students participated in modeling cycles during an intervention where they developed, evaluated, and applied models related to physics (Liang, Fulmer, Majerich, Clevenstine, and Howanski, 2012). The models that the students developed included diagrams, graphs, and algebraic equations. Students were exposed to multiple representations throughout the year to aid in the modeling process. Elementary students used lettuce leaves as models for leaf decay and observed and recorded changes in the model over time (Ero-Tolliver, Lucas, & Schauble, 2013). Students considered other factors, such as soil type, amount of water, decomposers, light, and temperature, and came up with four models to develop and observe: a jar with soil and leaf, a jar with compost material and leaf, a ziplock bag with leaf, and a ziplock bag with wet paper towels and leaf. Student periodically observed their models and drew illustrations (with descriptions) of the leaves which reflected the changes that were occurring. Students compared and revised their pictures, causing an improvement in detail. Two iterative cycles were identified in the modeling process from a Wilkerson-Jerde, Gravel, and Macrander's (2014) study. First, the participants engaged in “messing about,” where they selected and represented parts of their model. Second, the participants engaged in “digging in, “ where they evaluated, revised, and used their model to make explanations and predictions. The students used a variety of methods to express their models, such as drawings, animations, simulations, and even pipe cleaners. It was inferred that having students re-represent smell diffusion in different ways may have allowed the students to gain more sophisticated understandings of diffusion.

Some students actively manipulated models (technology-based in this case) to improve their understandings of the seasons (Hsu, 2008). A model (concept map) was also created at the beginning, the middle, and the end of the intervention to track students’ conceptual understandings as they experienced their given instruction. Students in another study completed three lessons during an intervention on blood circulation (Lee & Kim, 2014). In the first activity, students worked with a siphon pump to understand how water (and blood) moves in one direction. In the second activity, students studied the anatomy of a pig’s heart to build an explanatory model. In the third lesson, students worked in groups to draw a picture of blood circulation. Each group created a model of blood circulation, then two groups shared their models with the class. After sharing, the groups were able to revise their models as well as peer models. The authors noted that the discussions led to cognitive conflict, which further elaborated the student’s models, and interactive scaffolding, where students built on one another’s ideas.

Modeling activities gradually increased in complexity throughout an intervention on water (Ryu, Han, & Paik, 2015). Students began by exploring a phenomenon (surface tension) and developing a modeling question. Students next built and explained a model (e.g., ball-and-stick, drawings) for the phenomena and tested the model in a variety of ways, such as floating a needle on soapy water and experimenting with microtubes. Evaluation and modification of the models took place throughout the intervention as a result of the discussions between the students (in groups and whole class). In a final study by Louca and Zacharia (2015), students began the modeling process by investigating a phenomenon (e.g., accelerated motion) while referring to their prior experiences. This was followed by model construction, where students planned (e.g., identifying parts) and developed (e.g., troubleshooting) the model. Students had many methods of representation available to them, such as drawings, computers, and 3-dimensional materials. The authors observed that students went back and forth between the investigation and construction phases several times and, as a result, the model became progressively advanced (more parts and processes involved). During the next phase, evaluation, the students used their models to explain the data or experiences they had. The revision phase incorporated revisions (which was not an independent phase, but took place as students returned to the construction phase) and the planning of revisions (which was an independent phase). The authors noted that students went through several iterations, but did not pass through all phases in each iteration or go in order.

Summary. According to modeling theory, students should be afforded the opportunity to create and revise their own models in an iterative process. As seen in the previously reviewed literature, some of the studies that claim to use modeling instruction do not meet this standard. This does not mean that students only *using* or *creating* models in the classroom could not be considered modeling, but for the purposes of the present study the literature would be considered incomplete if all the components were not present. While there were a few examples of only using or creating models, the majority of the literature illustrated examples of students using drawings, technology, and multiple modes to create and revise models in an iterative fashion.

4. Equitable. Modeling instruction is equitable, as it helps all students reach the level of basic model. The following section of the review illustrates how different groups of students have benefitted from modeling instruction.

Gender. Many of the studies in the literature mentioned the gender makeup of the participants. Several of the studies had an equal or nearly equal number of male and female participants (Vosniadou & Brewer, 1992; Lehrer & Schauble, 2004; Ero-Tolliver, Lucas, & Schauble, 2013; Pallant & Lee, 2014; Keating, Barnett, Barab, & Hay, 2002; Lin, Hsu, & Yeh, 2012; Visintainer & Linn, 2015; Ozmen, 2011; Ryu, Han, & Paik, 2015), while some had unequal numbers (Hsu, 2008; Campbell, Zhang, & Neilson, 2011) and others had all female (Trundle, Atwood, & Christopher, 2007; Shen & Confrey, 2007) or all male (Barab, Hay, Squire, Barnett, Schmidt, Karrigan, Yamagata-Lynch, & Johnson, 2000) participants. For the all-male and all-female participant studies, the modeling instruction was found to advance the participant's scientific understandings, so it can be inferred that modeling instruction is gender equitable. Two of the studies found no noticeable differences between male and female performance or achievement (van Joolingen, Aukes, Gijlers, & Bollen, 2015, Lehrer & Schauble, 2004).

Socioeconomic Status. As with gender, several of the reviewed studies mentioned the socioeconomic status of the participants in the study. Some studies has participants from middle class backgrounds (Vosniadou & Brewer, 1992; Liang, Fulmer, Majerich, Clevenstine, & Howanski, 2012; Lee & Kim, 2014), others had participants from economically disadvantaged backgrounds (Bamberger & Davis, 2013; Ero-Tolliver, Lucas, & Schauble, 2013; Manz, 2012), and some had participants from a range of household incomes (Lehrer & Schauble, 2004; Duncan, Freidenreich, Chinn, & Bausch, 2011; Pallant & Lee, 2015; Visintainer & Linn, 2015).

A common finding amongst the literature was that modeling instruction can help students from all socioeconomic statuses advance their scientific understandings.

Ethnicity. The reviewed literature was not as thorough in considering equity in regards to ethnicity. Three of the studies had small numbers of minority participants (Trundle, Atwood, & Christopher, 2007; Liang, Fulmer, Majerich, Clevenstine, & Howanski, 2012; Campbell, Oh, & Neilson, 2012), one had a large number of minority participants (Bamberger & Davis, 2013), and two had ethnically diverse participant populations (Shen & Confrey, 2007; Visintainer & Linn, 2015). Since the participants in all of these studies experienced improved understandings of the science content, it can be inferred that modeling instruction was effective in helping students from different ethnic backgrounds to learn science content.

Special Needs (SPED and ELL). The only study that mentioned the effects of modeling instruction on a special needs population (either special education or English language learners) was the Lehrer, Schauble (2004) study. Amongst the findings, authors noted that three of the students were identified as learning or cognitively disabled, and two of the three performed well on the tasks.

Summary. Compared with the other three themes, the literature is limited in regards to modeling instruction being equitable. There is some evidence that modeling can help students of different gender, socioeconomic backgrounds, and ethnicities learn science, but special needs populations were almost never mentioned. This gap in the literature regarding the use of modeling with special needs populations is the focus of the current study.

Research Questions

The current study was developed to address the identified gap in the literature regarding equity in science instruction. To address this gap, the following research questions have been posed:

1. Does modeling instruction help students in all three groups (accelerated, regular, co-taught) improve their understandings of the phases of matter?
2. Does modeling instruction help students improve their understandings of the phases of matter more than regular instruction?

Hypotheses

For the first research question, it is expected that all three groups of students will improve their understandings of the phases of matter because other modeling interventions from the literature have had similar findings (Hsu, 2008; Shen & Confrey, 2007; Gobert & Pallant, 2004; Duncan, Freidenreich, Chinn, & Bausch, 2011; Ero-Tolliver, Lucas, & Schauble, 2013). It is also expected that students in all three groups will make similar gains in their understandings of the phases of matter because, according to modeling theory, modeling instruction is equitable (Halloun, 2004). For the second research question, it is expected that the modeling instruction groups (treatment) will perform better than the regular instruction group (comparison) because the cognitive engagement will be *interactive* (e.g., creating models, building on each other's ideas) for students in the modeling instruction group and *active* (e.g., using existing models) for students in the regular instruction group (Chi & Wylie, 2014). For example, Förtsch, Werner, Dorfner, von Kotzebue, and Neuhaus (2017) found that students who were cognitively engaged (interactive) in biology increased their levels of achievement.

Chapter 3: Methods

Participants and Setting

Participants. The teacher for the current intervention is also the author of this paper. All five of the author's sixth-grade science classes were used for the current study. One accelerated class (n = 28), one regular class (n = 29), and one co-taught class (n = 23) were selected for the treatment group (modeling instruction), and one regular class (n = 24) and one co-taught class (n = 24) were selected for the comparison group (regular instruction). Students are enrolled in the accelerated class based on their state math and reading test scores from the previous year. Regular science classes contain few high achieving students and special needs students because of scheduling (accelerated and co-taught classes). Co-taught classes include regular and special needs students (SPED and ELL) and have an aide to assist with instruction (e.g., one-to-one assistance). Many of the English Language Learners are also in the co-taught classes (see Table 3). Students of different abilities were used to increase the validity of the results by increasing the likelihood that the results will apply to the larger population (Creswell & Plano Clark, 2011). To address research question 1 (Does modeling instruction help students in all three groups (accelerated, regular, co-taught) improve their understandings of the phases of matter?), all 80 students in the treatment group were included. To address research question 2 (Does modeling instruction help students improve their understandings of the phases of matter more than regular instruction?), 52 students from the treatment group (the regular and co-taught classes) and the 48 students in the comparison group were included. Altogether, there were 128 participants in the study. Both groups learned in student-centered environments.

Table 3
Number of Special Needs Students per Class

	Number of SPED students	Number of ELL students
Treatment Group		
Accelerated	1	0
Regular	0	1
Co-Taught	12	8
Comparison		
Regular	2	4
Co-Taught	5	1

Setting. The study will took place at a suburban middle school located in the southwestern United States. The school is classified as a Title 1 school because more than half (56%) of the student population qualifies for free and reduced lunch. Science is part of the regular curriculum for sixth graders at the school, so they receive science instruction every day for fifty minutes. The total school population is 1650 students, with the number of male and female students being almost equal. The Hispanic population is the largest demographic (32%), followed by Caucasian (29%), Asian (12%), African-American (11%), two or more races (8%), and the remaining students (8%) unidentified. Approximately 11% of students have an IEP (individual education plan) and 8% of students are classified as ELL (English Language Learners).

Design and Instruments

This study utilizes a quasi-experimental design, as random assignment of students to the treatment and comparison groups was not possible (due to the enrollment of students in existing classes), and a control (comparison) group was present (Creswell, 2009). Rather than randomly assigning individual students to either the treatment group or comparison group, the author randomly selected one regular education class and one co-taught class to the treatment group and one regular education class one co-taught class to the comparison group.

Quantitative Data Collection. Two instruments were used to collect data during the intervention. The first instrument was used to collect data at the beginning and at the end of the intervention: a multiple-choice assessment generated from an online test bank. The author designed the multiple-choice test using the American Association for the Advancement of Science (AAAS) Project 2061 science assessment website (AAAS Science Assessment, 2018) to assess students' understandings of the phases of matter (Appendix A). Twenty-eight questions relating to the overall topic of phases of matter were selected from the assessment database and used for the pretest at the beginning of the unit on phases of matter and the posttest at the end of the unit. This instrument was determined to be reliable because the assessment items on the website "are the result of more than a decade of research and development by Project 2061, a long-term science education reform initiative of the American Association for the Advancement of Science" (AAAS Science Assessment, 2018). The author also used the Kuder-Richardson Formula 20 to evaluate the reliability of the instrument and found the items satisfactory (KR(20) = 0.86) (Kuder-Richardson 20 & 21, 2016). Each student was given a participant number that was used as an identifier and to log in to the test. The identifiers ensured student confidentiality and allowed the author to pair student's pre- and posttest scores. Results were automatically generated on the AAAS website, including individual test scores, a breakdown of individual student answers to each question, and an item analysis of which misconceptions students held at the time of the test.

The 28 questions were then divided into two categories, those that were explicitly taught during the intervention and those that were not. As mentioned previously, all 28 questions were selected because they were related to the topic of the phases of matter, however, only some parts were taught explicitly. For example, the standard that was being addressed (MS-PS1-4 Develop a model that predicts and describes changes in particle motion, temperature, and state of a pure substance when thermal energy is added or removed) required students to gain an understanding of particle speed and spacing, but not bonding. A wider selection of questions was chosen because the author had reason to believe that students might learn material directly related to the content during modeling instruction as well as material closely related to the content. For example, in a study conducted by Bamberger and Davis (2013), the authors found that the sixth-grade students improved their conceptual understandings of smell, which was explicitly taught, as well as evaporation, which was not explicitly taught but related (particulate nature of matter).

To examine if students in the present study might experience a similar transfer of learning, 18 questions were identified as being explicitly taught in the intervention and 10 questions were identified as not being explicitly taught. From the explicit category, nine of the questions (1, 8, 9, 13, 14, 19, 25, 26, and 28) related to the spacing of the molecules, which directly relates to the arrangement of molecules the students drew as they approached the target model (see Appendix B). For example, question 1 asks, “In which state of matter are the molecules spaced farthest apart?” Next, eight of the questions (4, 10, 12, 15, 16, 17, 22, and 23) related to the speed or motion of the molecules, which also relates to the target model (the “c” shaped marks representing molecule motion). For example, question 17 asks, “In a cup of liquid water, when would the water molecules stop moving?” The final question, number 7, asks students about the transformation of a liquid to a gas at the molecular level (“the water molecules became a gas and are now part of the air”), which is also part of the target model (the liquid and gas boxes).

From the implicit category, eight of the questions (2, 5, 6, 18, 20, 21, 24, and 27) related to the connections between molecules (intermolecular bonding). For example, question 18 asks, "In which state of matter is the connection between the molecules the strongest?" These questions are in the implicit category because intermolecular bonding is related to phases of matter but might be considered too abstract for middle school students (Stevens, Shinn, & Peek-Brown, 2013). For example, a study on intermolecular bonding with general chemistry college students found that a majority had difficulty understanding intermolecular bonds (Cooper, Williams, & Underwood, 2015). Granted, the expectations for college students are much higher than for sixth graders, but the basic concept is still one that might be challenging to middle school students. It should also be noted that in the NGSS, intermolecular bonding is reserved for the high school level (e.g., HS-PS1-3). The other two questions (3 and 11) do not relate to the target model for different reasons. For question #3, bubbles are not part of the model, as bubbles would be at the macroscopic level (like showing ice as a solid). The target model focuses on the molecular level of phases of matter. For question #11, molecules are not mentioned in the question or answer choices, so students would have to make inferences from the target model to answer this question correctly.

The second instrument used was a modeling prompt in the context of phases of matter (Appendix C). This prompt, which asks students to respond to three scenarios related to phase changes, was given to the participants four times throughout the intervention: once at the beginning, twice during, and once at the end of the intervention. The data from each modeling prompt were inspected to see if any group reached the level of basic model prior to the final modeling prompt (the "posttest"), but only the first and fourth modeling prompts were used in the quantitative analysis (to assess student growth as a result of the intervention). Students recorded the same participant number (from the AAAS tests) on each prompt so that individual student scores could be tracked throughout the intervention. A rubric was developed by the author to qualitatively assess the modeling prompt that was given four times throughout the intervention (Appendix D). The rubric was developed using Chiu and Wu's (2013) work on a learning progression for phase transitions, where the authors identified seven types of mental model from the literature and created a "conceptual evolutionary tree" for the mental models (Chiu & Wu, 2013, p. 378). A panel of experts reviewed the prompt to assess the validity of the instrument, and the reliability of the rubric was addressed by having a second expert (along with the author) score ten percent of the initial student prompt responses (interrater agreement). Cohen's Kappa was conducted to determine if there was agreement between two raters on the scores of the modeling prompts. There was sufficient agreement between the two raters, $k = .851$, $p < .001$. (Landis & Koch, 1977). In the rubric, Level 1 is reserved for student models that illustrate a continuous view of matter. Students who develop these models do not think of matter as being made up of smaller particles. Level 2 of the rubric is for student models that show a mixed view of matter. Students who develop these models are starting to understand the particulate view but are still holding onto some of their simpler ideas. Level 3 of the rubric is for student models that show a basic-particulate view of matter. This level is considered the paradigmatic threshold for the model of phase changes, or the level of "basic" model (Halloun, 2004). Students who develop these models have a basic understanding that matter is made up of particles and that particle distribution and speed vary depending on the state it is in. Level 3 also aligns with the grades 6-8 expectations of the learning progression described in Appendix E of the NGSS (National Research Council, 2013). Level 4, the highest level, is for student models that show a scientific-particulate view of matter. Students who develop models at this level have an advanced understanding of the particulate view of matter, such as the idea that particles can reach a state of dynamic equilibrium. Samples of student work that meets each of the four levels (except for prompt 2, level 4) are found in Appendices E-O. Statistical Package for the Social Sciences (SPSS) was used for the quantitative analysis to reduce errors and increase the reliability and internal validity of the results (Creswell & Plano Clark, 2011).

Threats to Validity. Based on the nature of the intervention, several threats to validity needed to be addressed or recognized. First, history might have been an issue, as some students might have missed several days of the intervention. To address this, the author did not collect data from students who miss any significant amount of time. Second, maturation might have been an issue if students get tired of drawing too many models. To address this issue, the author limited the number of individual models to four (in their journals) and allowed students to use different colors of pencils to record revisions on previous models. Third, statistical regression might have been an issue if higher level students begin with a high score on the modeling prompt. The author addressed this by creating a prompt that is differentially difficult; the model has a low floor and high ceiling so that a wide range of understandings could be expressed. Finally, testing could have been an issue if students became familiar with the AAAS questions. This was addressed by choosing to test only two times, at the beginning and at the end of the intervention, approximately four weeks apart.

Quantitative Data Analysis. To address research question 1, “Does modeling instruction help students in all three groups (accelerated, regular, co-taught) improve their understandings of the phases of matter?”, the author conducted several tests (see Figure 1). Since the results of the Kuder-Richardson Formula 20 test were greater than 0.70, it was determined that the internal reliability was sufficient for all 28 items to be included in the analysis. Several tests were used to analyze the data related to research question 1 (see Figure 1). To begin, a one-way ANOVA was conducted to determine if there was a difference between the AAAS change scores of the three groups. Follow-up dependent (paired samples) t-tests were also conducted to assess whether the three groups of students (accelerated, regular, and co-taught) improved their scores on the AAAS assessment. Second, a one-way MANOVA was conducted on the explicit and implicit AAAS test scores to determine if there was a difference between scores on content that was explicitly taught versus not-explicitly taught (implicit). T-tests for the two data sets (explicit and implicit scores) were conducted as follow up.

The other tests were conducted on the modeling prompt data. First, a Kruskal-Wallis H test was conducted to see if there was a difference between the scores of the three prompts for the three treatment classes. As a result of the Kruskal-Wallis, three additional Kruskal-Wallis H tests were conducted on the three individual modeling prompt data sets (prompt 1, 2, and 3). Follow-up Wilcoxon Signed Rank tests were also conducted to explore whether students in each of the three treatment classes improved their understandings on modeling prompts 1, 2, and 3.

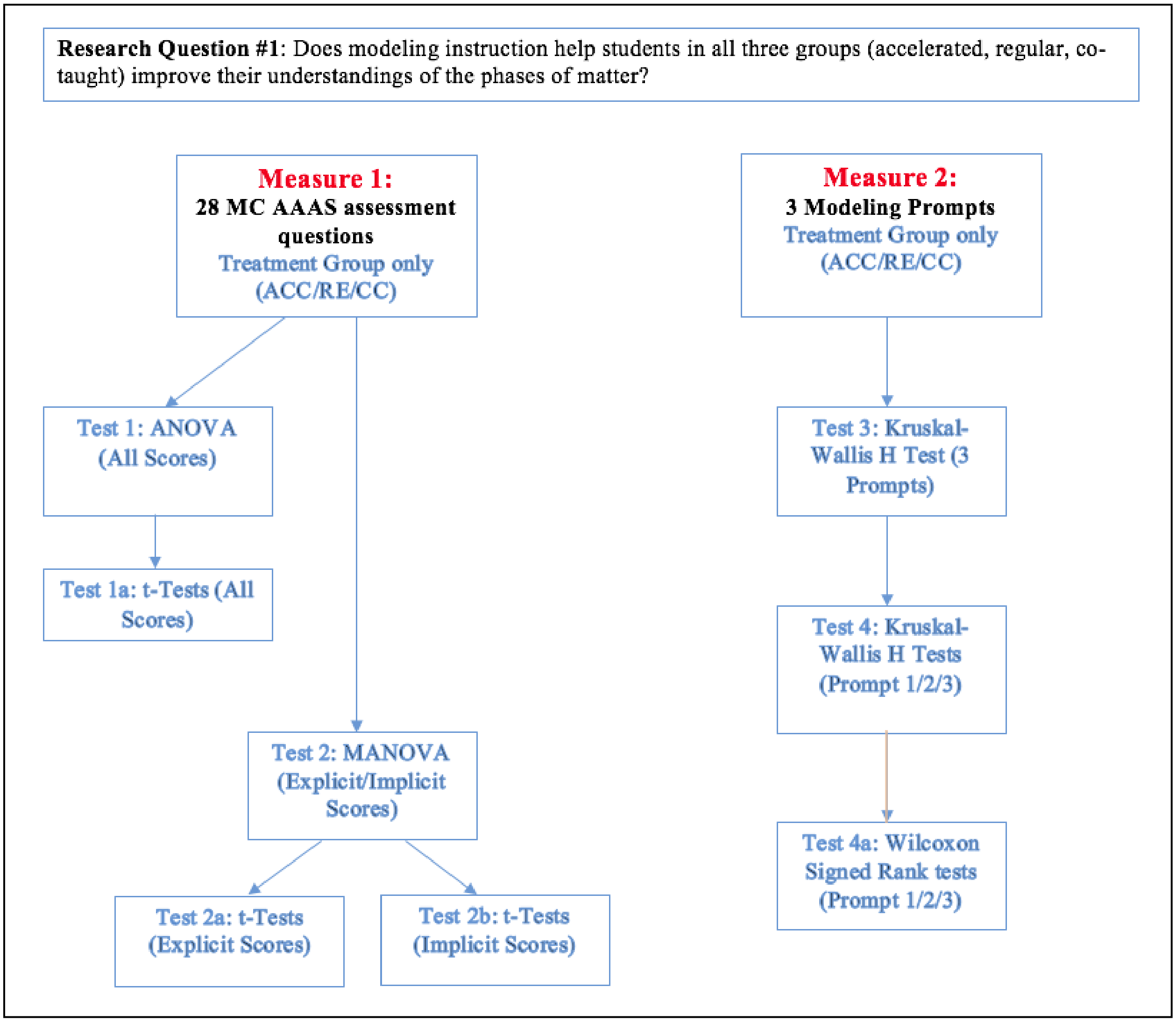


Figure 1. Testing procedures for Research Question 1.

To address research question 2, “Does modeling instruction help students improve their understandings of the phases of matter more than regular instruction?”, the author conducted another set of nonparametric tests (see Figure 2). To begin, a Kruskal-Wallis H test was conducted to determine if there was a difference between the AAAS scores of the treatment and comparison groups. Next, Wilcoxon Signed Rank tests were conducted to assess whether the two groups of students (treatment and comparison) improved their scores on the AAAS assessment. After the Wilcoxon Signed Rank tests, a two Kruskal-Wallis H tests were conducted on the explicit and implicit AAAS test scores of the treatment and comparison groups. Follow-up Wilcoxon Signed Rank tests for the two groups' explicit and implicit scores concluded the AAAS analysis.

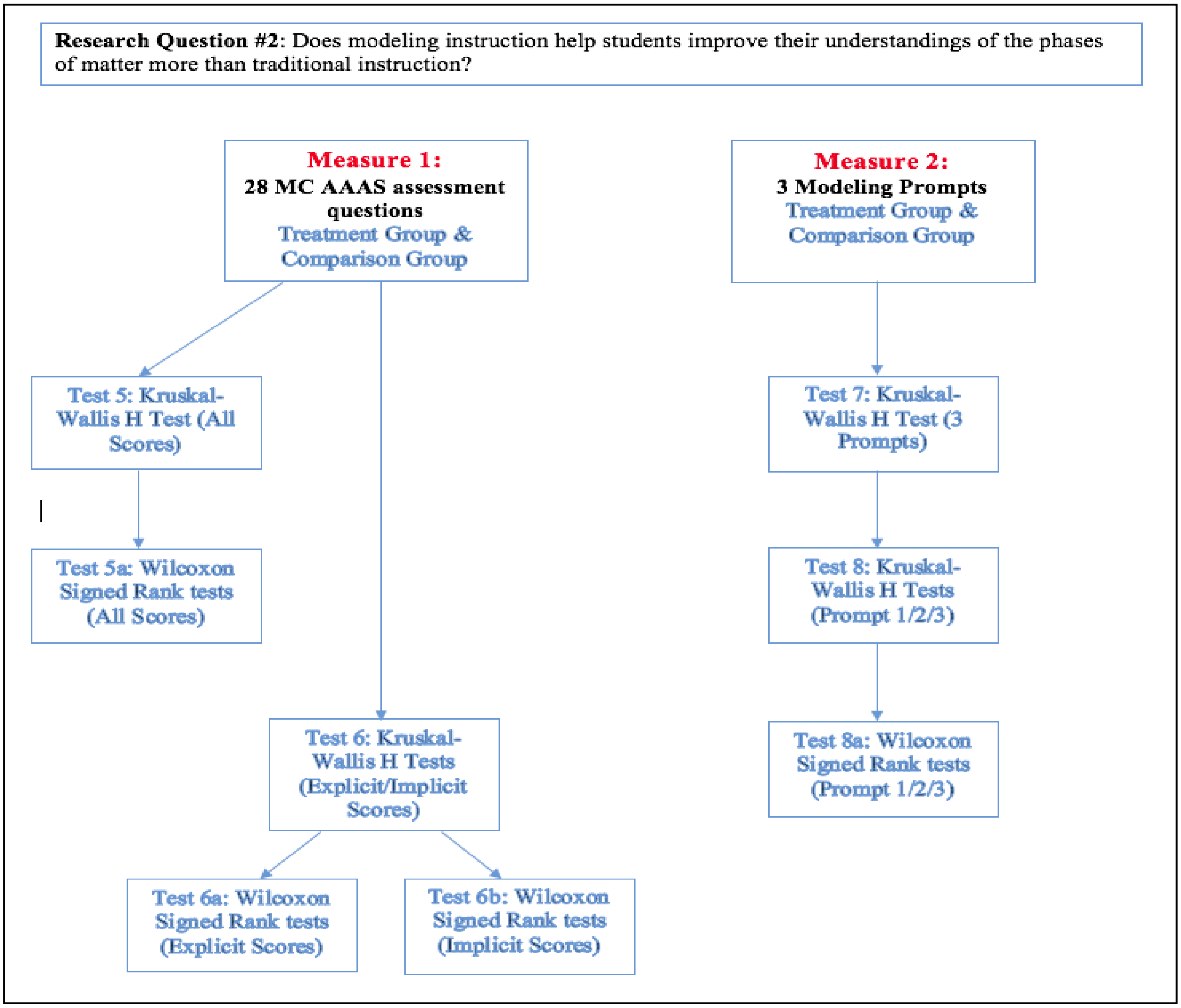


Figure 2. Testing procedures for Research Question 2.

The final tests were conducted on the modeling prompt data. First, a Kruskal-Wallis H test was conducted to see if there was a difference between the scores of the three prompts for the two groups (treatment and comparison). Next, three Kruskal-Wallis H tests were conducted on the treatment and comparison groups' modeling scores for the three prompts. Wilcoxon Signed Rank tests were also conducted to explore whether students in each of the groups improved their understandings on the three modeling prompts.

Procedures

Before the intervention began, all student participants received a short description of the study, completed consent forms, and received parental permission. The unit of instruction that was the focus of this study addressed NGSS (Next Generation Science Standard) MS-PS1-4 (see Table 4). Both groups (treatment and comparison) took the AAAS assessment at the beginning and ending of the intervention, as well as completed the modeling prompt four times throughout the intervention. Students in both the treatment group (modeling instruction) and the comparison group (regular instruction) focused on this standard, but did it in different ways. Students in the treatment group learned the content by using, creating, and revising models in an *interactive* way, while students in the comparison group learned the content by using existing models in an *active* way (Chi & Wylie, 2014). This differentiation was made with authenticity in mind; the idea was to compare the modeling instruction with instruction that might regularly occur in science classrooms. Table 5 shows a comparison of the activities that students in both groups did throughout the intervention. All activities in the table may be considered some form of model engagement. For the purposes of this study, however, the activities completed by only the treatment group (modeling sessions, marked with "**") will be considered the modeling instruction. The other activities have students think about and use models, but the modeling activities afford students the opportunities to generate, evaluate, and revise their models with their peers in an iterative fashion.

Table 4

MS-PS1-4: Matter and its Interactions

Students who demonstrate understanding can:
Develop a model that predicts and describes changes in particle motion, temperature, and state of a pure substance when thermal energy is added or removed.

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Developing and Using Models. Modeling in 6-8 builds on K-5 and progresses to developing, using and revising models to describe, test, and predict more abstract phenomena and design systems. Develop a model to predict and/or describe phenomena	PS1.A: Structure and Properties of Matter. Gases and liquids are made of molecules or inert atoms that are moving about relative to each other. In a liquid, the molecules are constantly in contact with others; in a gas, they are widely spaced except when they happen to collide. In a solid, atoms are closely spaced and may vibrate in position but do not change relative locations. PS3.A: Definitions of Energy. The term "heat" as used in everyday language refers both to thermal energy (the motion of atoms or molecules within a substance) and the transfer of that thermal energy from one object to another. In science, heat is used only for this second meaning; it refers to the energy transferred due to the temperature difference between two objects. The temperature of a system is proportional to the average internal kinetic energy and potential energy per atom or molecule (whichever is the approximate building block for the system's material). The details of that relationship depend on the type of atom or molecule and the interactions among the atoms in the material. Temperature is not a direct measure of a system's total thermal energy. The total thermal energy (sometimes called the total internal energy) of a system depends jointly on the temperature, the total number of atoms in the system, and the state of the material.	Cause and Effect. Cause and effect relationships may be used to predict phenomena in natural or designed systems.

Note. The NGSS standard for states of matter, MS-PS1-4 Matter and its Interactions, was taken from the Next Generation Science Standards (National Research Council, 2013).

Table 5
Student Activities During the Intervention

Week	Treatment Group (Modeling instruction: create, modify, and use models)	Comparison Group (Regular instruction: use models)
1	• **AAAS pretest *** • **Modeling Prompt 1 *** • Matter is made of parts/molecules (5 materials) • **Model generation (M1a) **** • States of Matter (Alien Xod)	• **AAAS pretest *** • **Modeling Prompt 1 *** • Matter is made of parts/molecules (5 materials) • States of Matter (Alien Xod) • **MobyMax (States of Matter) ****
2	• Molecule arrangement 1 (balloons and water: ice, water, steam) • **Modeling Prompt 2 *** • Molecule arrangement 2 (playdoh & marbles - **building and revising ****) • **Model evaluation and modification (M1b) **** • Heat and Thermal Energy (Blocks)	• Molecule arrangement 1 (balloons and water: ice, water, steam) • **Modeling Prompt 2 *** • Molecule arrangement 2 (playdoh & marbles – **using ****) • **Canvas (States of Matter) **** • Heat and Thermal Energy (Blocks)
3	• Exploring Heat and Motion of Particles (macro) (CE) • **Model evaluation and modification (M1d) **** • Molecule movement (PhET States of Matter Basics) • **Modeling Prompt 3 ***	• Exploring Heat and Motion of Particles (macro) (CE) • **MobyMax (Thermal Energy) OR Canvas (Thermal Energy) **** • Molecule movement (PhET States of Matter Basics) • **Modeling Prompt 3 ***
4	• Phases changes (Gizmo) • Phase changes (water) and graphing states of matter lab • **Model evaluation and modification (M1d) **** • **AAAS posttest *** • **Modeling Prompt 4 ***	• Phases changes (Gizmo) • Phase changes (water) and graphing states of matter lab • **MobyMax (State Changes) OR** • **Canvas (Phase Changes) **** • **AAAS posttest *** • **Modeling Prompt 4 ***

Note. The items marked * are assessment tasks and the items ** are differences in the type of activity between the two groups.

In order to develop the unit of instruction for this intervention, the author examined the learning targets for the standard (provided by the district) and created a learning pathway (Clement & Rea-Ramirez, 2008) (see Table 6).

Table 6
Learning Targets

Knowledge Targets (KT)

- Students know matter can be found in three states. (KT1)
- Students know the arrangement and movement of particles determine how matter behaves in solids, liquids, and gases. (KT2)
- Students know the difference between thermal energy and temperature. (KT3)
- Students know the effects of thermal energy on the motion of particles in a natural or designed system. (KT4)
- Students know adding or removing thermal energy increases or decreases the kinetic energy of particles until a change in state occurs. (Relates to MS-PS3-3 and MS-PS3-4) (KT5)
- Students know the changes of state that occur with variations in temperature can be described and predicted. (KT6)

Performance Targets (PT)

- Students can describe the arrangement and movement of particles in the three phases of matter. (PT1)
- Students can use simulations to compare the molecular behavior of a substance as it transitions through the three states of matter. (PT2)
- Students can use models and simulations to explain the molecular behavior of ice, water, and water vapor. (Relates to MS-ESS2-4) (PT3)
- Students can compare and contrast thermal energy and temperature. (PT4)
- Students can model and predict the effects of thermal energy changes on the motion of particles in a system. (PT5)

Note. The Learning Targets were taken from the district Curriculum Engine (curriculum.wiki-teacher.com/).

Students from both treatment and comparison groups used online journals (see Appendix P) to complete the activities and record notes from the intervention. The initial activities focused on the three states of matter (KT1). All students completed the “matter is made of parts/molecules” activity, where students broke-up five materials and discussed their parts, and the “states of matter” activity, where students tried to explain solids, liquids, and gases to an alien named Xod. The next two activities focused on the arrangement and movement of particles (KT2, PT1). The students in both groups first participated in a whole class activity where the author manipulated the three states of matter in balloons (a rock, water, and air) and asked probing questions. Next, students in the treatment group built, revised, and discussed models of the three phases with playdoh and marbles while the comparison group manipulated and discussed existing playdoh and marble models.

Following the states of matter activities, the students in both groups completed activities related to thermal energy and temperature (KT3, PT4, PT5). All students used aluminum and plastic blocks to explore thermal energy transfer (a discrepant event) and explored how heating relates to the inferred motion of molecules (students will observe the movement of water). Finally, students in both groups completed activities related to the changes in phases of matter (KT4, KT5, KT6, PT2, PT3). Students used two simulations (PhET and Gizmos) to explore the effects of thermal energy transfer on the states of matter, and completed one lab to explore the temperature changes that occur as water changes from a solid to a liquid to a gas. The role of the teacher (author) varied throughout the intervention from moderator to arbiter to scaffolder.

The main difference between the two interventions, as previously mentioned, was the presence (or lack) of model generation/evaluation/modification (GEM) activities. These activities have some elements of all of the modeling approaches described in Chapter 2 (Theoretical Framework), but it most closely resembled Clement and Rea-Ramirez's (2008) version. This approach might be best suited to guide sixth grade students through the modeling process, as many of the studies using this approach were conducted with middle school participants who needed additional guidance. In contrast, Halloun (2004) and Gilbert and Justi (2016) typically used high school or college participants with their versions of modeling instruction. During the modeling sessions that the treatment group engaged in throughout the intervention (the GEM activities), students worked in small groups to develop an explanatory model of the phases of matter. The model represented what happens to water at the molecular level as it changed from ice to liquid water to water vapor and back when thermal energy is added and removed. During the first part of the modeling activities (sessions), students used their prior ideas and experiences from previous class activities to develop their models on whiteboards. During the second part, groups took turns sharing, critiquing, and defending their models in whole class discussions. The author's roles during this part included (a) moderating the discussions by asking probing questions about the student models (although all three teacher roles, moderator, arbiter, and scaffolding, were be used to some extent) and (b) recording the negotiated target model elements on the board (Windschitl & Thompson, 2013). In the final part of the modeling activities, individual students were given the opportunity to create/revise their own models in their journals using the model elements that the teacher recorded and posted. The overall process of having students experience phenomena and collect evidence between modeling sessions is similar to what students might experience with a MEL diagram, although MEL activities differ in some ways (Lombardi, Sibley, & Carroll, 2013). Students who were in the comparison group did regular activities in the context of phases of matter (rather than the modeling sessions) that did not involve model construction and revision, such as completing online activities provided in Canvas and MobyMax and manipulating existing models.

Chapter 4: Results

Quantitative analysis related to the two research questions will be presented in this chapter. The first section after the preliminary analyses will address research question 1 by examining AAAS and modeling prompt data from the three classes in the treatment group (regular, co-taught, and accelerated). The second section will address research question 2 by examining AAAS and modeling prompt data from the two classes in the treatment group (regular and co-taught) and the comparison group (regular and co-taught).

Preliminary Analyses (Research Question 1)

The AAAS and modeling data were examined to identify the types of tests that would provide the most useful analysis without violating any assumptions. Testing of the AAAS data (pre/post, change scores, explicit/implicit) using the Shapiro Wilk test revealed that normality was not violated ($p > .05$), so additional assumptions were tested to determine the type of analyses to conduct. The AAAS pre and post data were continuous and consisted of matched pairs, so dependent t-tests were used for this data (Dependent T-Test Using SPSS Statistics, 2013). There were two outliers in the AAAS change scores, so they were removed because they did not affect the results (Outliers: To Drop or Not to Drop, 2018). The AAAS change score data were continuous, included three independent groups, and met the condition of homogeneity of variances, so a one-way ANOVA was selected for analysis of the scores (One-Way ANOVA in SPSS Statistics, 2013). The AAAS explicit and implicit scores were continuous, included three independent groups of adequate sample size, and reflected linear relationships between the dependent and independent variables. An examination of boxplots and the calculation of Mahalanobis distance revealed no univariate or multivariate outliers. The assumption of homogeneity of variance-covariance was met, as evidenced by the values for Box’s M ($p > .05$)

and Levene's test ($p > .05$). Finally, no multicollinearity was present (VIF = 1.00), so a one-way MANOVA was conducted for the data (One-Way MANOVA in SPSS Statistics, 2013).

Testing of the modeling prompt data using the Shapiro Wilk test revealed that normality was violated ($p < .05$). Rather than transforming the data, which would hinder the interpretation of the results, nonparametric testing was conducted (Field, 2013). The data for the Kruskal-Wallis H tests met the assumptions of being continuous, having at least two groups, and consisting of independent observations (Kruskal-Wallis H Test using SPSS Statistics, 2013). The data for the Wilcoxon Signed Rank tests met the assumptions of being dependent samples, independence of observations, and being continuous and at least ordinal in nature (Assumptions of the Wilcoxon Sign Test, 2018). A summary table for research question 1 can be found at the end of the section (Table 13).

Research Question 1 Findings

A one-way ANOVA and follow-up t-tests were conducted to explore the impact of modeling instruction on students' knowledge of phases of matter, as measured by their AAAS scores. The one-way ANOVA revealed that there was a significant difference between the change scores based on type of science class (regular, accelerated, or co-taught), $F(2, 74) = 3.88$, $p = .025$, and represented a medium effect size, $\eta^2 = 0.09$ (Cohen, 1988). A Tukey post hoc test revealed that there was not a statistically significant difference between the mean scores of the co-taught and regular class ($p = .654$) and the regular and accelerated class ($p = .145$), but there was a statistically significant difference between the co-taught and accelerated class ($p = .024$). An examination of the change in means (Table 7) and the follow up t-tests show that students in all three modeling classes performed better on the posttest compared to the pretest (Figure 3). For the accelerated modeling class, the mean increased from 12.96 to 21.30. This increase, 8.33, was significant $t(26) = -12.62$, $p < .001$, and represented a large effect size, $d = 2.43$. For the regular education modeling class, the mean increased from 8.85 to 15.04. This difference, 6.19, was significant $t(26) = -9.56$, $p < .001$, and represented a large effect size, $d = 1.84$ (Cohen, 1988). Finally, for the co-taught (special education) modeling class, the mean increased from 7.30 to 12.35. This increase, 5.04, was significant $t(22) = -6.31$, $p < .001$, and represented a large effect size, $d = 1.32$.

Table 7
Pre/Post AAAS Assessment Scores for the 3 Classes in the Treatment Group

		Pretest		Posttest	
Class	N	M	SD	M	SD
Accelerated	28	12.96	4.59	21.30	3.79
Regular	27	8.85	2.88	15.04	4.60
Co-Taught	23	7.30	3.11	12.35	4.77

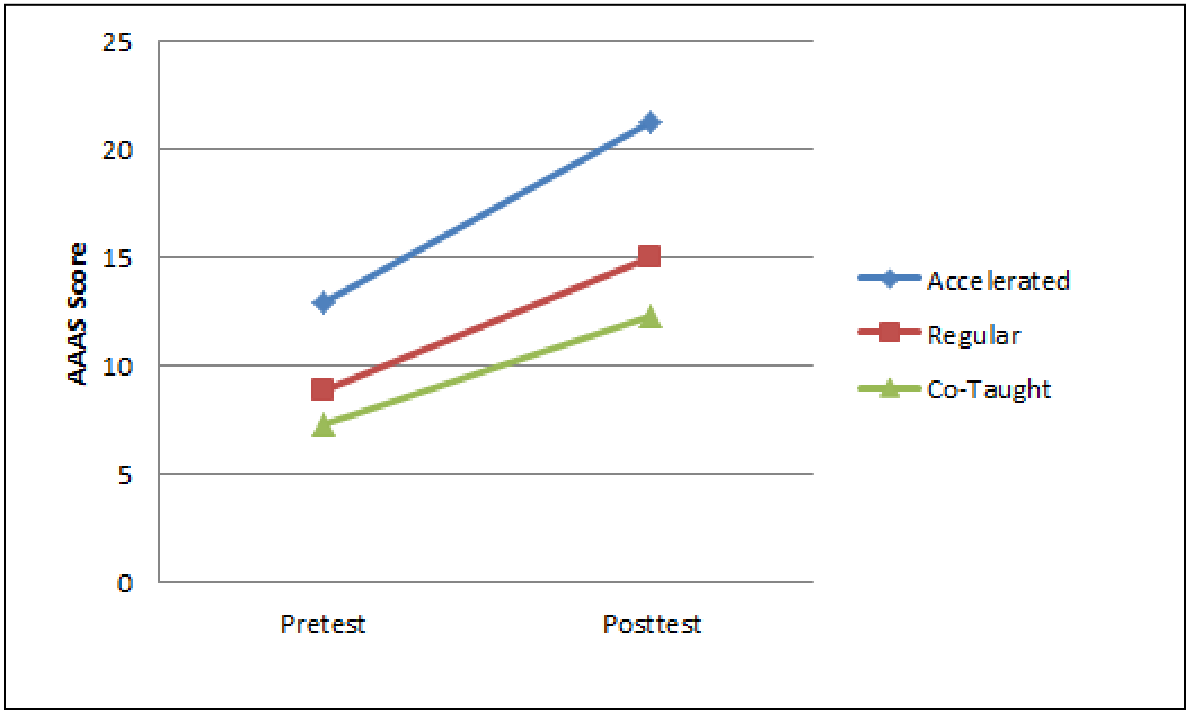


Figure 3. Change in students' content knowledge, based on AAAS scores, for the accelerated, regular, and co-taught classes in the treatment group.

Next, a one-way MANOVA and follow-up t-tests were conducted to explore the impact of modeling instruction on students' knowledge of phases of matter for content that was explicitly taught versus not explicitly taught in all three classes, as measured by their AAAS scores. The MANOVA revealed that there was a significant difference between the explicit and implicit scores based on type of science class (regular, accelerated, or co-taught), $F(4, 148) = 4.57$, $p = .002$, $\Lambda = .792$, and represented a large effect size, $\eta^2 = 0.208$ (Green, Salkind, & Akey, 1996). The type of class has a statistically significant effect on explicit scores ($F(2, 75) = 3.78$; $p = .027$) and implicit scores ($F(2, 75) = 6.30$; $p = .003$). There was not a statistically significant difference between the explicit mean scores of the co-taught and accelerated class ($p = .088$) or the co-taught and regular class ($p = .960$), but there was a significant difference between the accelerated and regular class ($p = .036$). For the implicit questions, there was not a statistically significant difference between the mean scores of the regular and co-taught class ($p = .092$) or the regular and accelerated class ($p = .314$), but there was a statistically significant difference between the co-taught and accelerated class ($p = .002$). An examination of the change in means (Table 8) and the follow up t-tests show that students in all three modeling classes performed better on the explicit AAAS posttest compared to the explicit AAAS pretest (Figure 4). For the accelerated modeling class, the mean increased from 8.50 to 13.86. This increase, 5.36, was significant $t(27) = -10.15$, $p < .001$, and represented a large effect size, $d = 1.92$. For the regular education modeling class, the mean increased from 6.00 to 9.63. This difference, 3.63, was significant $t(26) = -9.70$, $p < .001$, and represented a large effect size, $d = 1.87$. Finally, for the co-taught (special education) modeling class, the mean increased from 4.43 to 8.26. This increase, 3.83, was significant $t(22) = -6.54$, $p < .001$, and represented a large effect size, $d = 1.36$.

Table 8
Pre/Post AAAS Assessment Explicit Scores for the 3 Classes in the Treatment Group

		Explicit Pretest		Explicit Posttest	
Class	N	M	SD	M	SD
Accelerated	28	8.50	3.04	13.86	2.92
Regular	27	6.00	2.48	9.63	2.98
Co-Taught	23	4.43	2.71	8.26	3.26

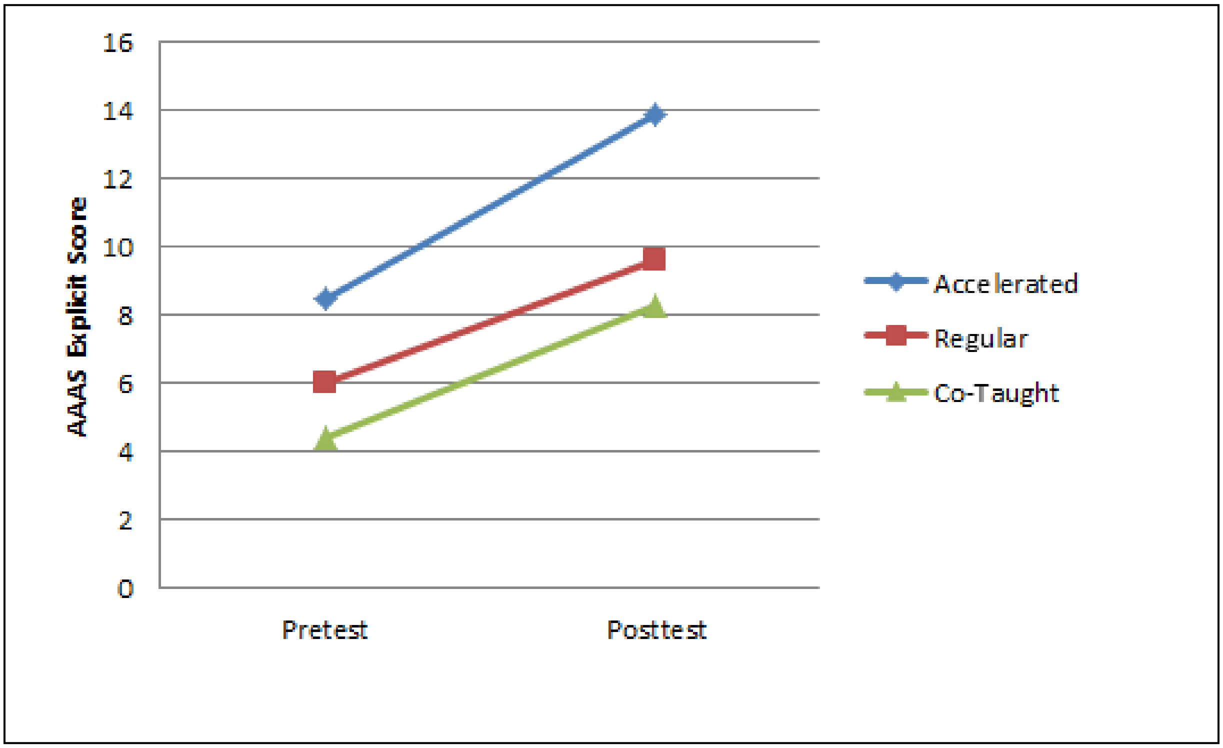


Figure 4. Change in students' content knowledge, based on AAAS explicit scores, for the accelerated, regular, and co-taught classes in the treatment group.

An examination of the change in means (Table 9) and the follow up t-tests show similar growth from pretest to posttest in relation to the implicit AAAS scores (Figure 5). For the accelerated modeling class, the mean increased from 4.25 to 7.50. This increase, 3.25, was significant $t(27) = -8.40$, $p < .001$, and represented a large effect size, $d = 1.59$. For the regular education modeling class, the mean increased from 2.67 to 5.11. This difference, 2.44, was significant $t(26) = -6.59$, $p < .001$, and represented a large effect size, $d = 1.26$. Finally, for the co-taught (special education) modeling class, the mean increased from 2.86 to 4.09. This increase, 1.22, was significant $t(22) = -2.71$, $p = .013$, and represented a medium effect size, $d = 0.57$.

Table 9
Pre/Post AAAS Assessment Implicit Scores for the 3 Classes in the Treatment Group

		Implicit Pretest		Implicit Posttest	
Class	N	M	SD	M	SD
Accelerated	28	4.25	2.13	7.50	1.29
Regular	27	2.67	1.41	5.11	1.93
Co-Taught	23	2.87	1.18	4.09	2.04

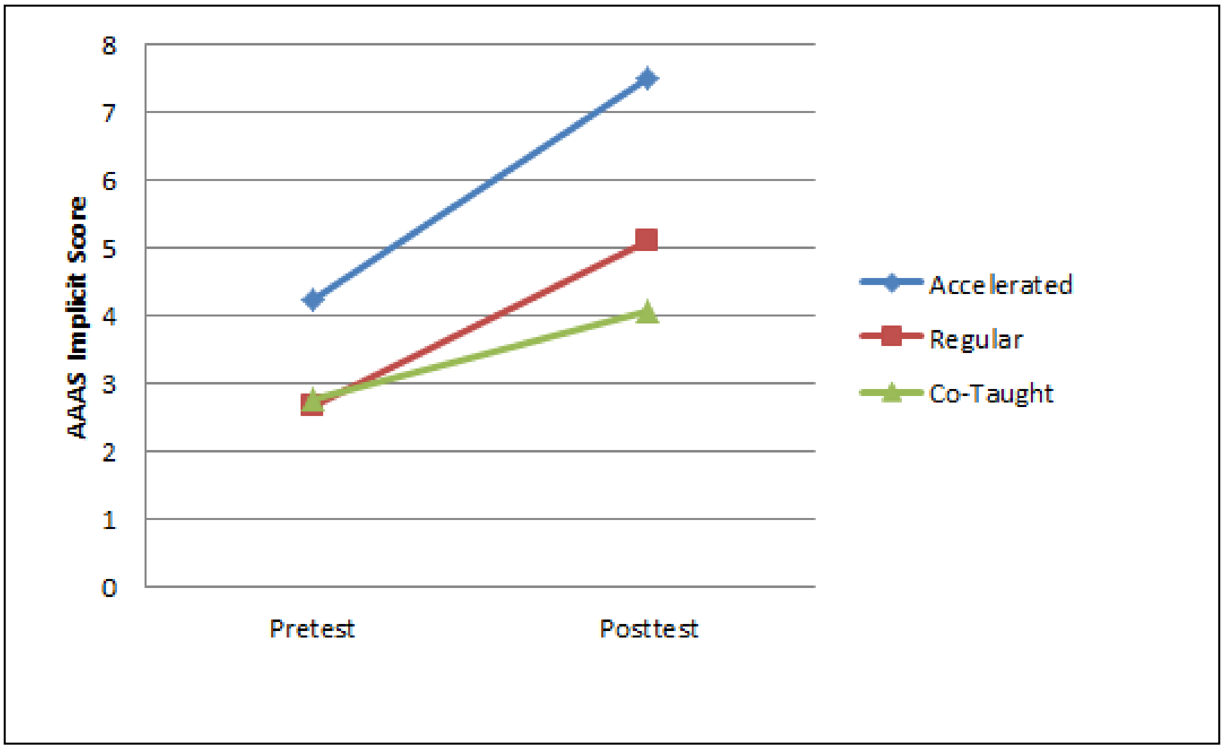


Figure 5. Change in students' content knowledge, based on AAAS implicit scores, for the accelerated, regular, and co-taught classes in the treatment group.

A Kruskal-Wallis H test was conducted on the modeling prompt scores to discover if there were any differences between the three modeling prompts for the treatment classes. The Krustal-Wallis revealed that there was a statistically significant difference between the three prompts, x^2 (2) = 45.86, p < .001), and represented a large effect size, $\eta^2 = 0.19$ (Green & Salkind, 2005). A Dunn's post hoc test revealed that the scores on modeling prompt 2 (mean rank = 84.50) were significantly lower than modeling prompt 1 (mean rank = 142.10), $p < .001$, and modeling prompt 3 (mean rank = 134.90), $p < .001$. There was no statistically significant difference between modeling prompt 1 and 3 ($p = .437$).

Three additional Kruskal-Wallis H tests were conducted to complete the modeling prompt analysis. The Kruskal-Wallis for modeling prompt 1 revealed that there was a statistically significant difference between the three classes (accelerated, regular, and co-taught), x^2 (2) = 7.24, $p = .027$), and represented a medium effect size, $\eta^2 = 0.09$. Post hoc Kruskal-Wallis H tests revealed that the scores for the accelerated class (mean rank = 47.07) were significantly higher than the regular class (mean rank = 37.47), $p = .014$, and the co-taught class (mean rank = 36.33), $p = .009$. There was no statistically significant difference between the regular and co-taught classes ($p = .824$). The Kruskal-Wallis for modeling prompt 2 revealed that there was not a statistically significant difference between the three classes (accelerated, regular, and co-taught), x^2 (2) = 3.49, $p = .175$. The Kruskal-Wallis for modeling prompt 3 revealed that there was a statistically significant difference between the three classes (accelerated, regular, and co-taught), x^2 (2) = 6.43, $p = .040$, and represented a medium effect size, $\eta^2 = 0.08$. A Dunn's post hoc test revealed that the scores for the accelerated class (mean rank = 47.14) were significantly higher than the regular class (mean rank = 35.78), $p = .044$, but not the co-taught class (mean rank = 38.37), $p = .229$. There was no statistically significant difference between the regular and co-taught classes ($p = 1.000$).

An examination of the change in means (Table 10) and the follow up Wilcoxon Signed Rank tests show growth from pretest to posttest in the modeling scores for prompt 1 (Figure 6). For the accelerated modeling class, there was a significant difference from pretest to posttest ($Z = -5.14$, $p < .001$), representing a large effect size, $r = 0.62$. For the regular education modeling class, there was a significant difference from pretest to posttest (Z = -4.94, p < .001), representing a large effect size, r = 0.65 (Pallant, 2013; Cohen, 1988). For the co-taught modeling class, there was a significant difference from pretest to posttest (Z = -4.38, p < .001), representing a large effect size, r = 0.65.

Table 10
Pre/Post Modeling Prompt 1 Scores for the 3 Classes in the Treatment Group

		Pretest 1		Posttest 1	
Class	N	M	SD	M	SD
Accelerated	28	1.00	0.00	2.96	0.19
Regular	29	1.00	0.00	2.72	0.45
Co-Taught	23	1.00	0.00	2.70	0.47

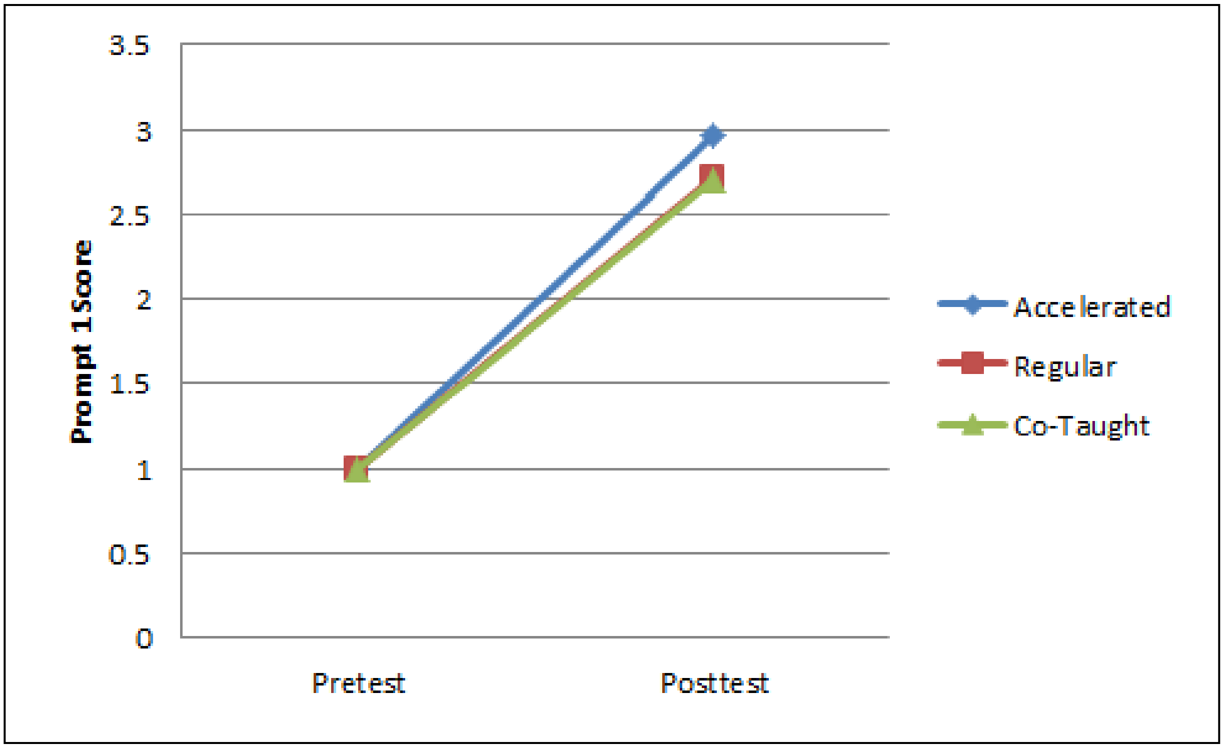


Figure 6. Change in students' content knowledge, based on modeling prompt 1 scores, for the accelerated, regular, and co-taught classes in the treatment group.

Next, an examination of the change in means (Table 11) and the follow up Wilcoxon Signed Rank tests also show growth from pretest to posttest in the modeling scores for prompt 2 (Figure 7). For the accelerated modeling class, there was a significant difference from pretest to posttest ($Z = -4.68$, $p < .001$), representing a large effect size, $r = 0.63$. For the regular education modeling class, there was a significant difference from pretest to posttest ($Z = -4.98$, $p < .001$), representing a large effect size, $r = 0.65$. For the co-taught modeling class, there was a significant difference from pretest to posttest ($Z = -4.46$, $p < .001$), representing a large effect size, $r = 0.66$.

Table 11
Pre/Post Modeling Prompt 2 Scores for the 3 Classes in the Treatment Group

		Pretest 2		Posttest 2	
Class	N	M	SD	M	SD
Accelerated	28	1.00	0.00	2.43	0.57
Regular	29	1.00	0.00	2.24	0.44
Co-Taught	23	1.00	0.00	2.22	0.42

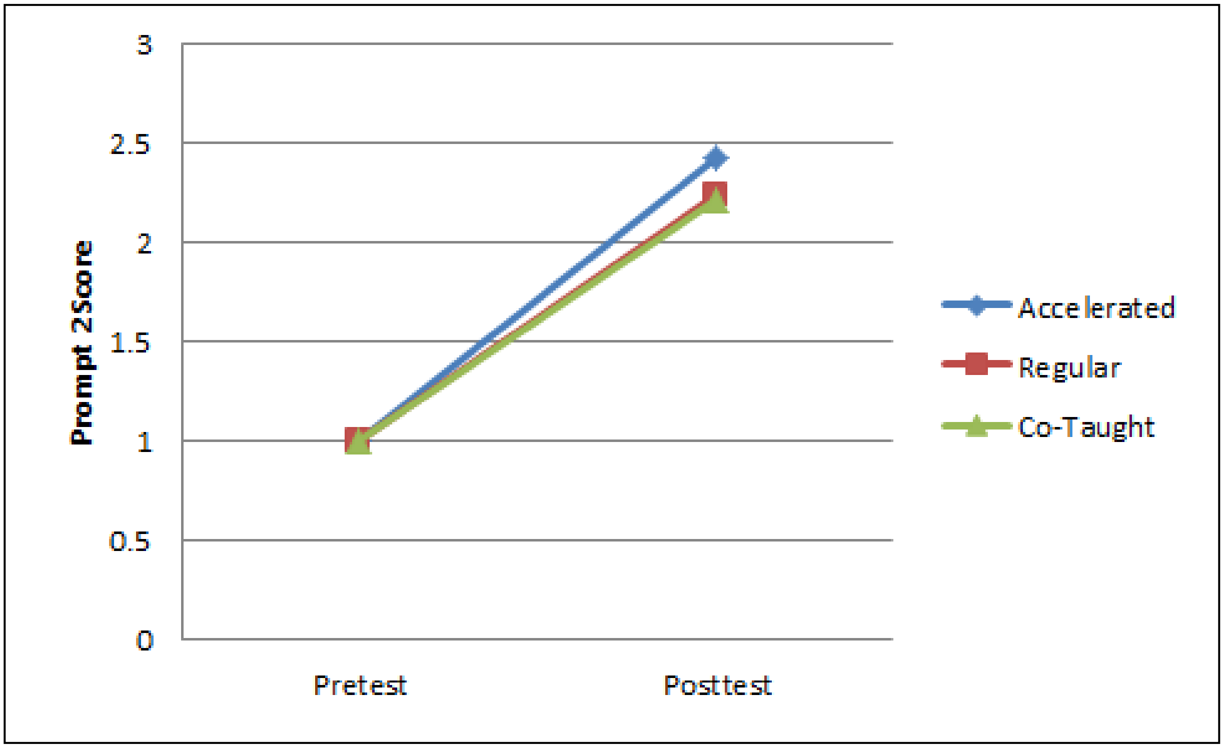


Figure 7. Change in students' content knowledge, based on modeling prompt 2 scores, for the accelerated, regular, and co-taught classes in the treatment group

Finally, an examination of the change in means (Table 12) and the follow up Wilcoxon Signed Rank tests also show growth from pretest to posttest in the modeling scores for prompt 3 (Figure 8). For the accelerated modeling class, there was a significant difference from pretest to posttest ($Z = -5.01$, $p < .001$), representing a large effect size, $r = 0.67$. For the regular education modeling class, there was a significant difference from pretest to posttest ($Z = -4.73$, $p < .001$), representing a large effect size, $r = 0.69$. For the co-taught modeling class, there was a significant difference from pretest to posttest ($Z = -4.25$, $p < .001$), representing a large effect size, $r = 0.63$.

Table 12
Pre/Post Modeling Prompt 3 Scores for the 3 Classes in the Treatment Group

		Pretest 3		Posttest 3	
Class	N	M	SD	M	SD
Accelerated	28	1.04	0.19	2.89	0.42
Regular	29	1.03	0.19	2.59	0.63
Co-Taught	23	1.00	0.00	2.61	0.66

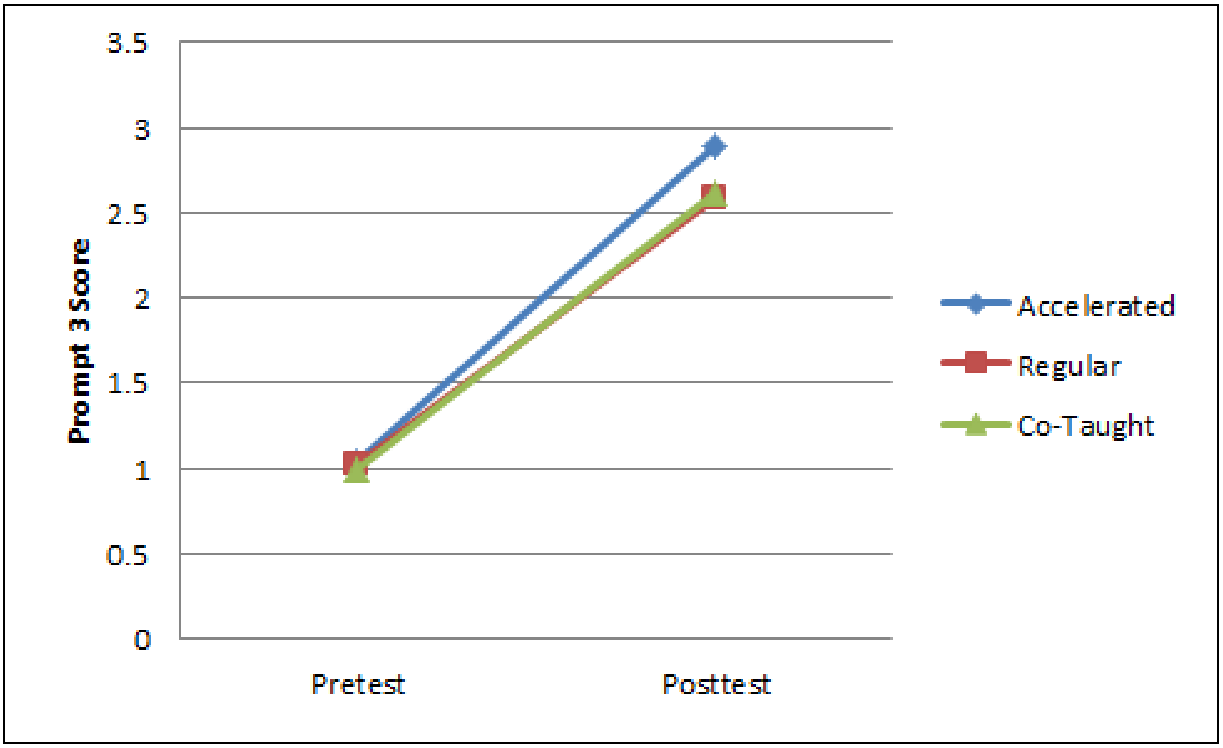


Figure 8. Change in students' content knowledge, based on modeling prompt 3 scores, for the accelerated, regular, and co-taught classes in the treatment group.

Table 13
Summary Table of Tests Addressing Research Question 1

Test #	Test Used	Results	Follow-up Results (t-test/Wilcoxon test)
1	One-way ANOVA	AAAS scores: ACC = RE ACC > CC * RE = CC	AAAS scores: ACC post > ACC pre ** RE post > RE pre ** CC post > CC pre **
2	One-way MANOVA	AAAS explicit scores: ACC > RE * ACC = CC RE = CC	AAAS explicit scores: ACC post > ACC pre ** RE post > RE pre ** CC post > CC pre **
		AAAS implicit: ACC = RE ACC > CC * RE = CC	AAAS implicit scores: ACC post > ACC pre ** RE post > RE pre ** CC post > CC pre **
3	Kruskal-Wallis H test	Prompt 1 = prompt 3 Prompt 3 > prompt 2 ** Prompt 1 > prompt 2 **	
4	Kruskal-Wallis H tests	Prompt 1: ACC > RE * ACC > CC * RE = CC	Prompt 1: ACC post > ACC pre ** RE post > RE pre ** CC post > CC pre **
		Prompt 2: ACC = RE ACC = CC RE = CC	Prompt 2: ACC post > ACC pre ** RE post > RE pre ** CC post > CC pre **
		Prompt 3: ACC > RE * ACC = CC RE = CC	Prompt 3: ACC post > ACC pre ** RE post > RE pre ** CC post > CC pre **

Note. The character ”>” represents a statistically significant difference between scores. The character “=” represents the absence of a statistically significant difference between scores.
* p < .05 ** p < .001

Preliminary Analyses (Research Question 2)

The AAAS and modeling data for the treatment and comparison groups were examined to identify the types of tests that would provide the most useful analysis without violating any assumptions. An examination of both types of data using the Shapiro Wilk test revealed that normality was violated ($p < .05$). Rather than transforming the data, nonparametric testing was again conducted. The data for the Kruskal-Wallis H tests met the assumptions of being continuous, having at least two groups, and consisting of independent observations (Kruskal-Wallis H Test using SPSS Statistics, 2013). The data for the Wilcoxon Signed Rank tests met the assumptions of being dependent samples, independence of observations, and being continuous and at least ordinal in nature (Assumptions of the Wilcoxon Sign Test, 2018). A summary table for research question 2 can be found at the end of the section (Table 20).

Research Question 2 Findings

A Kruskal-Wallis H test was conducted to investigate the impacts of modeling and regular instruction on students' knowledge of phases of matter, as measured by their AAAS scores. The Kruskal-Wallis revealed that there was no statistically significant difference between the two groups' AAAS scores, x^2 (1) = 3.67, $p = .055$). An examination of the change in means (Table 14) and results of Wilcoxon Signed Rank tests, however, show that students in both groups (treatment and comparison) performed better on AAAS posttest compared to the AAAS pretest. For the treatment group, there was a significant difference from pretest to posttest ($Z = -5.77$, $p < .001$), representing a large effect size, $r = 0.57$. For the comparison group, there was a significant difference from pretest to posttest ($Z = -4.67$, $p < .001$), representing a medium effect size, $r = 0.48$. While the gains in the treatment group were larger than the comparison group (Figure 9), the difference was not statistically significant.

Table 14
Pre/Post AAAS Assessment Scores for the Treatment and Comparison Groups

		Pretest		Posttest	
Group	N	M	SD	M	SD
Treatment	52	8.23	3.03	13.56	4.89
Comparison	48	8.71	3.05	12.75	5.70

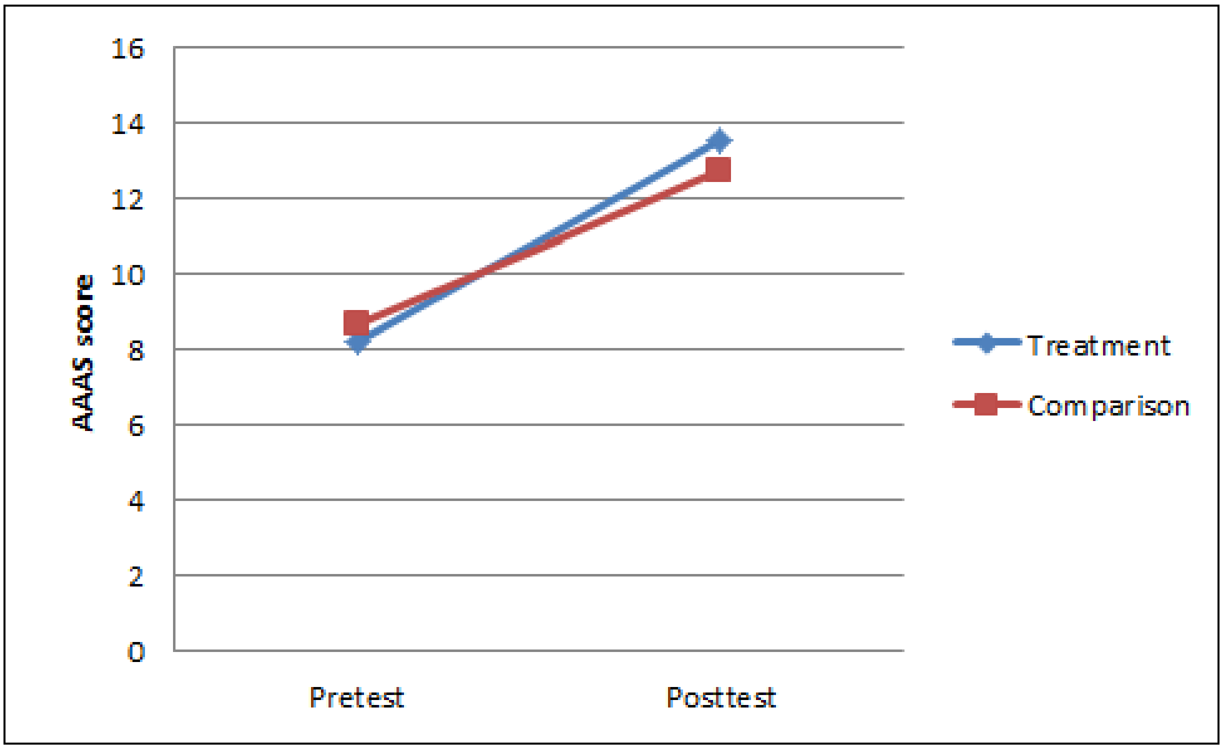


Figure 9. Change in students' content knowledge, based on AAAS scores, for the treatment and control group.

Next, another two Kruskal-Wallis H tests and follow-up Wilcoxon Signed Rank tests were conducted to investigate the impacts of modeling and regular instruction on students' knowledge of phases of matter for content that was explicitly taught versus not explicitly taught in both groups, as measured by their AAAS scores. The first Kruskal-Wallis revealed that there was a significant difference between the explicit AAAS scores for the two groups, x^2 (1) = 7.94, p = .005), representing a medium effect size, $\eta^2 = 0.08$. The second Kruskal-Wallis revealed that there was a no significant difference between the implicit AAAS scores for the two groups, x^2 (1) = 0.26, p = .661).

An examination of the change in means (Table 15) and results of the follow-up Wilcoxon Signed Rank tests show that students in both groups (treatment and comparison) performed better on AAAS explicit posttest compared to the AAAS explicit pretest (Figure 10). For the treatment group, there was a significant difference from pretest to posttest (Z = -5.74, p < .001), representing a large effect size, r = 0.56. For the comparison group, there was a significant difference from pretest to posttest (Z = -3.38, p = .001), representing a medium effect size, r = 0.34.

Table 15
Pre/Post AAAS Assessment Explicit Scores for the Treatment and Comparison Groups

		Explicit Pretest		Explicit Posttest	
Group	N	M	SD	M	SD
Treatment	52	5.35	2.66	9.04	3.32
Comparison	48	5.60	2.32	7.71	3.97

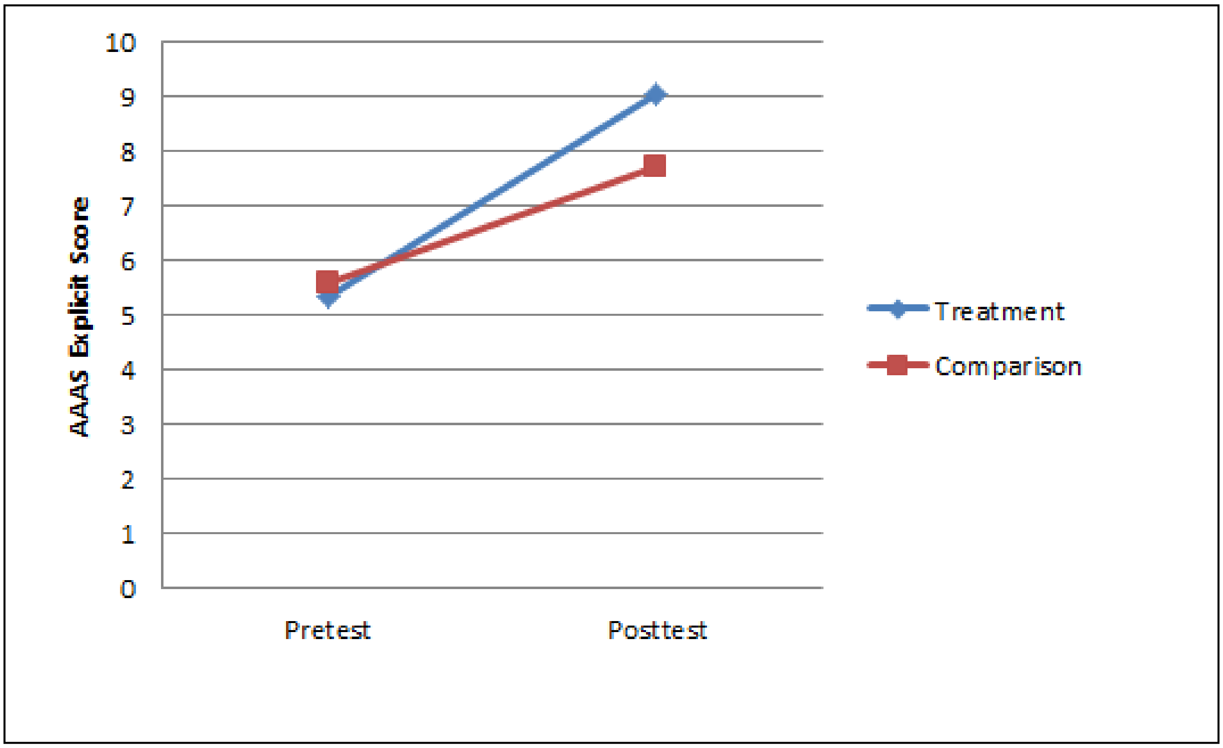


Figure 10. Change in students' content knowledge, based on AAAS explicit scores, for the treatment and control group.

Likewise, the examination of the change in means (Table 16) and results of the follow-up Wilcoxon Signed Rank tests show that students in both groups (treatment and comparison) also performed better on AAAS implicit posttest compared to the AAAS explicit pretest (Figure 11). For the treatment group, there was a significant difference from pretest to posttest ($Z = -4.17$, $p < .001$), representing a medium effect size, $r = 0.41$. For the comparison group, there was a significant difference from pretest to posttest ($Z = -4.62$, $p = .001$), representing a medium effect size, $r = 0.47$.

Table 16

Pre/Post AAAS Assessment Implicit Scores for the Treatment and Comparison Groups

		Implicit Pretest		Implicit Posttest	
Group	N	M	SD	M	SD
Treatment	52	2.88	1.44	4.52	2.08
Comparison	48	3.10	1.68	5.04	2.19

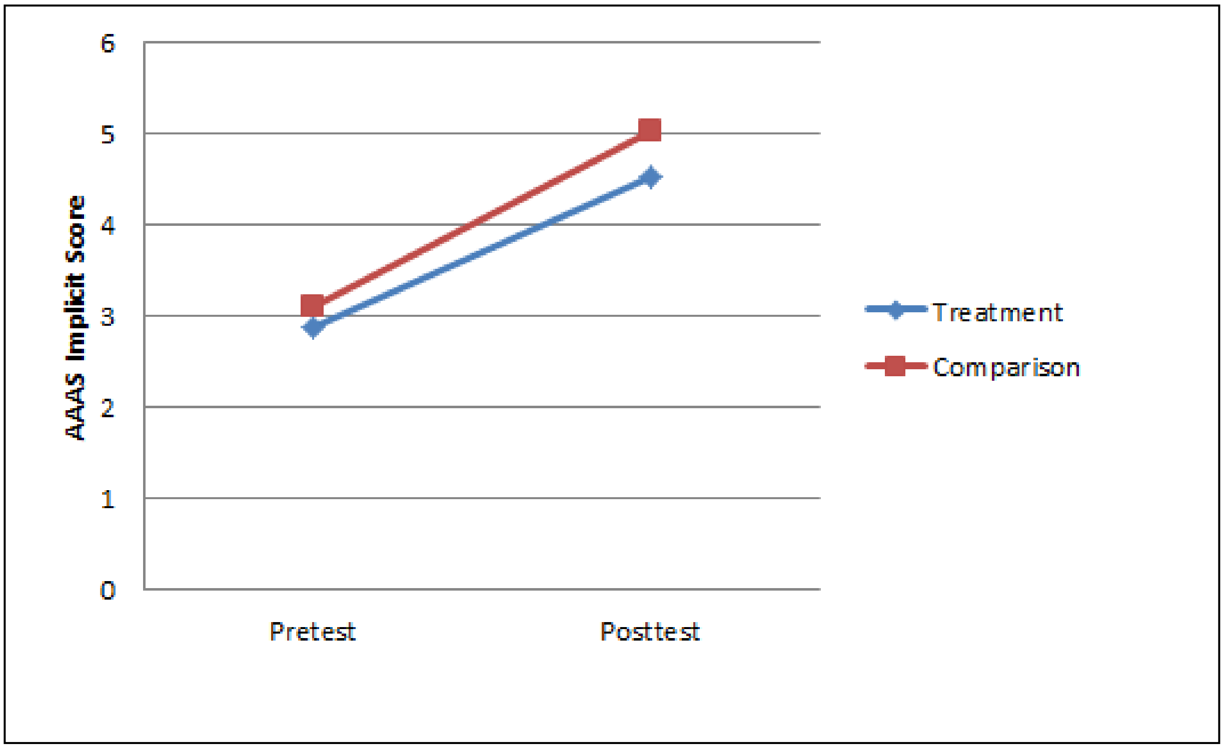


Figure 11. Change in students' content knowledge, based on AAAS implicit scores, for the treatment and control group.

A Kruskal-Wallis H test was conducted on the modeling prompt scores to discover if there were any differences between the three modeling prompts for the two groups. The Kruskal-Wallis revealed that there was a statistically significant difference between groups, prompts, x^2 (2) = 35.74, p < .001), and represented a medium effect size, $\eta^2 = 0.12$. A Dunn's post hoc test revealed that the scores on modeling prompt 2 (mean rank = 114.76) were significantly lower than modeling prompt 1 (mean rank = 176.89), p < .001, and modeling prompt 3 (mean rank =

159.86), $p < .001$. There was no statistically significant difference between modeling prompt 1 and 3 ($p = .338$).

Three additional Kruskal-Wallis H tests were conducted to complete the modeling prompt analysis. The Kruskal-Wallis for modeling prompt 1 revealed that there was a statistically significant difference between the two groups (treatment and comparison), x^2 (1) = 6.81, $p = .009$), and represented a medium effect size, $\eta^2 = 0.07$. An examination of the mean ranks, with the results of the Kruskal-Wallis, shows that the treatment group (mean rank = 56.72) performed significantly better on modeling prompt 1 than the comparison group (mean rank = 43.76). The Kruskal-Wallis for modeling prompt 2 revealed that there was a statistically significant difference between the two groups (treatment and comparison), x^2 (1) = 4.67, $p = .031$), and represented a small effect size, $\eta^2 = 0.05$. An examination of the mean ranks, with the results of the Kruskal-Wallis, shows that the treatment group (mean rank = 54.42) performed significantly better on modeling prompt 2 than the comparison group (mean rank = 46.25). The Kruskal-Wallis for modeling prompt 3 also revealed that there was a statistically significant difference between the two groups (treatment and comparison), x^2 (1) = 7.56, $p = .006$), and represented a medium effect size, $\eta^2 = 0.08$. An examination of the mean ranks, with the results of the Kruskal-Wallis, shows that the treatment group (mean rank = 57.37) performed significantly better on modeling prompt 3 than the comparison group (mean rank = 43.06).

An examination of the change in means (Table 17) and the follow up Wilcoxon Signed Rank tests show growth from pretest to posttest in the modeling scores for prompt 1 for both groups (Figure 12). For the treatment group, there was a significant difference from pretest to posttest ($Z = -6.59$, $p < .001$), representing a large effect size, $r = 0.65$. For the comparison group, there was a significant difference from pretest to posttest ($Z = -6.16$, $p < .001$), representing a large effect size, $r = 0.63$.

Table 17
Pre/Post Modeling Prompt 1 Scores for the Treatment and Comparison Groups

		Pretest 1		Posttest 1	
Group	N	M	SD	M	SD
Treatment	52	1.00	0.00	2.71	0.46
Comparison	48	1.00	0.00	2.44	0.54

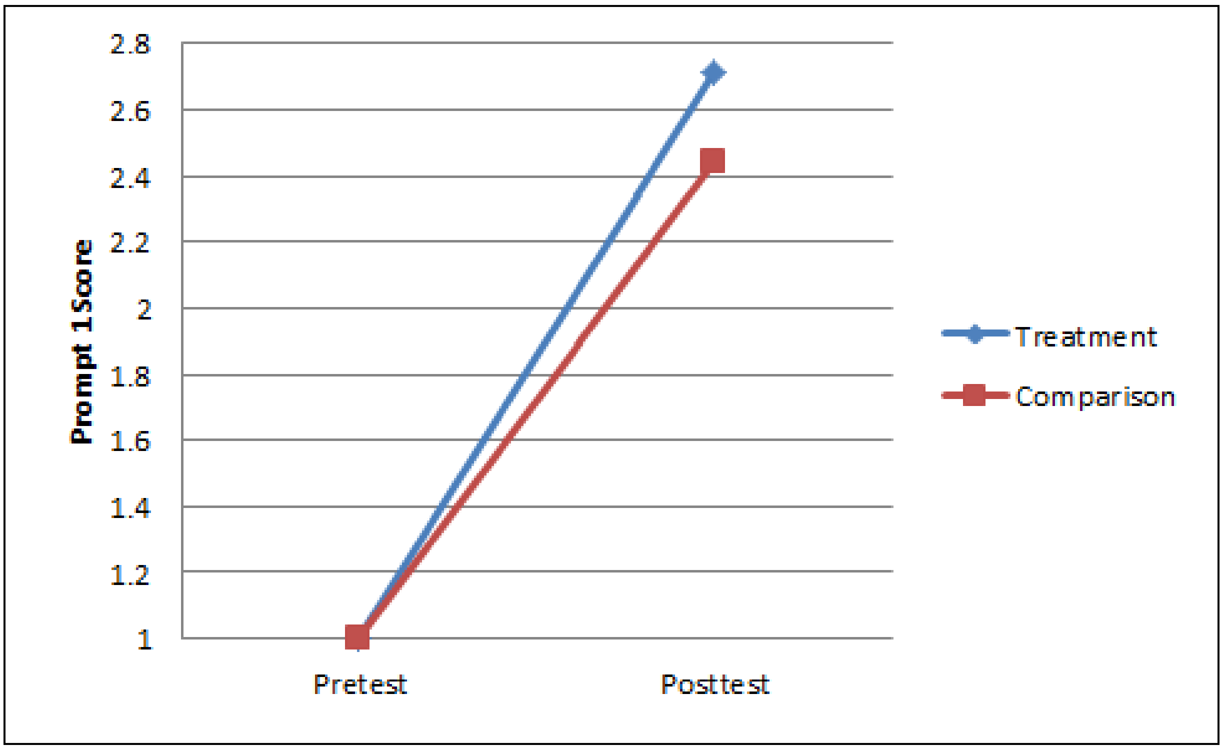


Figure 12. Change in students' content knowledge, based on modeling prompt 1 scores, for the treatment and control group.

Likewise, the change in means (Table 18) and the follow up Wilcoxon Signed Rank tests show growth from pretest to posttest in the modeling scores for prompt 2 for both groups (Figure 13). For the treatment group, there was a significant difference from pretest to posttest ($Z = -6.65$, $p < .001$), representing a large effect size, $r = 0.65$. For the comparison group, there was a significant difference from pretest to posttest (Z = -6.61, p < .001), representing a large effect size, r = 0.67.

Table 18
Pre/Post Modeling Prompt 2 Scores for the Treatment and Comparison Groups

		Pretest 2		Posttest 2	
Group	N	M	SD	M	SD
Treatment	52	1.00	0.00	2.23	0.43
Comparison	48	1.00	0.00	2.06	0.32

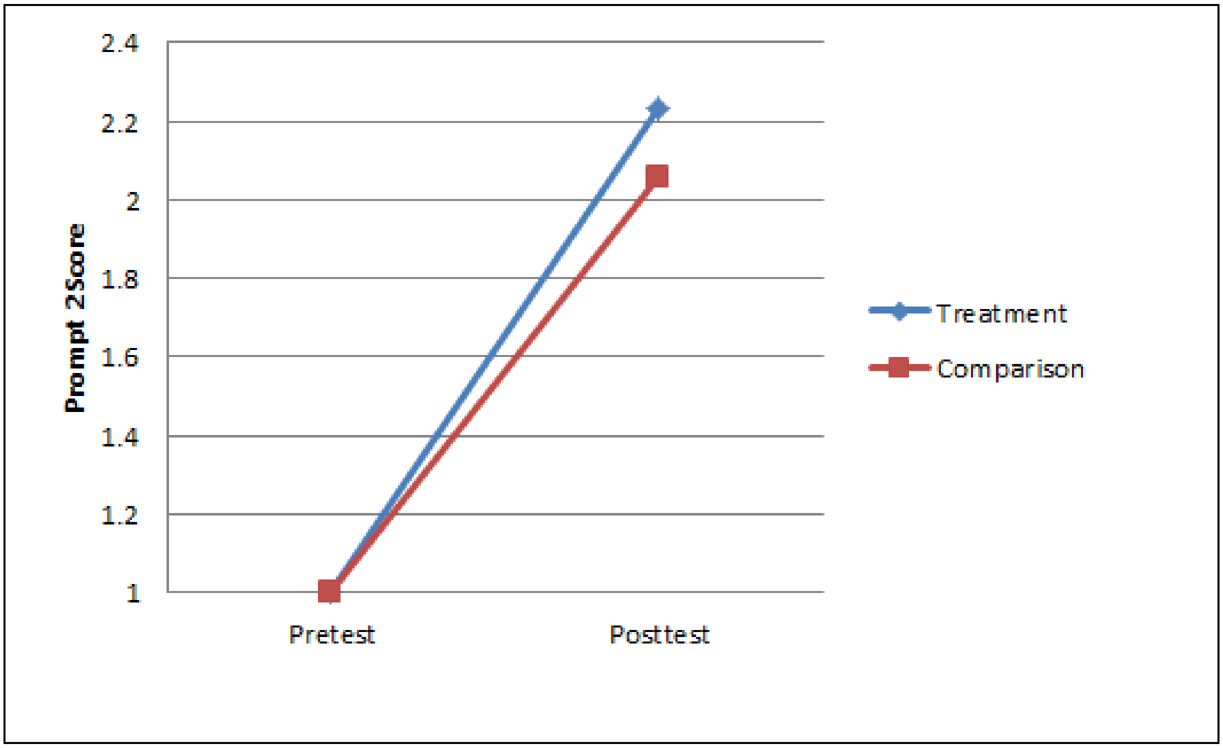


Figure 13. Change in students' content knowledge, based on modeling prompt 2 scores, for the treatment and control group.

Finally, the change in means (Table 19) and the follow up Wilcoxon Signed Rank tests show growth from pretest to posttest in the modeling scores for prompt 3 for both groups (Figure 14). For the treatment group, there was a significant difference from pretest to posttest (Z = -6.33, p < .001), representing a large effect size, r = 0.62. For the comparison group, there was a significant difference from pretest to posttest (Z = -5.92, p < .001), representing a large effect size, r = 0.60.

Table 19
Pre/Post Modeling Prompt 3 Scores for the Treatment and Comparison Groups

		Pretest 3		Posttest 3	
Group	N	M	SD	M	SD
Treatment	52	1.02	0.14	2.60	0.63
Comparison	48	1.00	0.00	2.25	0.64

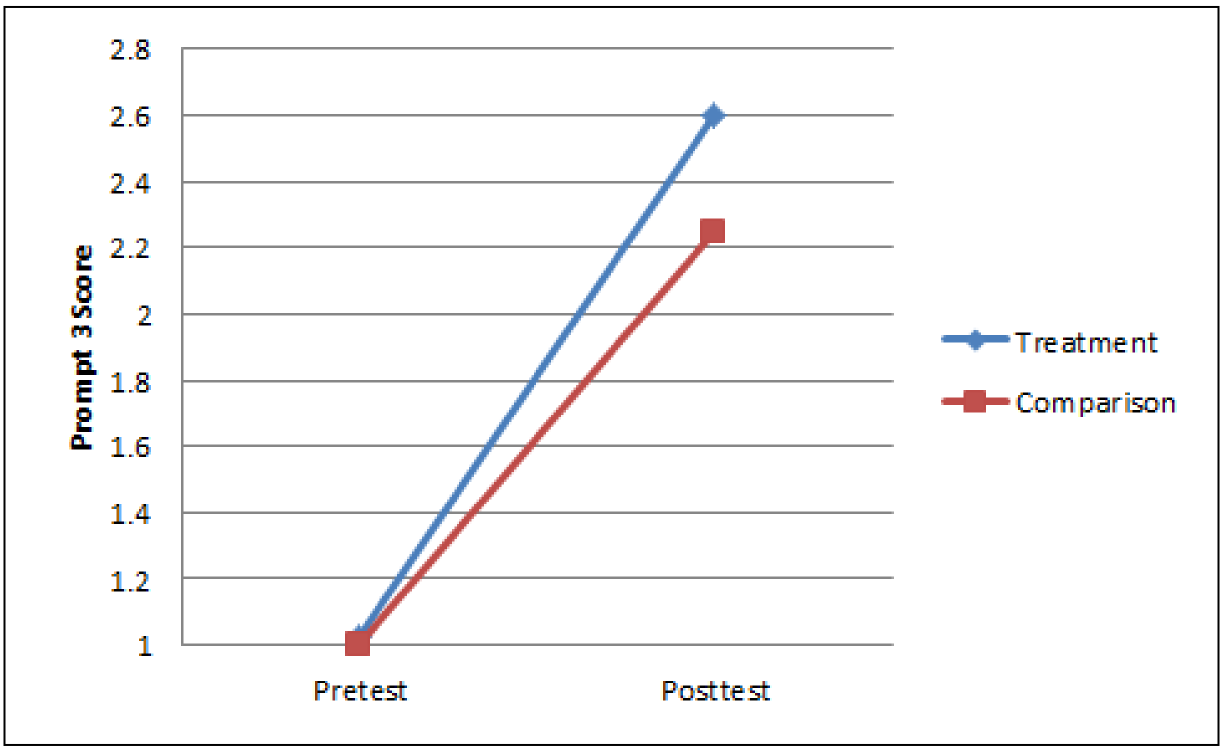


Figure 14. Change in students' content knowledge, based on modeling prompt 3 scores, for the treatment and control group.

Table 20
Summary Table of Tests Addressing Research Question 2

Test #	Test Used	Results	Follow-up Results (t-test/Wilcoxon test)
5	Kruskal-Wallis H test	AAAS scores: TG = CG	AAAS scores: TG post > TG pre ** CG post > CG pre **
6	Kruskal-Wallis H test	AAAS explicit scores: TG > CG * AAAS implicit scores: TG = CG	AAAS explicit scores: TG post > TG pre ** CG post > CG pre * AAAS implicit scores: TG post > TG pre ** CG post > CG pre *
7	Kruskal-Wallis H test	Prompt 1 = prompt 3 Prompt 3 > prompt 2 ** Prompt 1 > prompt 2 **	
8	Kruskal-Wallis H test	Prompt 1: TG > CG * Prompt 2: TG > CG * Prompt 3: TG > CG *	Prompt 1: TG post > TG pre ** CG post > CG pre ** Prompt 2: TG post > TG pre ** CG post > CG pre ** Prompt 3: TG post > TG pre ** CG post > CG pre **

Note. The character ">" represents a statistically significant difference between scores. The character "=" represents the absence of a statistically significant difference between scores.
* $p < .05$ ** $p < .001$

Chapter 5: Discussion

A discussion of the benefits of modeling instruction for students of different abilities, as well and the benefits of modeling instruction over regular instruction, is presented in this chapter. Educational implications, suggestions for future research, and limitations of the study follow the discussion of results.

Purpose of the Study Restated

The current study was designed to understand if modeling instruction can help students of different abilities learn science content. In order to explore this question, students of different abilities were included in the study, as well as students who received different types of instruction. The literature is full of studies that provide evidence for the effectiveness of modeling instruction for a variety of science concepts, such as seasons (Hsu, 2008), astronomy (Shen & Confrey, 2007), blood circulation (Lee & Kim, 2014), water cycle (Márquez, Izquierdo, & Espinet, 2006), global climate change (Visintainer & Linn, 2015), geology (Gobert & Pallant, 2004), smell (Wilkerson-Jerde, Gravel, & Macrander, 2014), genetics (Duncan, Freidenreich, Chinn, & Bausch, 2011), plant reproduction (Manz, 2012), and decomposition of matter (Ero-Tolliver, Lucas, & Schauble, 2013). Almost no literature, however, was found regarding the effectiveness of modeling instruction to promote science learning for students of different abilities. The current study addresses this gap in the literature.

Question 1: Impact of Modeling Instruction on Students at Different Levels

The first research question explored the impact that modeling instruction would have on the learning of phases of matter in students of different abilities. The findings from the dependent t-tests for the AAAS assessment, as well as the Wilcoxon Signed Rank tests for the modeling prompts, support the author's hypothesis that modeling instruction does help students of different abilities learn about phases of matter. All but one of the tests had a large effect size (the other being medium), so there is evidence that modeling instruction had a significant positive impact on student learning (Field, 2013). This finding is consistent with other findings in the literature for a variety of settings and participant groups, such as advanced students (Wilkerson-Jerde, Gravel, & Macrander, 2014), average classrooms (Acher, Arcà, & Sanmartí, 2007), and urban settings (Ero-Tolliver, Lucas, & Schauble, 2013). All of these studies, however, were conducted independently of one another. The current study investigated students at three identified levels of ability in the *same* intervention so that the additional analyses that follow (the comparison of the three groups) could take place.

Modeling theory proposes that modeling instruction is equitable; in other words, modeling instruction can help all students reach the level of "basic model" if they put in the effort. There are difficulties with the use of parametric and nonparametric testing to explore this idea, as the tests can only look for significant *differences* between groups, and the identification of what a level of basic model might be on the AAAS assessment would be difficult to determine as well. The results of the AAAS tests and examination of the graphs can, however, give us an idea of the differences (or lack thereof) between the three groups. Thus, the lack of significant differences between groups in the current study will not be interpreted as the groups being "the same," but may be interpreted as the groups being "similar" (Russell, 2001).

An examination of the results of the initial ANOVA on the three groups' AAAS change scores and the resulting graphs show that there was a significant difference between the accelerated group and the co-taught group, but there were no significant differences between the accelerated and regular class or the co-taught and regular class. We may conclude, then, that modeling instruction produced change scores that were similar between most groups of students, with the exception being the accelerated and co-taught students. One possible explanation for this finding is that the students' reading skills, such as decoding or making inferences, influenced their test scores on the AAAS test. Placement in accelerated science is determined by their reading and math scores from the previous year, so students in this class have high levels of reading (above grade level). Alternatively, many students in the co-taught class read below grade level and are part of resource reading classes. Allen (2014) investigated the relationship between reading ability and scores on a biology standardized test and found a strong positive relationship between the two. Education Testing Service also noted that, on state testing, some students are given a read-aloud accommodation to assess actual proficiency rather than another variable (e.g., reading level) (Stone & Cook, 2009). It is possible that students with special needs (SPED an ELL) struggled with the AAAS assessment because they either could not (a) decode some of the questions and/or answer choices or (b) make inferences from the target model to answer the implicit items on the test. If reading abilities do indeed influence the scores on content-level test scores, then this might account for the difference between the accelerated and co-taught students.

The results of the MANOVA revealed that there were significant differences between the explicit and implicit change scores based on the type of class. There was a significant difference found between the implicit scores of the accelerated and co-taught classes, but no significant difference between the accelerated and regular classes and the co-taught and regular classes. This result is consistent with the findings from the overall AAAS previously discussed. These findings, which were the result of content not explicitly taught in class, show that students in the co-taught class may not have been able to make the same connections (transfer their learning) as the regular and accelerated classes. Another possible explanation, as previously mentioned, is that the students' reading abilities might have also influenced these scores. The questions from the implicit category required students to make inferences from what they were taught (the target model) to arrive at the correct answer. For example, students would have to infer from the target model that the molecules of water transitioning from a liquid to a gas are also becoming connected “more strongly” (as the distance between the particles is reduced) in order to answer a particular question correctly. Making inferences from text is an important reading skill (Kellard, 2015), so it is possible that a deficit in this skill prevented students in the co-taught class from performing at a level consistent with the other two groups. Considering this, we might conclude that the ability to make inferences was a more important factor in the co-taught students’ AAAS scores than the ability to decode.

The results for the explicit scores (from the content taught explicitly in class) had an interesting finding. There was a significant difference found between accelerated and *regular* classes, but no significant difference between the co-taught and regular classes and the co-taught and accelerated classes. These findings suggest that something other than reading level might be influencing the explicit scores, such as the nature of the explicit instruction. The explicit scores are the result of testing of material explicitly taught in class, such as the spacing of molecules in the three phases of matter. In the case of students in the co-taught class, the modeling instruction might have provided certain affordances that might have assisted them in keeping pace with the accelerated group. For example, English Language Learners likely benefitted from (a) multiple opportunities to speak with peers in their groups as they generated group models (Eghigan, 2010), (b) explicitly learning new vocabulary through multiple representations, such as drawing models and speaking (Medina-Jerez, Clark, Medina, & Ramirez-Marin, 2007), and (c) engaging in visual literacy through the sharing of group models (Herr, 2008), during the modeling instruction sessions. Likewise, special education students likely benefitted from activity-oriented, constructivist learning (Haskell, 2000) and an inquiry-based, hands-on approach to their learning (Scruggs, Mastropieri, & Brigham, 1993) as they used, drew, and modified their models throughout the intervention. These affordances may have "leveled the playing field," helping to offset other potential deficits (e.g., reading ability) for the co-taught students. If this is the case, that would mean that another factor, such as level of engagement in the modeling sessions, may have played a part in the differences in scores. For example, if students in the regular class were less attentive during the group model sharing, it is possible that they would have missed information useful for evaluating their personal model. The current study did not collect evidence related to engagement, but as a result of these findings it might be a useful line on research to explore in the future.

The Kruskal-Wallis H test on the modeling prompt data from the treatment classes found that the scores for modeling prompt 2 were significantly lower than the other two prompts (large effect). All three prompts directly relate to the target model, but the concepts are not necessarily the same. For prompts 1 and 3, students must understand what happens when thermal energy is *added* to a pure substance. In contrast, students must understand what happens to a substance when thermal energy is *removed* in prompt 2. It is possible that students don't struggle with the former concept because they have observed it in real life (Varelas, Pappas, & Rife, 2006), such as melting an ice cube in their hand or boiling water in preparation of cooking food and watching the bubbles "disappear" into the air. On the other hand, students might have little experience observing water drops form "out of thin air" on the side of a can by staring at it for several minutes. Costu, Ayas, and Niaz (2012) stated that there are many misconceptions, as well as ontological and epistemological challenges for middle grade learners, related to condensation. Some misconceptions that students might hold include (a) water droplets came from inside the can/container (Ewings & Mills, 1994), (b) coldness from the container creates the drops (Osborne & Cosgrove, 1983), and (c) condensation occurs when air changes into a liquid (Lee, Eichinger, Anderson, Berkheimer, & Blakeslee, 1993). According to Costu, Ayas, and Niaz (2012), students need to (a) realize the abstract idea that water is in the air at all times and (b) switch between macroscopic and microscopic levels in order to understand condensation. Another study found that a majority of non-science majors at the collegiate level held misunderstandings of condensation (Chang, 1999), so it appears that condensation misconceptions can persist throughout K-12 education.

The struggles that all students experience with the concept of condensation is evident in the initial Kruskal-Wallis H test results, however, students in all three classes still experienced gains in their scores for modeling prompt 2. There was no significant difference between the mean rank scores of the three groups, so we can conclude that students in the treatment group performed similarly on modeling prompt 2 as a result of the modeling instruction. There were, however, some instances of significant findings between the three groups on modeling prompts 1 and 3, which yielded medium effect sizes. For prompt 1, the accelerated class had significantly greater scores than both the co-taught and regular classes. For prompt 3, the accelerated class once again had significantly greater scores than the regular group, but not the co-taught group. There was no statistically significant difference between the scores for the co-taught and regular classes for both prompts 1 and 3. One factor that may explain these findings is that the students in the accelerated class were more actively engaged in the modeling instruction sessions than the other two classes. Another factor may relate to the explanation given earlier regarding the AAAS explicit scores. All of the content for the three modeling prompts was taught explicitly during the intervention. If students in the co-taught class were more engaged in the other modeling session activities (e.g., the drawing of the group model, listening to others' ideas) compared to the regular class, then an increase in modeling scores as well as AAAS scores might result. Increased engagement in the modeling process might help prepare students to respond to more advanced modeling scenarios such as prompt 3. Prompt 1 could be considered a simpler task because it asks students to explain a change from a solid to a liquid (both visible), while prompt 3 could be considered more difficult (abstract) because it asks students to explain a change from a solid (or liquid) to a gas (one visible, one invisible) (Costu, Ayas, & Niaz, 2012).

One thing that should be highlighted from these findings is that there were no significant differences between the regular and co-taught classes on any of the measures. This suggests that modeling instruction is equitable for regular and special needs populations. There were also instances where there were no significant differences between the accelerated class and the regular and co-taught classes, but these findings were inconsistent. Overall, there is some evidence that modeling instruction is equitable, but additional factors (e.g., engagement, ability to make inferences) need to be investigated to gain a clearer picture of modeling instruction's impact on student's learning of the phases of matter.

Question 2: Impact of Modeling Instruction in Contrast to Regular Instruction

The second research question compared the impact of modeling instruction and regular instruction on the learning of phases of matter in sixth grade students. Results from the initial Kruskal-Wallis H test revealed that there was not a significant difference between the AAAS scores of the treatment group and control group, even though the gains were greater for the treatment group. The follow-up Wilcoxon Signed Rank tests found that both treatment and comparison group's AAAS scores improved significantly from pretest to posttest, although the treatment group had a large effect size and the comparison group had a medium effect size.

Two additional Kruskal-Wallis H tests were conducted on the explicit and implicit change scores of the treatment and comparison groups to determine if the type of questions (implicit vs. explicit) were a factor in the students' overall understanding of the phases of matter, as measured by the initial Kruskal-Wallis H test. The second Kruskal-Wallis H test found that the treatment group's explicit scores were significantly larger than the comparison group's scores (medium effect size). The third Kruskal-Wallis H test, however, found that there was not a significant difference between the two groups. From these two tests, we can conclude that modeling instruction improves phases of matter content knowledge that is explicitly taught significantly more than regular instruction. We can also conclude that there is no significant difference between the treatment and comparison groups for phases of matter content that is taught implicitly. Follow-up Wilcoxon Signed Rank tests found that students in both groups performed significantly better on the posttest than on the pretest for the explicit and implicit questions. There was a large effect size for the treatment group (explicit) data, and a medium effect size for the comparison group (explicit), treatment group (implicit), and comparison group (implicit) data.

The AAAS test included all 28 questions (both explicit and implicit), and while the initial Kruskal-Wallis finding was not expected (no difference between the two groups), it was also not a surprise. This finding was not surprising because there are examples in the science education literature of concepts that need to be taught explicitly, such as the nature of science (Abd-el-Khalick & Lederman, 2000). The finding was not expected because, in their particulate nature of matter study involving sixth students, Bamberger and Davis (2013) found that students were able to transfer their learning of a smell model to a "near content" model of evaporation. The author of this paper hypothesized that students would be able to experience a similar transfer of learning, using the target model (explicit content) to make inferences regarding the intermolecular bonds (implicit content) between the molecules of water. Unfortunately, this type of transfer might not be the same type of transfer that Bamberger and Davis (2013) tested. According to the authors, the use of the smell model to create an evaporation model was an example of "transfer-in-situation" because the two situations are related. In the current study, using the target model (molecule spacing and speed) to understand intermolecular bonding could be considered "transfer-in-situation" because one could infer from the target model that molecules of water are "bound" together as a solid and move "freely" as a gas. The results of the previous tests, however, suggest that this scenario might instead be a case of "transfer-between-situations." In Chapter Three, the author explained that intermolecular bonding is a concept that is typically taught at the high school level, so it is possible that middle school students would have a difficult time transferring their knowledge to a concept that is abstract to them. If this is indeed the case, then we should not expect middle school students to be able to transfer their knowledge of the target model (explicit learning) to the concept of intermolecular bonding (implicit learning). In summary, we can conclude that if one wants students to be able to transfer their learning "between-situations," explicit instruction should be utilized.

The Kruskal-Wallis H test on the modeling prompt data for the treatment and comparison groups found that the scores for modeling prompt 2 were significantly lower than the other two prompts (medium effect). These results are consistent with the finding from the treatment group's modeling test. Next, the author hypothesized that the treatment group would perform better than the comparison group on the modeling assessments, and the results of the three Kruskal-Wallis H tests supported this hypothesis. The treatment group had significantly higher scores on all three modeling prompts compared to the comparison group. There were medium effect sizes for prompts 1 and 3 and a small effect size for prompt 2. Follow-up Wilcoxon Signed Rank tests found that both groups showed significant improvements from pretest to posttest on all three modeling prompts (all had large effect sizes).

There are several reasons why modeling instruction might promote scientific understandings of the phases of matter more than regular instruction. First, modeling is an iterative process, where students continuously examine their current understandings (model), evaluate their thinking in light of new evidence, and revise their models (Halloun, 2004; Gilbert & Justi, 2016; Clement & Rea-Ramirez, 2008). In the current study, students generated an initial model during the first week of the intervention that was based on their prior knowledge and beginning activities (e.g., Xod activity). The following weeks, students evaluated and revised their models after gathering evidence of molecule arrangement, thermal energy's role, and molecule movement. The comparison group learned the same content, but they did not have the opportunity to build and revise models (only study existing models), thus they had little opportunity to build on their current understandings.

Second, the modeling instruction had elements of argumentation that aided students in improving their models. During the modeling instruction, students had to create and justify their models in small groups as they drew their models on the whiteboard, as well as when they had to share their models with the class. The students were able to see all group models at the same time during the whole class discussions, which allowed then to analyze the consistency of the models. Finally, students were able to discuss the usefulness and limitations of the different group models as they prepared to draw their own individual models. These elements of argumentation were also present in the Mendonça & Justi's (2013) study previously reviewed.

The students in the comparison group did not have the opportunity to engage in argumentation, as they completed individual work instead of the modeling sessions.

Third, the modeling sessions allowed the students to learn in an *interactive* way rather than just an *active* way (Chi & Wylie, 2014). Students in the treatment group used, created, and revised models in small groups throughout the intervention. For example, they (a) used two simulations to understand the movement of molecules in a solid, liquid, and gas state, (b) created models of the three states using marbles and playdoh, and (c) revised their individual models at the end of each modeling session. During the modeling sessions, students had opportunities to interact with one another; they shared ideas as they constructed their group models. This is the key aspect of modeling instruction that the comparison group did not get in the regular instruction. The regular instruction is active, however, because the students manipulated models (e.g., PhET simulation: States of Matter) that focused their attention on the content (e.g., the movement of molecules in different states of matter) (Chi & Wylie, 2014).

Educational Implications

The results of this study provide evidence that modeling instruction has potential benefits for the learning of science content. The participants were all sixth grade students, but they had different levels of ability. In spite of these differences, students of all three levels made significant gains in their understandings of the phases of matter. As a result, these findings might transfer to upper (high school) and lower (elementary) levels of education. This is consistent with the body of literature showing the effectiveness of modeling instruction at different levels of education (see Chapter 2, Section 1). In addition to possibly helping students at different grade levels learn the content, modeling instruction might help students of all levels make similar gains in their learning of some grade-level content (e.g., condensation). While there were still some differences observed between the accelerated class and the regular and co-taught classes, there were no differences observed between the regular and co-taught classes. This finding might be of special interest to policy makers who are seeking ways to promote "science-for-all."

A second implication from this study is that the phases of matter should be taught explicitly through modeling instruction. Bamberger and Davis (2013) found that modeling instruction could help students learn content implicitly, but they did not investigate this impact on students with special needs. The findings from the current study suggest that students with special needs (as well as students in the general population) would benefit from explicit modeling instruction. A third implication from these results is that efforts need to be taken to make levels of engagement in the modeling process more equitable. For example, during the modeling session whole-class discussions, there was not enough time for all students to share, and some students might have not paid as much attention during these times as others. In order to address these potential issues, the teacher might ask students to post pictures of their whiteboard models online and require that all students comment on three of the models. These two implications might be of particular interest to curriculum designers and teachers who wish to implement modeling instruction into their classrooms.

A final implication of these findings is that modeling instruction might be fairly simple to implement. Once a teacher identifies (or creates) a target model, they could organize activities related to the model along a learning pathway and insert periods of modeling generation, evaluation, and revision (modeling sessions) throughout the unit. Teachers could use preexisting activities in the learning pathway, so teachers would not have to create new lessons from scratch. The practical aspect of this version of modeling instruction, like the promotion of "science-for-all," might also interest policy makers.

Suggestions for Further Research

The current study adds to the literature on the benefits of modeling instruction by providing evidence of how modeling promotes the advancement of scientific understandings. One suggestion for future research is to examine the role that student engagement plays in the modeling process. Halloun (2004) states that modeling instruction can help all students reach the level of basic model *if they put in the* effort, so it might be helpful to investigate if student engagement levels vary depending on the type of activity they are doing, such as the group model-building, the whole class sharing, and the individual model generation. The identification of activities where students are not engaged could help curriculum developers improve modeling instruction. A second suggestion is to study other areas of science content to identify where modeling instruction promotes equity. The identification of areas where equitable instruction is not evident could narrow the focus of research on those areas where there are large gaps between students of different abilities at the same grade level.

A third suggestion involves the exploration of equitable instruction through modeling at the elementary and high school levels. This might be more important at the elementary level because if modeling instruction could help all students grow as a similar pace through the first few years of school, then there might be less of an achievement gap between students as they enter middle and high school. A final suggestion is to develop and test different methods of teaching the concept of condensation. This might involve the development of interventions, the enhancement of learning progressions, and the further study of knowledge transference for this content (Barnett & Ceci, 2002).

Limitations

There are several limitations of this study which need to be addressed. First, there was no way for the researcher to randomly assign students to treatment and comparison groups. From a practical standpoint, however, using complete, existing classes was more authentic and applicable to the real-world education scenarios. Second, the varying roles (e.g., arbiter, moderator) that the teacher played throughout the intervention may have been a limitation. Each modeling session was unique, and it is possible that the teacher was not consistent with the roles they took on during each session. Third, the school population may have been a limitation in this study. A majority of students at the school qualify for free and reduced lunch, so the findings may not be generalizable to student populations that have a different socioeconomic status. Fourth, the generalizability of the results was impacted by the fact that the author is a teacher at the school where the intervention took place (convenience sampling).

Appendix A: Phases of Matter Assessment

1. In which state of matter are the molecules spaced farthest apart?
   A. A gas
   B. A liquid
   C. A solid
   D. All are equal.

2. When a substance changes from a liquid to a solid, which of the following is TRUE?
   A. The molecules of the substance get heavier.
   B. The molecules of the substance change shape.
   C. The molecules of the substance change from soft to hard.
   D. The molecules of the substance connect more strongly to one another.

3. When water boils, bubbles rise to the surface of the water. What are the bubbles made of?
   A. Air molecules
   B. Heat molecules
   C. Water molecules
   D. Oxygen molecules

4. A container of water was closed and kept at a constant temperature. Which of the following statements about the motion of the water molecules is TRUE?
   A. The water molecules stopped moving.
   B. The average speed of the water molecules stayed the same.
   C. The average speed of the water molecules increased a little bit.
   D. The average speed of the water molecules decreased a little bit.

5. Why is ice harder than liquid water?
   A. The molecules of ice are not moving.
   B. The molecules of ice are linked more tightly together.
   C. The molecules of ice are harder than the molecules of liquid water.
   D. The molecules of ice are made of solid atoms, and the molecules of liquid water are made of liquid atoms.

6. A piece of solid wax is placed in a pan and heated on a stove. After a while, the solid wax becomes a liquid. Which one of the following explains why the wax becomes a liquid?
   A. Some of the wax molecules get smaller.
   B. Some of the wax molecules are destroyed.
   C. The wax molecules change into water molecules.
   D. The wax molecules are more loosely connected to each other.

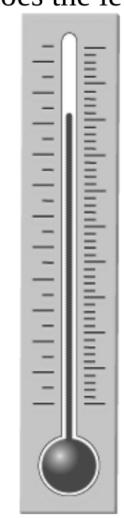
7. You spill a little water on a tile floor but don't have time to wipe it up. A few hours later, most of the water is gone. What happened to the water?

A. The water molecules were destroyed.
B. The water molecules got smaller and now take up less space.
C. The water molecules became a gas and are now part of the air.
D. The water molecules broke down into hydrogen and oxygen atoms, which are now in the air.

8. What happens when a cup of water is warmed?

A. The water molecules break down.
B. The number of water molecules increases.
C. The mass of the water molecules decreases.
D. The distance between the water molecules increases.

9. A glass thermometer has a colored liquid inside it. The level of colored liquid rises when the thermometer is placed in hot water. Why does the level of liquid rise?

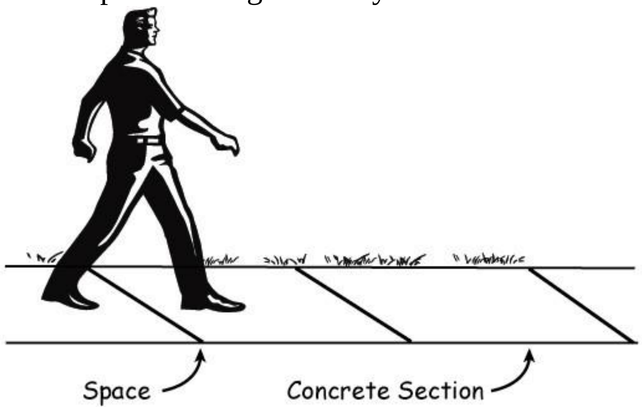


A. Water molecules are pushed into the thermometer.
B. Heat molecules push the molecules of the liquid upward.
C. Heat causes the molecules of the liquid to get farther apart.
D. The molecules of the liquid break down into atoms and take up more space.

10. An artist heats a solid iron rod and bends it into a new shape. The iron cools down when the artist is finished. What happens to the iron atoms as the solid iron rod cools?

A. The iron atoms move more quickly.
B. The iron atoms slow down and stop moving.
C. The iron atoms slow down but do not stop.
D. The speed of the iron atoms does not change.

11. Most sidewalks are made out of solid concrete sections. There are spaces between the sections. What happens to the spaces during a hot day in the summer and why?



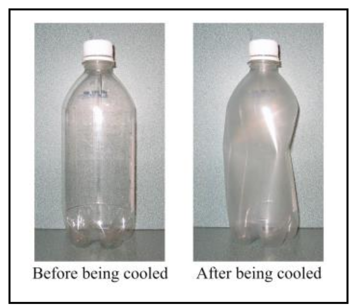
A. The spaces get wider because the concrete sections shrink.
B. The spaces get narrower because the concrete sections expand.
C. The spaces stay the same because the concrete sections does not shrink or expand.
D. Some spaces get wider, some spaces get narrower, and some spaces stay the same because each concrete section behaves differently on a hot summer day.

12. A liquid is stirred so that the speed of its molecules increases. What happens to the temperature of the liquid?

A. The temperature increases.
B. The temperature decreases.
C. The temperature stays the same.
D. It is not possible to say anything about the temperature without more information.

13. You drink all of the water from a plastic bottle. You put the cap on the bottle and tighten it. Then you put the bottle in the refrigerator. An hour later, you notice that the bottle is dented. Why is the bottle dented after being cooled in the refrigerator?

A. All the molecules of air went out of the bottle.
B. Heat molecules inside the bottle were destroyed.
C. The molecules of air inside the bottle broke down.
D. The molecules of air inside the bottle got closer together.



14. A cook places an iron frying pan on the stove. What happens as the iron pan heats up?

A. The number of iron atoms increases, so the pan gets a tiny bit larger.
B. The number of iron atoms does not change, so the pan remains the same.
C. The distance between the iron atoms increases, so the pan gets a tiny bit larger.
D. The distance between the iron atoms does not change, so the pan remains the same.

15. A balloon full of air is placed on a chair. Which of the following statements about the atoms and molecules of the chair and the atoms and molecules of the air in the balloon is TRUE?

A. The atoms and molecules of both the chair and the air in the balloon are moving.
B. The atoms and molecules of both the chair and the air in the balloon are not moving.
C. The atoms and molecules of the chair are not moving, and the atoms and molecules of the air in the balloon are moving.
D. The atoms and molecules of the chair are moving, and the atoms and molecules of the air in the balloon are not moving.

16. There is a solid wooden table with a cup of water sitting on it. Which of the following statements about the atoms and molecules of the table and the atoms and molecules of the water is TRUE?

A. The atoms and molecules of both the liquid water and the table are moving.
B. The atoms and molecules of both the liquid water and the table are not moving.
C. The atoms and molecules of the liquid water are not moving, and the atoms and molecules of the table are moving.
D. The atoms and molecules of the liquid water are moving, and the atoms and molecules of the table are not moving.

17. In a cup of liquid water, when would the water molecules stop moving?

A. The molecules would stop moving if the liquid water in the cup became a solid.
B. The molecules would stop moving if the liquid water in the cup became a gas.
C. The molecules would stop moving if the liquid water in the cup became still.
D. The molecules would not stop moving in the cup of liquid water.

18. In which state of matter is the connection between the molecules the strongest?

A. A gas
B. A liquid
C. A solid
D. All are equal.

19. Which statement describes the molecules of a gas?

A. The molecules are soft.
B. The molecules do not move.
C. The molecules are far apart from one another.
D. The molecules are often in contact with one another.

20. Why does liquid water take the shape of a cup it is poured into, but solid ice cubes do not?

A. Because the molecules of liquid water are softer than the molecules of solid ice
B. Because the molecules of liquid water are smaller than the molecules of solid ice
C. Because the molecules of liquid water are moving but the molecules of solid ice are not
D. Because the molecules of liquid water can easily move past one another but the molecules of solid ice cannot

21. What happens as liquid water boils?

A. The molecules are destroyed.
B. The mass of the molecules decreases.
C. The molecules become separated from each other.
D. The molecules break down into hydrogen and oxygen atoms.

22. You wash a pair of jeans. You hang the wet jeans on a clothesline. A few hours later, the jeans are dry. What happened to the water molecules?

A. The water molecules became part of the jeans.
B. The water molecules disappeared and no longer exist.
C. The water molecules moved faster and became part of the air.
D. The water molecules broke down into hydrogen and oxygen atoms.

23. The windows of your school are made of glass. Which of the following statements describes the motion of the molecules that make up the glass?

A. The molecules of the glass are never moving.
B. The molecules of the glass are always moving.
C. The molecules of the glass move only when the sun warms the window.
D. The molecules of the glass move only when the window is being opened or closed.

24. Which of the following describes what happens as a substance changes state?

A. The type of molecules of the substance changes.
B. The mass of the molecules of the substance changes.
C. The shape of the molecules of the substance changes.
D. The connection between molecules of the substance changes.

25. Why can gases be compressed more easily than solids?

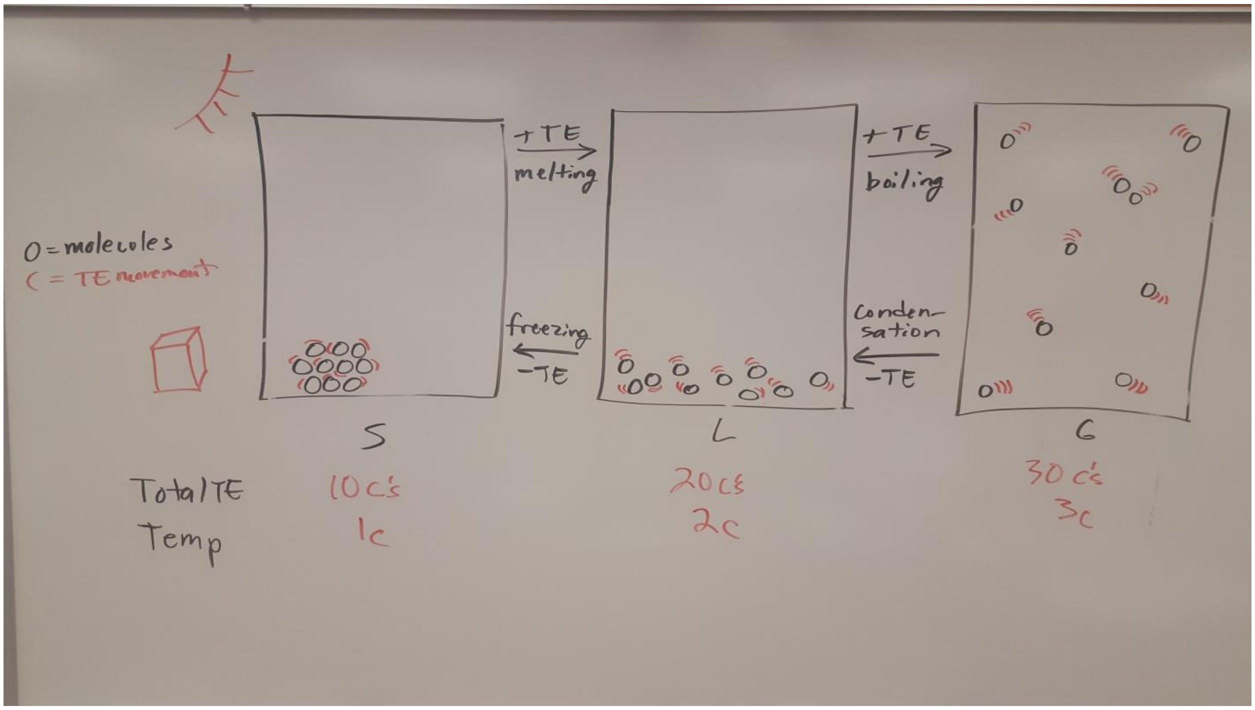
A. Because the molecules of gases are softer than the molecules of solids
B. Because the molecules of gases weigh less than the molecules of solids
C. Because the molecules of gases move faster than the molecules of solids
D. Because the molecules of gases are farther apart than the molecules of solids

26. Which statement describes the location of the molecules of a gas in a sealed container?

A. The molecules are packed closely throughout the container.
B. The molecules are spread far apart throughout the container.
C. Almost all of the molecules are at the top of the container.
D. Almost all of the molecules are at the bottom of the container.

27. Why does liquid candle wax flow but solid candle wax does not?
    A. Because the molecules of liquid candle wax are softer than the molecules of solid candle wax
    B. Because the molecules of liquid candle wax weigh less than the molecules of solid candle wax
    C. Because the molecules of liquid candle wax are moving but the molecules of solid candle wax are not
    D. Because the molecules of liquid candle wax can easily move past one another but the molecules of solid candle wax cannot
28. How do the molecules of hot air differ from the molecules of cold air?
    A. The molecules of hot air are farther apart than the molecules of cold air.
    B. The molecules of hot air have less mass than the molecules of cold air.
    C. The molecules of hot air have more heat molecules mixed with them.
    D. The molecules of hot air are smaller than the molecules of cold air.

Appendix B: Target Model



Appendix C: Modeling Prompt

Student Code: ______________________________________

Complete the following below. You may use additional paper if needed.

1. Draw and use a model (picture) to explain how ice changes when it is left in the sun. Be sure to include:
    a. at least **one** drawing (Box 1)
    b. labels for your drawing(s) (Box 1)
    c. an explanation of your model (Box 2)

Draw and label your model here.

Write your explanation here.
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2. Draw and use a model (picture) to explain how water drops form on the side of a can of cold soda on a hot day. Be sure to include:

- a. at least **one** drawing (Box 1)
- b. labels for your drawing(s) (Box 1)
- c. an explanation of your model (Box 2)

Draw and label your model here.

Write your explanation here.
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3. Draw and use a model (picture) to explain how you can smell melting chocolate on the stove in the kitchen when you are in another room of the house. Be sure to include:

a. at least **one** drawing (Box 1)
b. labels for your drawing(s) (Box 1)
c. an explanation of your model (Box 2)

Draw and label your model here.

Write your explanation here.

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Appendix D: Modeling Rubric

Modeling Level	Description
4 **(particulate view - *scientific*)**	Model illustrates all of level 3 and: 1. change in phases at certain temperatures. 2. latent heat (temperature stable during changes).
3 **(particulate view - *basic*)** **The level of "basic model"**	Model illustrates: 1. a particulate view for all three states of matter. 2. the particles do not change during phase transitions (size/shape/number are similar).. 3. appropriate distribution (spacing), location, and speed of particles (shows change). 4. the addition or removal of thermal energy correctly (e.g., sun, fire, +/- TE). 5. the correct phase change.
2 **(mixed view)**	Model illustrates: 1. a particulate view for at least one of the states of matter. 2. the particles change during phase transitions (size/shape/number are not similar). 3. inappropriate distribution (spacing), location, or speed of particles. 4. the addition or removal of thermal energy incorrectly. 5. an incorrect phase change.
1 **(continuous view)**	Model illustrates: 1. a continuous view for all three states of matter. 2. matter is changed during phase transitions or phases are different matter altogether. 3. the addition or removal of thermal energy is missing. 4. no phase change present.

Note: This rubric was developed using Chiu and Wu's (2013) work on developing a learning progression for phase transitions.

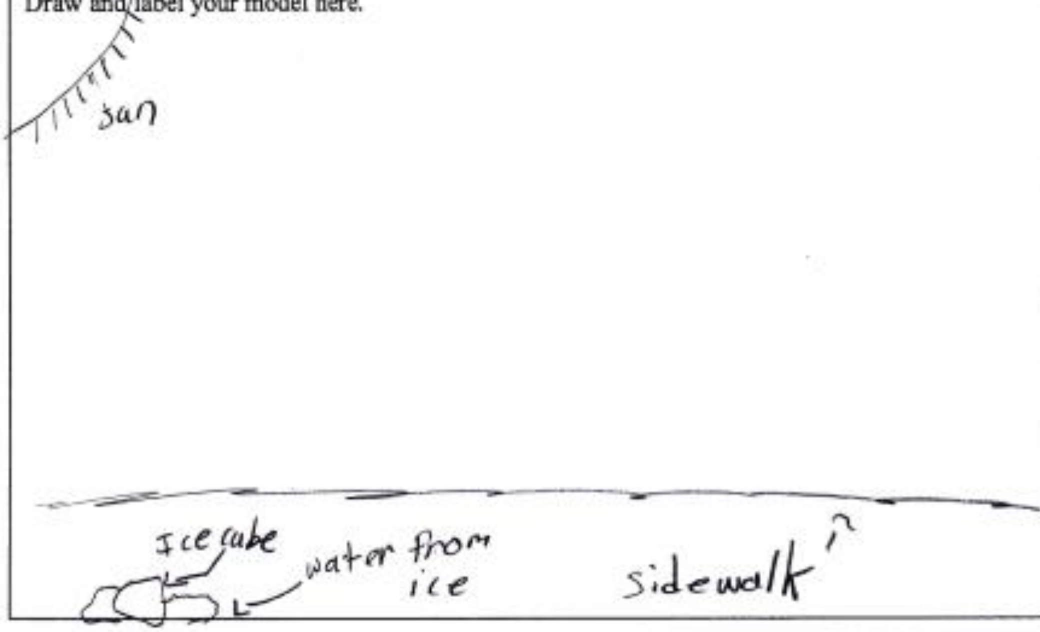
Appendix E: Example of Level 1 (Prompt 1)

Student Code: 111

Complete the following below. You may use additional paper if needed.

1. Draw and use a model (picture) to explain how ice changes when it is left in the sun. Be sure to include:
   a. at least **one** drawing (Box 1)
   b. labels for your drawing(s) (Box 1)
   c. an explanation of your model (Box 2)

Draw and label your model here.



Write your explanation here.

the Sun causes raidation so the radiation heats up the ice cube, so then the ice cube tunes to a liquid. then the Radiation from the san will make the water evaporate so the water and ice cube would no longer be thair.

Appendix F: Example of Level 1 (Prompt 2)

2. Draw and use a model (picture) to explain how water drops form on the side of a can of cold soda on a hot day. Be sure to include:
   a. at least **one** drawing (Box 1)
   b. labels for your drawing(s) (Box 1)
   c. an explanation of your model (Box 2)

Draw and label your model here.

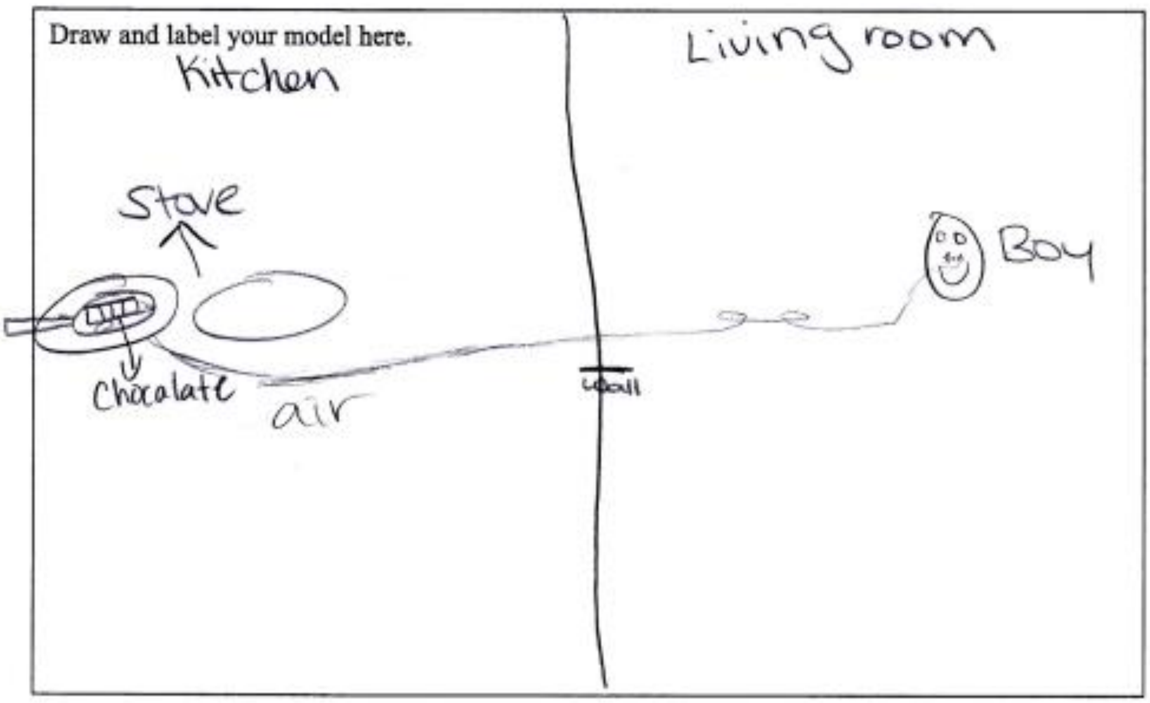
Write your explanation here.

The sun is heating up the can but the can was cold so the cold water around it is melting.

Appendix G: Example of Level 1 (Prompt 3)

3. Draw and use a model (picture) to explain how you can smell melting chocolate on the stove in the kitchen when you are in another room of the house. Be sure to include:

   a. at least **one** drawing (Box 1)
   b. labels for your drawing(s) (Box 1)
   c. an explanation of your model (Box 2)



Write your explanation here.
the choclate is letting of smell into the air wich is going throuqh the house and when the Boy breaths in he smells it.

Appendix H: Example of Level 2 (Prompt 1)

Complete the following below. You may use additional paper if needed.

1. Draw and use a model (picture) to explain how ice changes when it is left in the sun. Be sure to include:
   a. at least **one** drawing (Box 1)
   b. labels for your drawing(s) (Box 1)
   c. an explanation of your model (Box 2)

Draw and label your model here.

Write your explanation here.

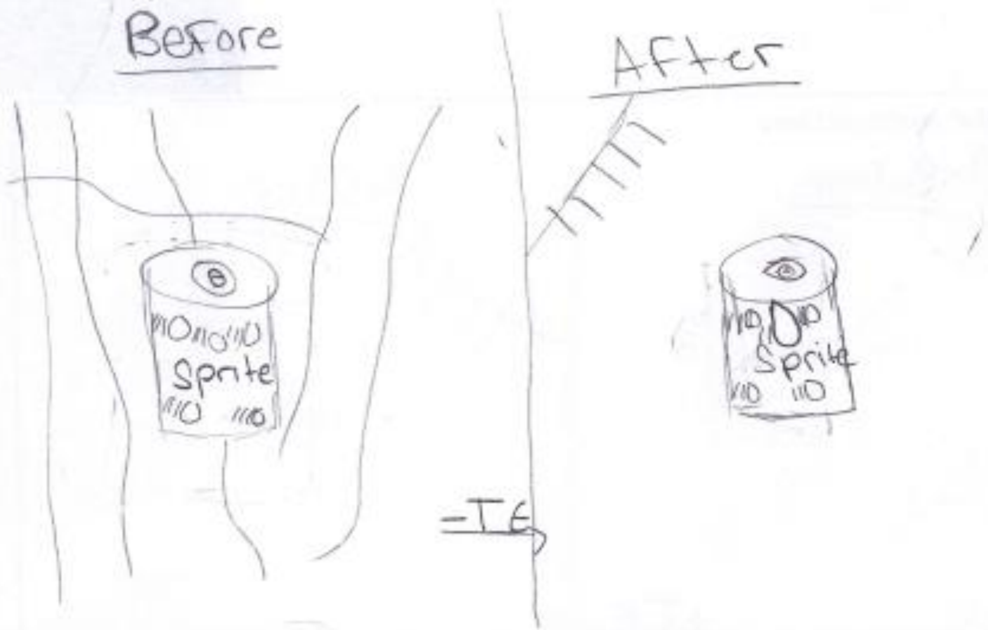
So inthe before it is a solid because it is in the Freezer So it is a solid since it hasnt melted, and the mole.cules are toghter them. In the After it is in the sun and so it is melting. Also inthe Before there are 3 C's and in the after there are 2 C's.

Appendix I: Example of Level 2 (Prompt 2)

2. Draw and use a model (picture) to explain how water drops form on the side of a can of cold soda on a hot day. Be sure to include:

a. at least **one** drawing (Box 1)
b. labels for your drawing(s) (Box 1)
c. an explanation of your model (Box 2)

Draw and label your model here.



Write your explanation here.

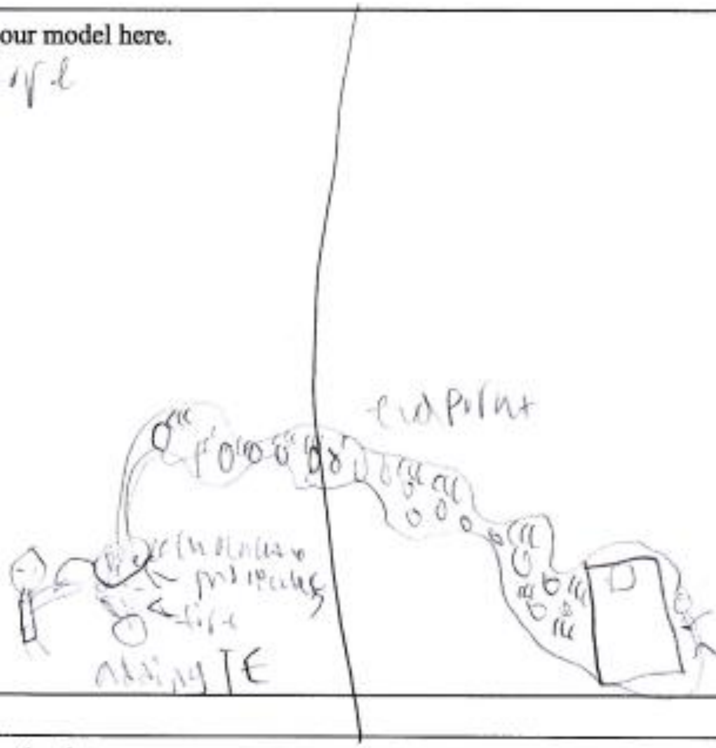
Before the sprite used to be a gas, but what happend was it had formed a big raindrop from the gas. The Soda started to melt from the sun to because if you have a soda out side it starts to form raindrops.

Appendix J: Example of Level 2 (Prompt 3)

3. Draw and use a model (picture) to explain how you can smell melting chocolate on the stove in the kitchen when you are in another room of the house. Be sure to include:

   a. at least **one** drawing (Box 1)
   b. labels for your drawing(s) (Box 1)
   c. an explanation of your model (Box 2)

Draw and label your model here.



Write your explanation here.

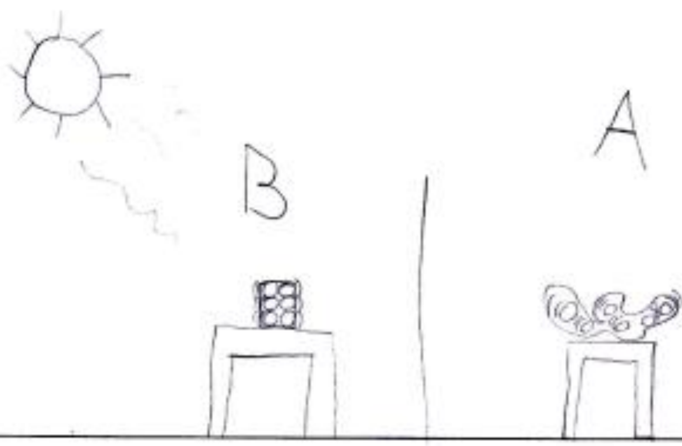
The way we could smell the chocolate is because the chocolate is a solid now but it is being heated so it is getting more energy and and turns into a gas and now you can smell it

Appendix K: Example of Level 3 (Prompt 1)

Complete the following below. You may use additional paper if needed.

1. Draw and use a model (picture) to explain how ice changes when it is left in the sun. Be sure to include:
   a. at least **one** drawing (Box 1)
   b. labels for your drawing(s) (Box 1)
   c. an explanation of your model (Box 2)

Draw and label your model here.



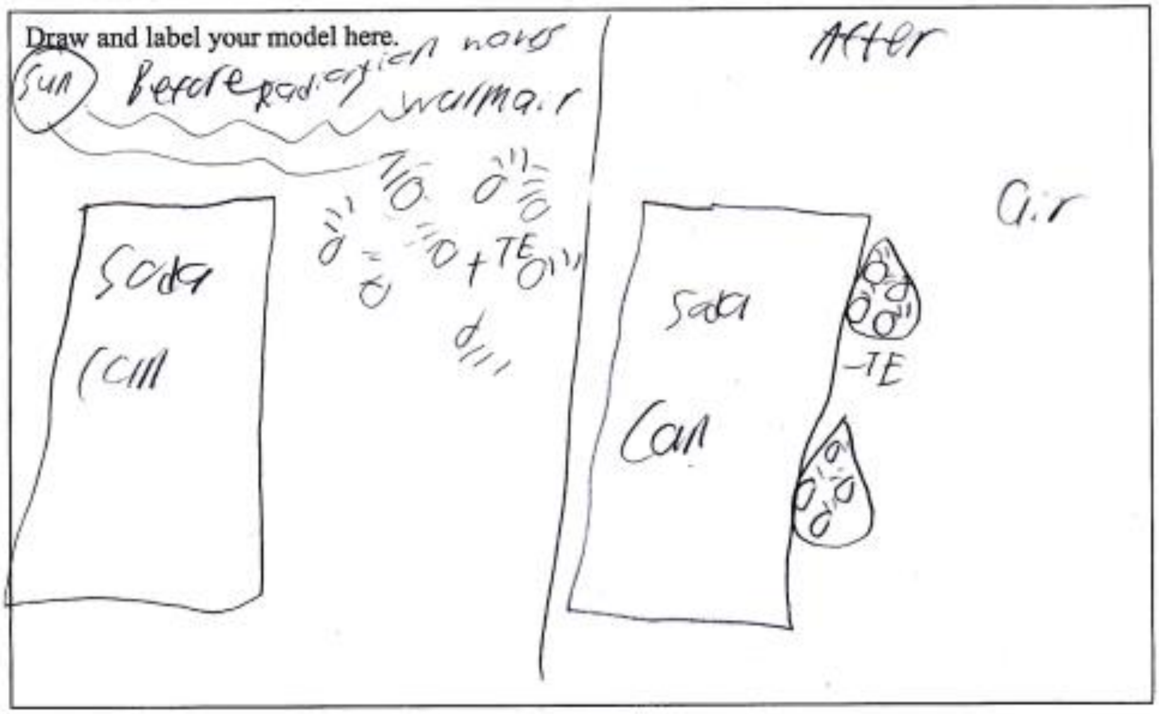
Write your explanation here.

The ice cube is getting energy from the sun so the ice cube melts and becomes a liquid.

Appendix L: Example of Level 3 (Prompt 2)

2. Draw and use a model (picture) to explain how water drops form on the side of a can of cold soda on a hot day. Be sure to include:

   a. at least **one** drawing (Box 1)
   b. labels for your drawing(s) (Box 1)
   c. an explanation of your model (Box 2)



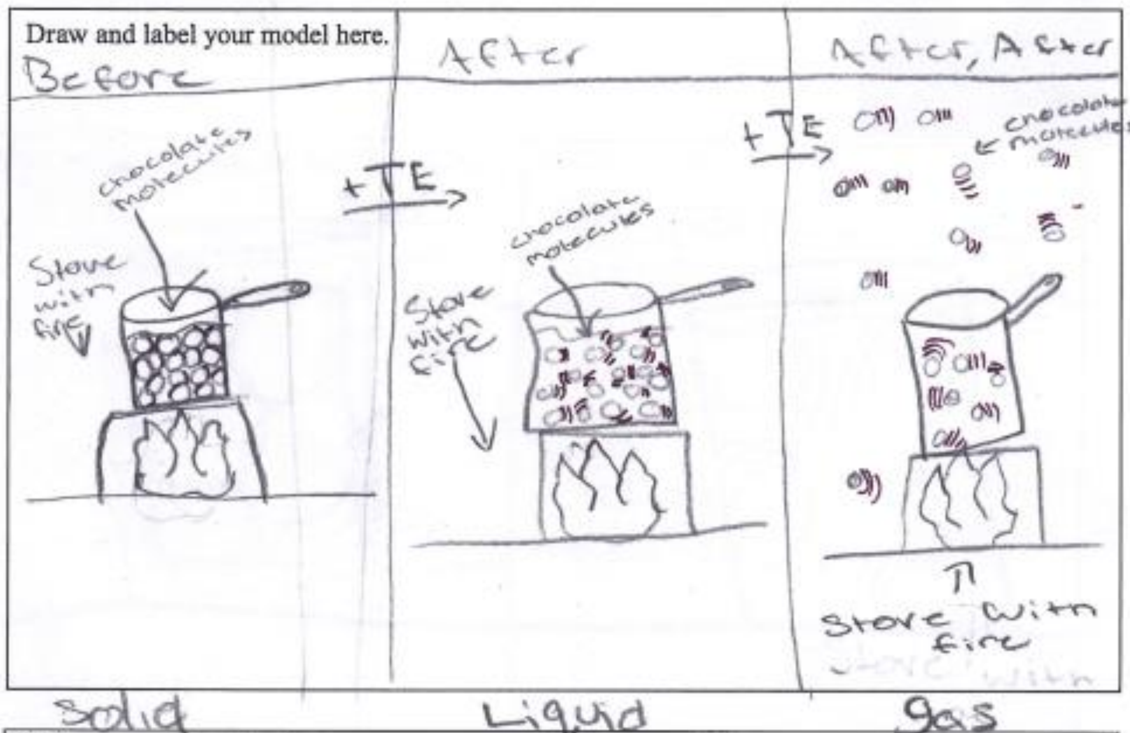
Write your explanation here.

On a hot day the sun heats up the air molecules and they bounce around everywhere. When they touch the cold can they converse on it and form water droplets.

Appendix M: Example of Level 3 (Prompt 3)

3. Draw and use a model (picture) to explain how you can smell melting chocolate on the stove in the kitchen when you are in another room of the house. Be sure to include:

a. at least **one** drawing (Box 1)
b. labels for your drawing(s) (Box 1)
c. an explanation of your model (Box 2)



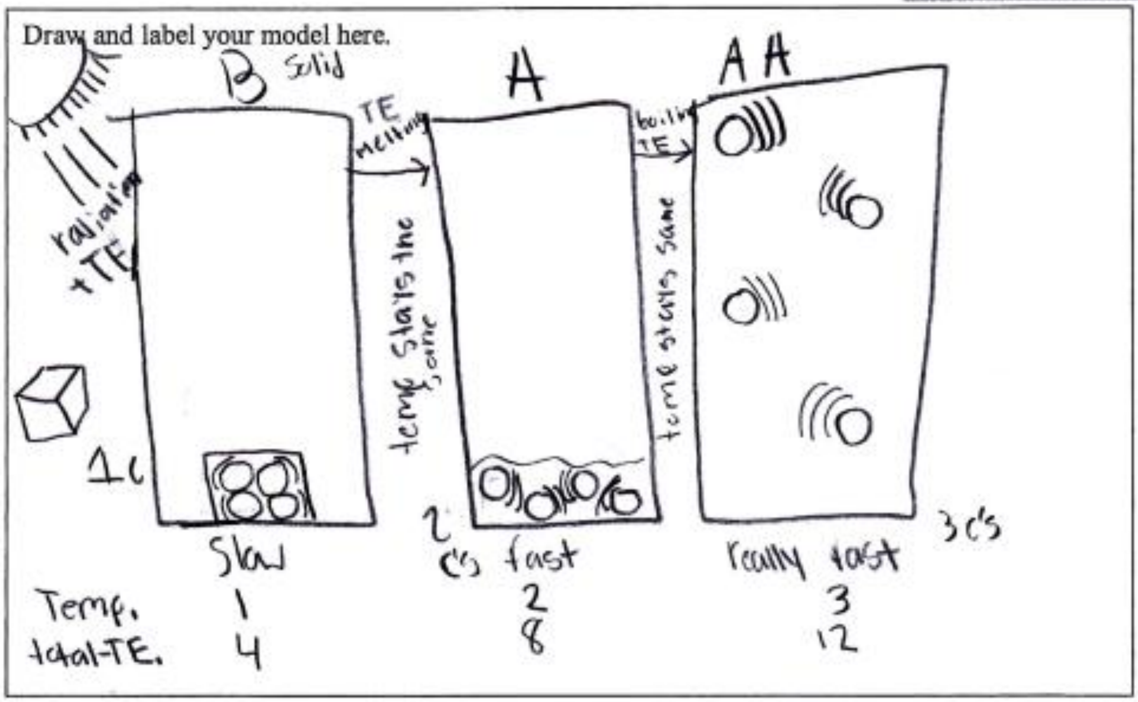
Write your explanation here.

The reason you can Smell Chocolate that is being heated up, in another room, is because [redacted] the fire from a stove Sends thermal energy to the Chocolate and over time the molecules in the Chocolate move So fast that they become a gas. Once the molecules become a gas they move throughout the house.

Appendix N: Example of Level 4 (Prompt 1)

Complete the following below. You may use additional paper if needed.

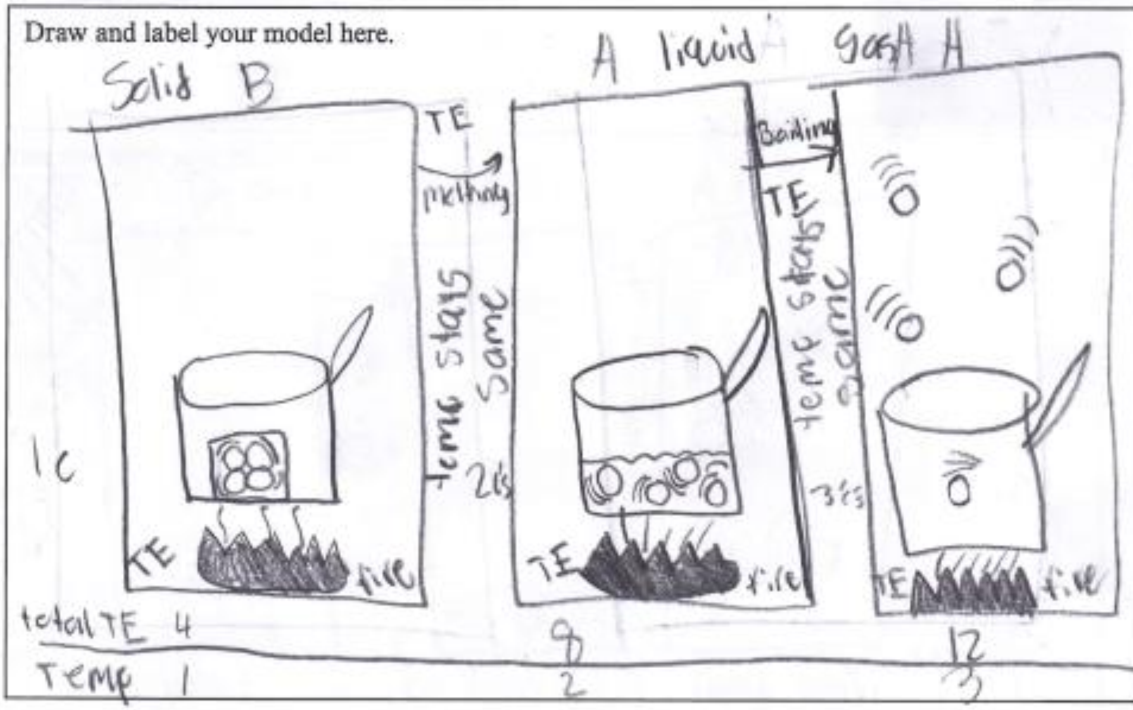
1. Draw and use a model (picture) to explain how ice changes when it is left in the sun. Be sure to include:
    a. at least **one** drawing (Box 1)
    b. labels for your drawing(s) (Box 1)
    c. an explanation of your model (Box 2)



Write your explanation here.

As the ice absorbs the thermal energy, molecules have more energy and start to vibrate slowly. Therefore it only has one "C", and the total Thermal energy is 4 because it has 4 c's and the average temp is 1. As the ice is melting the temperature stays the same, but when it's all melted then the temperature goes up and the molecules move faster with 2 c's. Now the temperature is 2 and the total Thermal energy is 8. Again the temperature stops until it's gas and the temperatures starts to go up again and the molecules move faster with 3 c's. With the thermal energy it has gone from boiling to gas. The temperature is 3 and the

Appendix O: Example of Level 4 (Prompt 3)



Write your explanation here.

As the Chocolate molecuse are a solid they only have 1c of energy from the fire so the average temperature is 1 and the total thermal energy is 4.50 as more thermal energy is added the temperature stays the same until is is all melted then it starts to rise. The total thermal energy is 8 and the temperature is 2. Finally the temp stops and starts when it boiling so the temp is now rising which is causing them to have more thermal energy with 3 c's each. As more and more energy is being added the molecuse are now a gas. The reason why you can smell it in a different room is because eventually the molecules will be equally spread apart throwout the whole house.

Appendix P: Student Journal

Science Notebook Unit 1 - Journal 3
Name:

INSTRUCTIONS: Follow the prompts, which are in color, and respond in the white sections. Each section matches a part of your online lesson. Write in complete sentences and include details from the lesson or text as much as possible. Example answer prompts have been provided for you.

Day 14: IN List things you think ARE matter and NOT matter.
• Matter: • NOT Matter: • My rule:
Day 14: What do you think your objects look like inside? Insert your pictures below.
•
Day 14: OUT How might the insides of the 5 objects be similar? Different?
• Similar: • Different:
Day 15: IN If you broke down one of your 5 objects into its tiniest pieces, what would the pieces be like (appearance, size, other characteristics)?
•
Day 15: What do the pieces of your objects look like? Insert your pictures below.
•
Day 15: OUT Re-do the IN question from the last lesson using your new experiences.
• Matter:

- NOT Matter:

- My rule:

Day 16: IN
Do you think air is matter? Why or why not?

-

Day 16: What is Matter?
Matter….

1. Is made of… molecules
2. Takes up… space (has volume)
3. Has… mass (weight)
4. Takes some… form (solid/liquid/gas)

Day 16: What about air?
What evidence can we find that air is matter too?

1.
2.
3.
4.

So, is air matter?

Day 16: OUT
How might the molecules of gases be similar and different to molecules in a solid?

- Similar:
- Different:

Day 17: IN
What do you think is a difference between a solid, a liquid, and a gas? Give a characteristic of each.

- Solid:
- Liquid:
- Gas:

Day 17: Explanations

- A nail is a solid and water is a liquid. Explain to Xod the difference between the two phases.

- What would you say about salt (is it a solid or liquid)? Explain.

- Gases are easily compressed; liquids are not. Why is a sponge not a gas/why can it be easily compressed? Explain.

- How do you know there is a gas in the “empty” test tube (what evidence can you find)?

Day 17: OUT
How has your thinking from the IN question changed (solid/liquid/gas)?

- Solid:
- Liquid:
- Gas:

Day 18:
Do one of the following:
1. Insert an image of your initial model (**M4a**) of the 3 states of matter below.
2. Write a summary of what you learned about the states of matter below.

-

Day 19: IN
How might the molecules in a solid, a liquid, and a gas be **different** from each other?.

- Solid:
- Liquid:
- Gas:

Day 19: Observations
Record your observations below.

- Balloon with ROCK:
    - What might the molecules be like?
- Balloon with WATER:
    - What might the molecules be like?
- Balloon with AIR:
    - What might the molecules be like?
- Ice:
- Water:
- Steam:
- In what way are the molecules of ice, water, and steam the same? Different?
    - Same: type (water), size
    - Different: how far they are spread, how tight/loose they are

Day 19: OUT
Answer the IN question again, using your new experiences.

- Solid:

• Liquid: • Gas:
Day 20: IN Remember the ice melting activity from Day 19. How would you describe the difference in the **molecules** of ice, water, and steam as we heated it?
•
Day 20: Models Insert an image of the models (playdoh) below.
• Solid: • Liquid: • Gas:
Day 20: Explanation After doing the student-molecule class model, describe the molecules in a solid, a liquid, and a gas.
• Solid: • Liquid: • Gas:
Day 20: OUT How did the models (marbles/playdoh/group) help you understand the molecules of solids, liquids, and gases better?
•
Day 21: Do one of the following: 1. Insert an image of your revised model (**M4b**) of the 3 states of matter below. 2. Write a summary of what you learned about the states of matter below.
•
Day 22: IN Is It Melting? List some examples of "melting." Explain your thinking (a "rule" for melting).
• Examples: • Rule:
Day 22: Observations How does each block feel in your hand?
• Plastic: • Aluminum:

Day 22: Prediction Which block will melt the ice the fastest? Why?
•
Day 22: Data Which block actually melted the ice the fastest?
•
Day 22: Argument Why do you think you got the results you did?
• **Claim**: I claim the… block melted the ice the fastest. • **Evidence**: The evidence I have that it melted the fastest was… • **Reasoning**: The scientific reason why the ice melted the fastest on this block was… • Insert an image of your model below.
Day 22: OUT Use the argument above to explain why the plastic and aluminum blocks felt the way they did.
•
Day 23: IN How do you think thermal energy affects the motion of water molecules?
•
Day 23: Prediction What do you think will happen if we put one drop of food coloring in a beaker of hot, warm, and cold water? Why do you think the food coloring will act that way?
•
Day 23: Observations Describe what you saw in Beaker A, B, and C.
• Beaker A (hot): • Beaker B (room temperature): • Beaker C (cold):
Day 23: OUT Create an Argument.
• **Claim**: I claim that there is (more) thermal energy in the (hot) water. • **Evidence**: The evidence from the beakers showed that… • **Reasoning**: The scientific reason why this happened is...

Day 24:
Do one of the following:

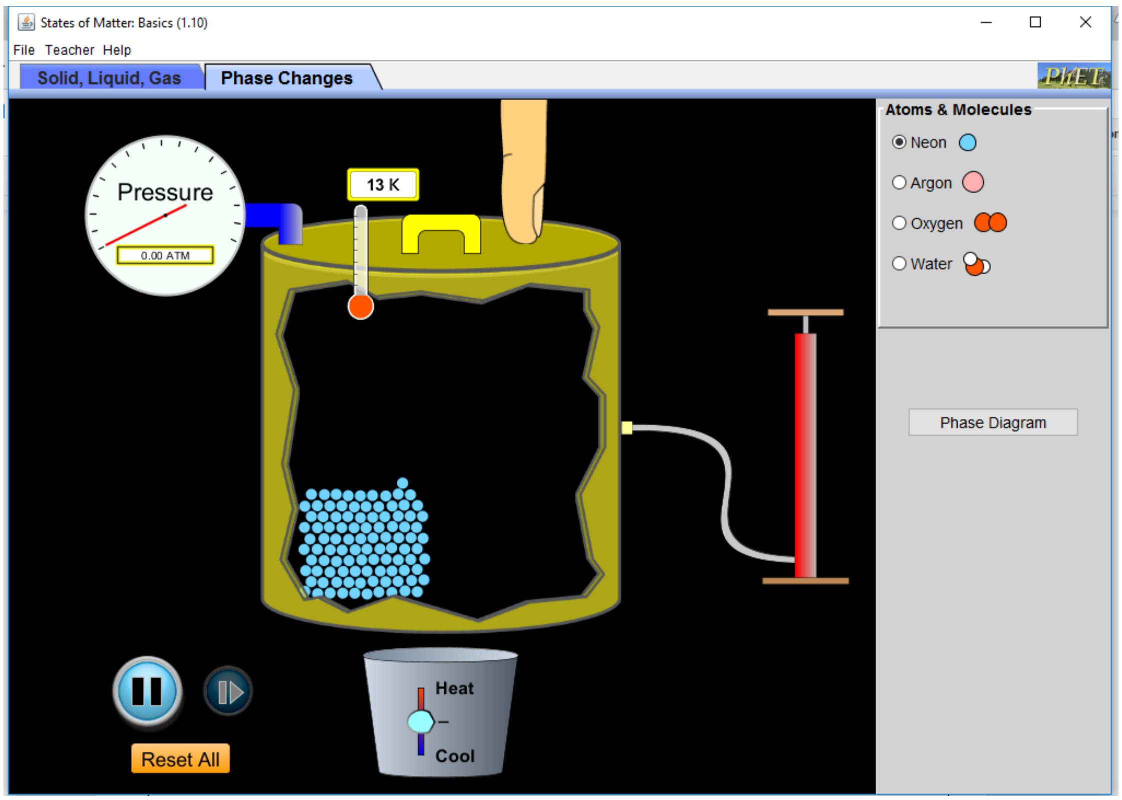
1. Insert an image of your revised model (**M4c**) of the 3 states of matter below.
2. Write a summary of what you learned about thermal energy below.

-

Day 25: IN
How do you think fire affects water molecules?

-

Day 25: Prediction
What do you think will happen to the volume, pressure, temperature, and motion of molecules as the finger presses down on the lid?

- 

- Volume:
- Pressure:
- Temperature:
- Motion of molecules:

Day 25: Analysis

- At approximately what temperature did the substance appear to change to a:
  - Liquid:

- Gas:
- What did the molecules do as you added more heat?
- What did the molecules do as you increased the pressure?
- What did the molecules do as you decreased the space (volume)?
- Where did the molecules go when you heated the substance and it became less dense (more spread out)?
    - So, where would hot air or water go (up or down)?
    - And where would cold air or water go (up or down)?
- When you added ice ("cool"), where did the thermal energy (heat) go?
- Describe how the molecules behaved when the lid blew off (equilibrium).
- Try the same investigation with a different molecule. How were your results:
    - Similar:
    - Different:

Day 25: OUT
What did you observe in regards to volume, pressure, temperature, and motion of molecules as the finger pressed down on the lid?

- Volume:
- Pressure:
- Temperature:
- Motion of molecules:

Day 26: IN
What do you think the temperature of the full glass of water will be after the water (70^{o} & 30^{o}) is mixed?

-

Day 26: Prediction
What do you think will happen if you heat ice cubes for several minutes?

-

Day 26: Data
Insert your data here.

-

Day 26: Argument

- **Claim**: I claim that when water changes phases, the temperature…
- **Evidence**: The evidence from the graph showed that…
- **Reasoning**: This happened because…

Day 26: OUT

- What temperature did melting occur?

• What temperature did vaporization (boiling) occur? • What temperature might condensation occur? • What temperature might freezing occur?
Day 27: Do one of the following: 1. Insert an image of your revised model (**M4d**) of the 3 states of matter below. 2. Write a summary of what you learned about phase changes below.
•

Appendix Q: UNLV IRB Approval Notice

UNLV

UNLV Social/Behavioral IRB - Expedited Review
Approval Notice

DATE:	July 5, 2017
TO:	Hasan Deniz
FROM:	UNLV Social/Behavioral IRB
PROTOCOL TITLE:	[1028370-2] Exploring the Effectiveness of Model-Based Instruction to Improve Sixth Grade Students' Science Content Knowledge
SUBMISSION TYPE:	Revision
ACTION:	APPROVED
APPROVAL DATE:	July 3, 2017
EXPIRATION DATE:	July 2, 2018
REVIEW TYPE:	Expedited Review

Thank you for submission of Revision materials for this protocol. The UNLV Social/Behavioral IRB has APPROVED your submission. This approval is based on an appropriate risk/benefit ratio and a protocol design wherein the risks have been minimized. All research must be conducted in accordance with this approved submission.

PLEASE NOTE:
Upon approval, the research team is responsible for conducting the research as stated in the protocol most recently reviewed and approved by the IRB, which shall include using the most recently submitted Informed Consent/Assent forms and recruitment materials. The official versions of these forms are indicated by footer which contains approval and expiration dates. If your project involves paying research participants, it is recommended to contact Carisa Shaffer, ORI Program Coordinator at (702) 895-2794 to ensure compliance with subject payment policy.

Should there be *any* change to the protocol, it will be necessary to submit a **Modification Form** through ORI - Human Subjects. No changes may be made to the existing protocol until modifications have been approved.

ALL UNANTICIPATED PROBLEMS involving risk to subjects or others and SERIOUS and UNEXPECTED adverse events must be reported promptly to this office. Please use the appropriate reporting forms for this procedure. All FDA and sponsor reporting requirements should also be followed.

All NONCOMPLIANCE issues or COMPLAINTS regarding this protocol must be reported promptly to this office.

This protocol has been determined to be a Minimal Risk protocol. Based on the risks, this protocol requires continuing review by this committee on an annual basis. Submission of the **Continuing Review Request Form** must be received with sufficient time for review and continued approval before the expiration date of July 2, 2018.

If you have questions, please contact the Office of Research Integrity - Human Subjects at IRB@unlv.edu or call 702-895-2794. Please include your protocol title and IRBNet ID in all correspondence.

Office of Research Integrity - Human Subjects
4505 Maryland Parkway . Box 451047 . Las Vegas, Nevada 89154-1047

(702) 895-2794 . FAX: (702) 895-0805 . IRB@unlv.edu

Appendix R: CCSD IRB Approval Notice

ASSESSMENT, ACCOUNTABILITY, RESEARCH, AND SCHOOL IMPROVEMENT DIVISION

4212 Eucalyptus Avenue • LAS VEGAS, NV 89121 • (702) 799-1041 • FAX (702) 799-2855

CCSD
CLARK COUNTY
SCHOOL DISTRICT

August 21, 2017

Scot Ewen
5287 Via De Palma Drive
Las Vegas, Nevada 89146

Dear Scot:

The Research Review Committee of the Clark County School District has reviewed your request titled: *Exploring the Effectiveness of Model-Based Instruction to Improve Sixth Grade Students' Science Content Knowledge.* The committee is pleased to inform you that your proposal has been approved with the following provisos:

1. Participation is strictly and solely on a voluntary basis.
2. Provide letter of acceptance from any additional principals who agree to be involved with the study.
3. The project is approved to take place at Silvestri Junior High School.

This research protocol is approved for a period of one school year from the approval date. The expiration of this protocol is 6/30/2018. If the use of human subjects described in the referenced protocol will continue beyond the expiration date, you must provide a letter requesting an extension. The letter must indicate whether there will be any modifications to the original protocol. If there is any change to the protocol it will be necessary to request additional approval for such change(s) in writing to the Research Review Committee.

Please provide a copy of your research findings to this office upon completion. We look forward to the results. If you have any questions or require assistance please do not hesitate to contact this office at (702) 799-1041 Ext. 5269 or e-mail at kretzl@interact.ccsd.net.

Sincerely,

Kenneth Retzl
Coordinator III
Department of Accountability & Research
Chair, Research Review Committee

Main Office: 5100 WEST SAHARA AVENUE • LAS VEGAS, NEVADA 89146 • TELEPHONE (702) 799-CCSD (2273)

Appendix S: Facility Authorization Letter

Merry Sillitoe, Principal
Erik Skramstad, Asst. Principal

1055 Silverado Ranch Boulevard
Las Vegas, NV 89183

Charles Silvestri Jr. High School

Melissa Giannantonio, Dean
Gregory Jacobs, Dean

Phone: 702-799-2240
Fax: 702-799-2247
www.silvestrijhs.com

May 10, 2017

Office of Research Integrity - Human Subjects
University of Nevada, Las Vegas
4505 S. Maryland Parkway, Box 451047
Las Vegas, NV 89154-1047

Subject: Letter of Acknowledgement of a Research Project at a CCSD Facility

Dear ORI - Human Subjects:

This letter will acknowledge that I have reviewed a request by Scot Ewen and Dr. Hasan Deniz to conduct a research project entitled "Exploring the Effectiveness of Models-Based Instruction in Improving Sixth Grade Students' Science Content Knowledge" at Silvestri Junior High School.

When the research project has received approval from the UNLV Institutional Review Board and the Department of Research of the Clark County School District, and upon presentation of the approval letter to me by the approved researcher, as site administrator for Silvestri Junior High School, I agree to allow access for the approved research project.

If we have any concerns or need additional information, the project researcher will be contacted or we will contact the UNLV Office of Research Integrity - Human Subjects at 895-2794.

Sincerely,

Merry Sillitoe

Merry Sillitoe, Principal
Silvestri Junior High School

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Curriculum Vitae

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Education:

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Work Experience:

August 2011 – present
Teacher
Grade 6 science
Silvestri Junior High School
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August 2004 – August 2011
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August 1998 – June 2004
Teacher
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Lana'i High and Elementary School
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September 1995 – June 1998
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Awards and Honors:

Heart of Education Nominee (2016)
Silvestri Teacher of the Month (February 2013, September 2015, November 2017)
National Board Certification (NBPTS) – Early Adolescence Science (2010)
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Commencement Speaker, Lana'i High and Elementary School (2005, 2007)
Who's Who Among America's Teachers (05-06)
National Dean's List (1992, 1993)
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