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Explicitly Teaching Multiple Modes of Representation in Science Discourse: The Impact on Middle School Science Student Learning

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ABSTRACT

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The purpose of this study was to determine the effect of explicitly teaching multiple modes of representation (MMR) on middle school students' understanding of science content and their use of MMR on a science unit test. Participants in this quasi-experimental study were seventh- and eighth-grade students enrolled in science courses taught by three different middle school science teachers. Half of the students received explicit instruction in MMR in addition to their regular science instruction; the other half received only regular science instruction. Ordinary least squares multiple regression analysis was used to determine the relationship between gain scores on unit assessments, whether students received explicit MMR instruction, and demographic variables. Additionally, regression analysis was used to examine how receiving explicit instruction in MMR and demographic variables predicted student use of MMR on the final test. These analyses indicated that receiving explicit instruction in MMR did not influence students' gain scores or use of MMR on a final test. However, Latinos and females used MMR more often than Whites and males, respectively, on the final test, even though these two groups of students did not use MMR more often on the first test. This suggests that Latinos and females may be placed at a disadvantage when compared to some of their peers by the bias towards using words that is present in the U.S. school system. This study also highlights challenges in creating instruments that assess student learning in MMR and difficulties in interpreting multimodal responses. Implications for classroom teachers and educational researchers are also discussed.

Keywords: modes of representation, science, middle school, scientific literacy

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Chapter 1

Introduction

All communication is understood to employ a variety of ways of representing messages (Kress, 2010). These different ways, *modes*, can include things such as spoken words, written words, images, or diagrams (Jewitt, Kress, Ogborn, & Tsatsarelis, 2001; Kress, 2010). Each mode has affordances (strengths) and limitations (weaknesses), which dictate when a mode of representation is most apt to communicate messages (Kress, 2000, 2010). For example, when sending a message of warning to a person nearby, one would be inclined to use verbal speech rather than handwritten words because of the affordance of being able to quickly transmit the message across a distance.

The specialized ways of communicating in science, science discourse, require the use of multiple modes of representation (MMR) (Lemke, 1998c). This is because the ideas of science, which often deal with variation and degree, cannot be adequately expressed solely using the mode of written words (Lemke, 1998c). Instead, to communicate the ideas of science one must often use modes other than, or in addition to, words (e.g., graphs, mathematical symbols).

Because the overarching goal of contemporary science education in the United States is for all students to become scientifically literate by the time they complete their K-12 education (American Association for Advancement of Science [AAAS], 1989; National Research Council [NRC], 1996, 2012) students must be able to negotiate and create the various modes of representing ideas used in the discourse of science. According to the *National Science Education Standards* (NRC, 1996), a person who is scientifically literate understands the content of science and is able to participate in science discourse, or the “language of science” (Bisanz & Bisanz, 2004, p. 4). An understanding of the content of science includes a “knowledge of scientific concepts and processes” (NRC, 1996, p. 22); participation in science discourse requires an individual to negotiate and create representations in the various modes used by scientists (Lemke, 2004; Norris & Phillips, 2003). Thus, science educators have the responsibility to help students develop both aspects of scientific literacy (Hand, Prain, Lawrence, & Yore, 1999; NRC, 1996; Wellington & Osborne, 2001).

Science content is communicated and learned from representations that include a variety of modes. In order to make meaning, or learn, from these representations, students must know how each mode is used (Schonborn & Anderson, 2009). However, it has been suggested that teachers do not typically teach students how to negotiate and create these modes of representation (Lemke, 1998c). Instead, students are often left on their own to decipher the meanings of the representations they encounter in science classrooms. While some may be successful, others are not.

Recent studies suggest that students learn more when they are able to learn from MMR because the multiplicity of modes requires greater cognitive involvement (Ainsworth, 1999, 2006; Gunel, Hand, & Gunduz, 2006). These studies, conducted with high school and college students, found that students’ science content knowledge increased when they were taught using MMR and were required to create representations in multiple modes (Adadan, Irving, & Trundle, 2009; Hand, Gunel, & Ulu, 2009; Mayer, 1997, 2003; McDermott & Hand, 2010, 2012; Rosengrant, Van Heuvelen, & Etkina, 2005, 2006). These types of studies have not been conducted with younger students.

Research also suggests that because of the multimodal nature of the language of science, students may find it difficult to actively participate within the discourse unless they are prepared to negotiate and create representations in the variety of modes typically used in science (Airey & Linder, 2009). Additionally, in order to create multimodal representations as scientists do, students must learn how to *embed* different modes. Embedding involves using multiple modes to create a single representation, with each mode contributing to the overall meaning of the representation (Gunel et al., 2006; Hand et al., 2009; McDermott & Hand, 2010). For example, Bohr (1935) used written words *and* mathematical equations to explain the behavior of a particle passing through a slit—two modes to convey a single idea.

While scientists regularly embed modes of representation when communicating a science idea or concept, researchers have found that students often do not embed. For example, McDermott and Hand (2012) found that when students were asked to use more than one mode on a writing activity, students simply added another mode to their writing after the text was completed. The text and the other mode did not work together to signify a single, meaningful science idea or concept. Likewise, when college physics students were asked to respond to questions using as many modes of representation as possible, most responded using words only (Treagust, Kuo, Zadnik, Siddiqui, & Won, 2012). Thus, though scientists naturally embed MMR, it is clear that many students do not.

It is also notable that some researchers suggest that when teachers do not explicitly teach students how to negotiate and create the various ways science ideas are represented, teachers are favoring students whose culture most closely aligns with the culture of science and the culture found in the typical science classroom in the United

States (Kist, 2000; Kress, 2010). This is because Western cultures rely more on print modes than do other cultures (Kress, 2010). Often, this means placing students from minority cultures at a disadvantage. This is particularly troubling inasmuch as minority students continue to score significantly lower than their majority peers on national and international science achievement tests (Lutkus, Lauko, & Brockway, 2006; National Center for Education Statistics, 2003). This practice also fails to grant access to scientific literacy for *all* students, as suggested in national science reform documents (AAAS, 1989; NRC, 1996, 2012).

Statement of the Problem

The extant research suggests that all communication occurs in MMR, particularly the discourse of science (Kress, 2000, 2010; Lemke, 1998b). As part of becoming scientifically literate, which is the primary goal of science education (NRC, 1996), students need to be able to communicate about science ideas in the language of science. It follows, then, that students must become fluent in the modes of representation used in the discourse of science, such as diagrams, charts, and equations. However, it has been suggested that science teachers do not typically teach students how to negotiate and create the variety of modes of representation used in science (Lemke, 1998c). Rather, students are often left on their own to decipher the meanings of the representations they encounter. While some students may independently, or intuitively, become fluent in these modes, it is possible that many students never will, especially those from minority backgrounds (Gee, 2002; Kress, 2000, 2010).

It can be inferred from the current literature that explicitly teaching students how to negotiate and create in MMR will be beneficial for students' learning of science content and participation in science discourse (e.g., Gunel et al., 2006; Hand et al., 2009; Kozma & Russell, 2005; McDermott, 2009; McDermott & Hand, 2012). However, this body of research has primarily focused on learning with representations (e.g., Ainsworth, 1999, 2006; Schonborn & Anderson, 2009). Few studies have focused on how science learning occurs while focusing on the modes of representation (e.g., Hand et al., 2009; McDermott, 2009).

No studies have been found that examined younger students' (e.g., middle school students') science content learning related to representational use in science classrooms. Additionally, none of the studies found on students' representational use made an attempt to account for the ethnicity, gender, or socioeconomic status (SES) of the participants. In fact, many studies have relied on homogeneous groups of students in terms of ethnicity (e.g., Gunel et al., 2006), gender (e.g., Hand et al., 2009 ; McDermott, 2009), and SES (e.g., Adadan et al., 2009). This gap in the literature is especially critical because this indicates a dearth of research on how explicit instruction on the modes of representation used in science discourse specifically impacts populations of students typically underserved by science education, such as minority ethnicities, females, and those from low-SES backgrounds (see AAAS, 1989; NRC, 2012; Southerland, Smith, Sowell, & Kittleson, 2007).

Research Questions

This quasi-experimental study investigated the effect of explicit instruction of MMR on middle school students' understanding of science content and their use of multiple modes of representation. Because of the potential challenges that students face in successfully participating in this discourse, and the existing gaps in the extant research on the impact of instruction designed to support diverse populations of middle school students' ability to understand a variety of modes of representing science ideas, the following research questions were examined in this study:

1. How well does explicit instruction in MMR, as well as ethnicity, SES, and gender, predict student gain scores on unit assessments?
2. Controlling for embeddedness prior to the instructional unit, how well does explicit instruction in MMR, as well as ethnicity, SES, and gender, predict embeddedness on a final unit test?

Chapter 2

Review of Literature

The overarching purpose of this study was to determine the effect of explicit instruction of multiple modes of representation (MMR) on middle school students' understanding of science content and their use of multiple modes of representation. Based on previous research with high school and college students (e.g., McDermott & Hand, 2010), it was predicted that this explicit instruction about MMR would improve middle school students' science content knowledge and thus contribute to improving their participation within the discourse of science.

In order to ground this study within the existing literature, this literature review will first describe what has been learned through research on learning with multiple representations, including theoretical explanations for the observed challenges and benefits. This description will be followed by a review of multimodal communication, particularly in the discourse of science and the discourse of science classrooms. Next, scientific literacy for all will be presented as the goal of contemporary science education, and the potential benefits of teaching MMR for the promotion of scientific literacy will be discussed. Finally, this chapter will end by detailing the expected benefits of explicitly teaching MMR, as described in the extant literature.

A background of what is meant by *discourse*, as opposed to *Discourse*, is important here. According to Gee (2008) the term *discourse* (with a lowercase "d") refers to the specialized ways in which language is grouped together to create meaning. For example, there is a discourse specific to physicists. Within this discourse, people use words with very specific meanings that are sometimes different than the meanings used in other discourses. For example, to physicists, "work" refers to the energy used to move an object a distance, rather than a place of employment. Gee's (2008) notion of *Discourse* (with a capital "D") involves discourse, along with ways of being, thinking, believing, and doing. If one is to be a member of a Discourse, one must communicate as other members do (discourse) *and* must do, think, and act as they do. For example, though John may be able to use the discourse of physicists by using the specialized vocabulary of quantum mechanics, he would be immediately identified as being outside of the Discourse if he does not do basic research in physics or attend physics conferences. Those who are members of the physicist Discourse would recognize that John is not really a physicist. John does not belong in the group of physicists even if John can communicate as they do, because John does not also *act* as they do.

Because this study focused specifically on communicating as scientists do, rather than on students joining or proving membership in a group of professional scientists, this study will focus on the discourse of science (with a lowercase "d"). While students become involved in using the communicative tools and methods of scientists as they move toward scientific literacy in science courses, it is not necessary, nor realistic, for them to enter the Discourse of science at this stage of their lives.

Representations

It has been stated that the purpose of this paper is to determine the influence of explicitly teaching the use of multiple modes of representation (MMR) on middle school students' science content knowledge. In order to understand this purpose, a definition of *representation* and *mode of representation* are in order. Following these definitions, an outline of the research conducted on learning involving multiple representations will be provided.

For the purposes of this study, a *representation* is a sign or combination of signs that has meaning (Airey & Linder, 2009; Draper & Siebert, 2010; Kress, 2010). A letter can be a sign that could stand alone as a representation ("A" as the highest possible grade in school) or it can be a part of a representation ("a" as a part of the word "about"). Representations are created within *modes*, "organised [sic], regular, socially specific means of representation" (Jewitt et al., 2001, p. 5). Thus, a representation is made utilizing a mode or combination of modes.

A number of researchers (e.g., Ainsworth, 1999; Ainsworth, 2006; Mayer, 1997, 2003; Schonborn & Anderson, 2009) have looked at learning involving multiple representations, without distinguishing between the modes of representation utilized. In this research, it has been found that learning with multiple representations can bring with it challenges and benefits. Some of these challenges and benefits will be detailed below.

Challenges of learning with multiple representations. Learning with multiple representations can be challenging for students (Ainsworth, 1999, 2006). One of the many challenges is that students have a tendency to focus on the surface features of a representation rather than negotiating the deeper, conceptual meanings represented (Kozma, 2003; Schonborn & Anderson, 2009; Wu, Krajcik, & Soloway, 2001). This challenge is seen when a student notices that a graph with a negative slope looks like a hill rather than noticing that the value on the y-axis is decreasing.

Another challenge is that students find it difficult to identify shared meaning between representations, and instead, view each representation as separate and distinct in meaning (Ainsworth, 1999, 2006; van der Meij & de Jong, 2006; Wu et al., 2001). For example, a student is presented with the elemental symbol for helium from the periodic table and an atomic structure diagram of a helium atom (see Figure 1). In order to make sense of these two representations, the student must connect the features of each representation that indicate the number of protons in the atom (i.e., the atomic number on the periodic table and the number of protons shown in the atom).

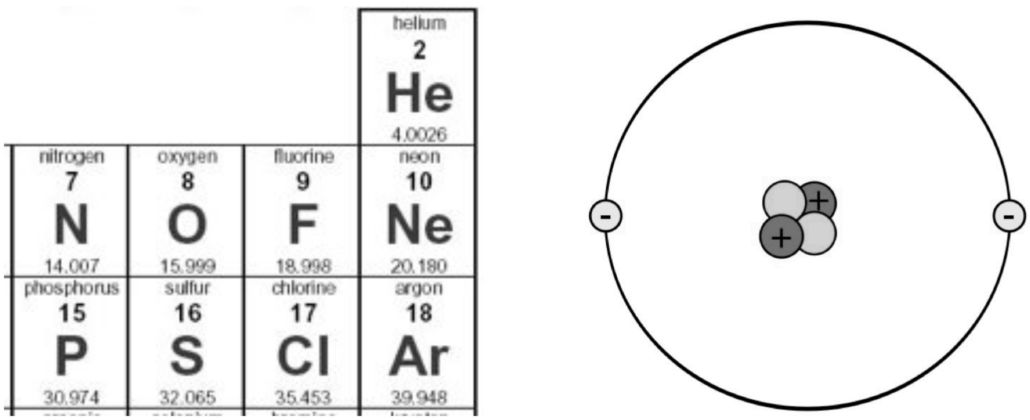

Figure 1. Representations of the element helium. On the left, the top right portion of the periodic table (Brewton-Parker College, 2010) showing helium (He) and, on the right, a diagram of a helium atom (Helmenstine, n.d.).

A third and related challenge is that students often struggle to identify meaningful differences between representations (Ainsworth, 2006). A meaningful difference that students may not notice between the representations shown in Figure 1 is that the number of protons in the diagram is the same as the atomic number, or that the valance (outermost) electron shell is shown to be filled with electrons in both representations (as indicated by helium's position on the periodic table and the two electrons in the valence shell). Students may also fail to notice a disparity: although helium's valence electron shell is full, it only has two electrons in it, as opposed to the eight electrons in the valence shells of the elements below helium on the periodic table.

Similarly, learning with multiple representations requires that students know how to negotiate each separate representation (van der Meij & de Jong, 2006). In order to negotiate the meanings of the representations of helium in Figure 1, a student needs to understand what is meant by the elemental symbol and its position on the periodic table. A student also must know what is being represented by the various circles and locations of the circles in order to understand the atomic structure diagram.

Lastly, students also struggle when learning from multiple representations because they do not understand the affordances and limitations of the representations being used (Schonborn & Anderson, 2009). For example, the elemental symbol of helium has the affordance of being very specific about certain features of helium (e.g., number of protons) while it has the limitation of not specifying the spatial relation of each component of the helium atom. The atomic diagram, on the other hand, affords one the ability to represent the position and number of each of the subatomic particles (i.e., proton, neutron, electron) while engendering the limitation of inaccurately depicting subatomic particles as circles.

Because of the complexity of understanding multiple representations, Schonborn and Anderson (2009) created a model for determining students' ability to understand representations. This model includes three related and interconnected factors: (a) the student's prior knowledge related to the represented meaning, (b) the student's cognitive abilities associated with negotiating the meaning of a representation, and (c) the representation's characteristics (e.g., color, spatial relationships of components, affordances and limitations). Each of these factors interacts and affects a student's ability to negotiate a representation's meaning.

Each of these challenges limits students' ability to learn science content from multiple representations, which in turn, limits their ability to become scientifically literate. While students' cognitive abilities and prior knowledge are outside of a teacher's control, their understanding of a representation (factor c above) may be influenced by explicit teaching. However, research suggests that many science teachers continue to leave students on their own to make sense of representations (Lemke, 1998c; Prain & Waldrip, 2006).

Benefits of learning with multiple representations. Though there are clearly challenges associated with learning with multiple representations, studies have also found there to be benefits connected to learning with multiple representations (Eilam & Poyas, 2008; Prain, 2006; van der Meij & de Jong, 2006; Wu et al., 2001). Two of these studies found that a computer program linking representations increased student learning(van der Meij & de Jong, 2006; Wu et al., 2001). In their study, Eilam and Poyas (2008) also found that undergraduates who had homework that included multiple representations did better on a posttest than those undergraduates whose homework included only printed text.

There are three primary explanations for the benefits of learning from multiple representations. The first of these explanations, offered by Ainsworth (1999), is that multiple representations serve the functions of complementing, constraining, and constructing. To *complement* each other, multiple representations add greater information than just one representation would have alone (e.g., a street map and a satellite image of the same area). One representation *constrains* the other by limiting the possible meanings (e.g., a simulation of a skater alongside a velocity-time graph). Finally, representations can work together to *construct* deeper understandings by aiding abstraction, generalization, and translation (e.g., a velocity-time graph and an acceleration-time graph). Because of these three functions of multiple representations, student understanding may be increased when learning from multiple representations.

The second reason student understanding may be enhanced when learning from multiple representations is explained by the generative theory of multimedia learning (Adadan et al., 2009; Mayer, 1997, 2003). This theory relies on three conditions of human learning, which Mayer (1997, 2003) calls (a) the dual-channel (also dual-coding) assumption, (b) the limited capacity assumption, and (c) the active learning assumption. The dual-coding assumption supposes that there are two channels, a visual channel and a verbal channel, in the human brain that code information separately. Each of these channels can only process a limited amount of information (limited capacity assumption) at a time, and the information that gets processed is actively selected by the learner (active learning assumption). Therefore, when information is presented as visual and verbal representations, the information can enter both channels at the same time. Because information is entering through both channels, and each channel has a limited capacity, more total information can be processed and, therefore, more information can be selected and attended to. In all, more learning happens when information is represented in both visual and verbal representations (Mayer, 1997, 2003).

Third, some researchers would argue that the increase in student learning from multiple representations is because learning is the product of creating representations

(Hand et al., 2009; Hand et al., 1999; Jewitt et al., 2001; Kress, 2010; Lesh, Post, & Behr, 1987; Márquez, Izquierdo, & Espinet, 2006; Prain, 2006). Hand (1999), for example, stated that writing text is an "epistemological tool that enables the construction of knowledge and understanding" (p. 1029). Gunther Kress (2010) took that assertion beyond written text by positing that "*sign-making* is *meaning-making* and *learning* is the result of these processes" (p. 178). Thus, as students are engaged in creating representations (sign-making) their learning is increased because they are constructing and clarifying knowledge (Airey & Linder, 2009; Hand et al., 1999; Márquez et al., 2006; Prain, 2006).

As described above, researchers have discovered many things about learning with multiple representations. Research in recent years has begun to examine learning as it occurs with modes of representation. While many of the challenges and benefits of learning involving multiple representations can be expected to carry over into learning involving multiple modes of representation, little work has been done specifically at this level of focus.

Multimodality

This section of Chapter 2 will first discuss how communication involves the use of many modes (e.g., words, graphs, images), as described in the theory of multimodal communication (Kress, 2000, 2010). Then, it will be shown that the discourse (specialized ways of communicating) of professional science and the science classroom occurs in MMR.

Multimodal communication. As the distinct, but related, notions of D/discourse acknowledge, the theory of multimodal communication recognizes the complexity of communication and meaning making. Traditionally, communication has been thought to occur through the exchange of words—spoken, heard, written, and read (Jaipal, 2010; Jewitt et al., 2001; Lemke, 1998b). In contrast, the theory of multimodal communication posits that communication occurs in a multiplicity of different modes of representation (Kress, 2000, 2010). When someone is speaking, for example, he is creating a representation in the modes of spoken sounds, tone of voice, speed of speech, facial expression, and gesture.

While there is a vast variety of modes of representation (Kress, 2010), some researchers have grouped modes together for simplicity. For example, Lesh (1987) proposed five categories of modes of representation used in mathematics: (a) real scripts (texts related to the physical world, such as story problems with real life examples), (b) manipulative models (three dimensional physical models available for manual manipulation, such as plastic molecular models), (c) static pictures (such as a photograph of a lake), (d) spoken language, and (e) written symbols (such as numbers or the "+" sign). Lemke's (2004) categorization of modes of representation is more broad: (a) natural language (words, whether written or spoken), (b) mathematical modes (including all the symbols of math), (c) visual modes (such as images, graphs, tables), and (d) actional modes (such as gesture). Others (Jewitt et al., 2001) have used just three groups: (a) linguistic (including words), (b) visual (images and pictures), and (c) actional (such as gestures).

Each mode of representation has specific affordances and limitations (Kress, 2000, 2010; Lemke, 1998c). Affordances are the characteristics of a mode that give it a specific advantage over another mode of representation; limitations are those characteristics that make using that mode of representation less beneficial than others. Consider the example of getting instructions to a distant location. Someone could provide oral directions or could draw a map. Here there are the options of two modes—spoken words and a map. The affordances of spoken words are that the directions will likely be delivered quickly and efficiently, and the person providing the directions can edit his or her speech based on real-time reactions of the listener, clarifying where there seem to be misunderstandings. However, spoken words have the limitation of being impermanent. As soon as they are spoken they are gone, which means they might be forgotten. That is an affordance of a map: it is permanent. It can be referred back to later. Additionally, the map has the affordance of being more spatially specific. However, it will likely take longer for someone to draw a map than for someone to speak, a limitation of a map. As a result, if time were limited, one would probably convey the directions through speech; if getting to the destination were most important, a map would be drawn. In this way, people choose the mode to use based on affordances and limitations.

This ability to select a mode based on the affordances and limitations is considered an important piece of being representationally competent (diSessa, 2004; Kozma & Russell, 2005; Schonborn & Anderson, 2009). A study of chemists found that expert chemists selected the most appropriate mode for communicating a specific idea (Kozma & Russell, 2005). Additionally, in delineating five levels of representational competence, Kozma and Russell (2005) described a student with the highest level of representational competence as being able to "construct the representation most appropriate for a particular situation and explain why that representation is more appropriate than another" (p. 133). If a student can do this, it means that he or she understands the affordances and limitations of the modes involved because it is the affordances and limitations that make one mode superior to another in a specific situation. Some students may learn these nuances of modes independently, almost intuitively, or through experiences outside of school. Still, explicit instruction regarding the affordances and limitations of modes is hypothesized to help these students learn this feature of modes more quickly. In addition, it follows that explicit instruction in affordances and limitations of modes would aid students who may have never developed the skill of selecting the most apt mode on their own.

A multimodal view of communication requires that researchers and teachers look beyond words, written or spoken, to understand the full meaning that people are communicating. When communication was defined only in regard to words, the terms reading, writing, speaking, and hearing were appropriate. However, these terms are inadequate within the current understanding of what it means to communicate because of their long-term connotative ties to *words*. For this reason, this study will use the terms *negotiate* (making meaning from a representation) and *create* (to represent a meaning) (Draper & Siebert, 2010) when discussing an individual's ability to understand and use various modes of representing ideas while communicating. These terms are much more apt because they expand the representational potentials beyond words, and serve as a reminder that communication occurs in MMR (Kress, 2010).

Discourse of science as multimodal. Perhaps more than other discourses, the discourse of science is, by nature, multimodal (Coleman, McTigue, & Smolkin, 2011; Prain, 2006; Prain & Waldrip, 2006; Smolkin & Donovan, 2004). Rather than being composed of one mode of representation,

> [The language of science] is natural language as linguists define it, extended by the meaning repertoire of mathematics (the set of possible meanings that can be made with mathematical symbols and the conventions for interpreting them), contextualized by visual representations of many sorts, and embedded in a language…of meaningful, specialized actions afforded by the technological environments in which science is done. (Lemke, 2004, p. 33)

Science discourse is multimodal because the ideas that need to be represented in science often cannot be represented using one mode (Kress, 2000, 2010; Lemke, 1998b, 1998c). Words alone do not adequately express the analytical meanings needed in science. Rather, science discourse is, of necessity, composed of modes of representation that can express continuous change, variation, degree, and intricate quantitative relationships (e.g., mathematical symbols, graphs, diagrams) (Lemke, 1998b, 1998c, 2004). To illustrate this need for other modes, consider a beaker of hot water, an item of interest in some scientific settings. Using the mode of words, one can describe the water's temperature with the words: hot, lukewarm, cold (with perhaps some adjectives preceding those words to fine-tune the gradations). These words alone are not sufficient for the discourse of science, however, where one might be attempting to measure the change in temperature over time or compare the temperature of water to the temperature of the air. For increased specificity, a scientist needs the mode of mathematics (e.g., 13^{o} C, 97^{o} C).

Research has been conducted supporting the claim that science discourse is multimodal. For example, in his research, Lemke (1998b) examined three groupings of professional science articles for their representational use. The first group, which included articles from a variety of publications and on a variety of science content areas, had an average of 1.1 graphics per page and 1.4 mathematical equations per page. The second group was composed of articles from a prestigious physics research journal and had an average of 1.2 graphics per page, and an average of 2.7 mathematical equations per page. The third group, comprised of articles from a prestigious earth science journal, had an average of 2.5 graphics per page and 1.9 mathematical equations per page. This study clearly indicates that science discourse among professional scientists occurs in MMR.

Because of the body of research that has been conducted on representational use in chemistry, the discipline of chemistry will be detailed below to further argue that the discourse of science employs MMR. This body of research has found that professional scientists use MMR in their work. In describing chemists, Zare (2002) stated that, "Chemists are highly visual people who want to 'see' chemistry and to picture molecules and how chemical transformations happen" (p. 1290).

The history of chemistry can be viewed from the perspective of representational systems changing in response to the needs of the scientific community (Kozma & Russell, 2005). "The invention of representations constitutes a fundamentally important class of [scientific] advances" (diSessa, 2004, p. 296) because as new modes of representation have been developed, new ways of thinking about chemistry concepts have been created (diSessa, 2004; Kozma & Russell, 2005; Sfard, 2000). For example, early in the history of chemistry, substances were represented with reference to their perceived characteristics (e.g., color, smell). Over time, the systems used to represent substances have been refined. Modes of representation have been developed which allow a substance to be represented with diagrams showing the three-dimensional structures of a substance, the elements within a substance, the linkage order, and the spatial orientation of each component (Kozma & Russell, 2005; Wu et al., 2001). These advances with modes of representation have aided chemists as they seek to learn more about matter (Kozma & Russell, 2005).

Chemists use MMR to help them reason through various chemistry problems. Kozma et al. (2000) found that chemists working in academic and pharmaceutical laboratories regularly used many modes of representation in their discourse about chemicals and chemical synthesis. For this reason, the pharmaceutical lab provided white boards and markers at group areas for chemists to use in their conversations. When discussing their work, the professional chemists frequently referred to chemical equations, molecular structure diagrams, and spectra charts. For example, during one day of observations a chemist began to explain his work to a researcher, “There’s actually a connection between these two things that are in the pot here and…maybe I can…wait while I get my pen” (Kozma et al., 2000, p. 119). The chemist needed to create two-dimensional representations in order to communicate his thinking. Throughout the chemistry lab, representations were “omnipresent” (Kozma & Russell, 2005, p. 125).

These omnipresent representations had multiple purposes. One purpose was to represent that which cannot be perceived (e.g., the connections between atoms). By signifying the atoms and spatial orientation of the atoms, chemists were able to represent what was happening with the chemicals (Kozma & Russell, 2005). These representations also facilitated social interactions, and socially constructed knowledge, by allowing chemists to communicate with each other (Kozma & Russell, 2005).

In summary, it has been shown that the discourse of science includes prevalent use of many different modes of representation. It follows, then, that if students are to participate within the discourse of science, they must be able to negotiate and create the many types of representations used in science.

Science classroom discourse as multimodal. Just as professional scientists use many different modes of representation in their work, communication within the science classroom about science involves MMR. This section will outline the role of MMR in the discourse of the science classroom.

The science education standards documents, such as the *National Science Education Standards* (NSES; National Research Council [NRC], 1996) and *Science for All Americans* (American Association for Advancement of Science [AAAS], 1989), indicate that teachers should be instructing students in the use of MMR (Coleman et al., 2011). These documents state that students should be able to interpret the meaning of tables, graphs, diagrams, and charts. Additionally, the NSES suggest that students should learn how to understand and use graphical representations through activities like sketching the moon or creating graphs (Coleman et al., 2011). Despite this recommendation, there is evidence that many teachers do not instruct students in modal use even though a variety of modes of representation are used during classroom instruction (Coleman et al., 2011; Lemke, 1998a; Prain & Waldrip, 2006).

The multimodal nature of science classroom discourse has been described by a number of authors, without measuring how these modes are used (Adadan et al., 2009; diSessa, 2004; Eilam & Poyas, 2008; Gunel et al., 2006; Hand et al., 2009; Jaipal, 2010; Lemke, 1998c, 2004; Prain & Waldrip, 2006; Rosengrant et al., 2005, 2006; Schonborn & Anderson, 2009; Smolkin & Donovan, 2004; van der Meij & de Jong, 2006; Wellington & Osborne, 2001; Wu et al., 2001; Yore, 2004). For example, while writing about the various modes of representation used in classroom science discourse, the "languages of science" (Lemke, 1998c, "Languages and Concepts in Science," para. 16), Lemke stated that for science students it is "as if [the teacher] taught science plainly and clearly, but…said the first words of each sentence in Chinese, then the next few in Swahili, and then the last few in Hindi" ("Lesson from a Case Study," para. 4). Rather than just talking about science's specialized ways of using words, Lemke is referring to the "languages of visual representation…mathematical symbolism, and…experimental operations" (Lemke, 1998c, "Languages and Concepts in Science," para. 16). Though this study, and the other studies cited above, does not provide direct evidence that science classroom discourse occurs in MMR, the number of manuscripts that presume the use of many modes provides strong evidence that science classroom discourse is multimodal.

Beyond simply describing the multimodal nature of classroom science discourse, some researchers have directly investigated the use of MMR in science classrooms (Airey & Linder, 2009; Coleman et al., 2011; Jewitt et al., 2001; Lemke, 1998a; Márquez et al., 2006; Prain & Waldrip, 2006). After observing an elementary teacher's lesson on the water cycle, Marquez et al., (2006) found that MMR were prevalent throughout the lesson. An illustrative example is seen in an episode where the teacher explained a concept with spoken words, hand gestures, a diagram, and a drawing (Márquez et al., 2006). Similarly, Prain and Waldrip (2006) observed elementary teachers and found that a variety of modes of representation were used when teaching students about electricity. These included spoken words, diagrams, videos, bar graphs, written words, mathematical symbols, three-dimensional models, and actional modes (e.g., hands-on experiences).

One of the most detailed studies supporting the claim that science classroom communication occurs in MMR included observations of a student in his high school chemistry and physics classes (Lemke, 1998a). In this study, Lemke found that this student needed to negotiate a wide variety of modes of representation in quick succession (Lemke, 1998a). During the time of observation, the student had to negotiate meanings from (a) the teacher's spoken words and gestures; (b) written words in the textbook, on his paper, and on the board; (c) chemical symbols and equations; (d) mathematical equations; (e) various diagrams; and (f) physical apparatuses—all different modes of representation. This study provides strong evidence that the science classroom is filled with multimodal communication.

Another study, conducted by Airey and Linder (2009), offers similar evidence, suggesting that students need to become competent in a "critical constellation of modes" (p. 21) to be able to learn the content of science and participate in the discourse of a university physics classroom. This constellation includes the modes of representation important for communicating about physics (e.g., mathematics, diagrams). These researchers, therefore, proposed that effective teachers need to identify the modes of representing ideas that are critical for their particular discourse, and allow students to practice negotiating and creating these modes of representation.

Summary. In summary, all communication, particularly that which occurs among scientists and in science classrooms, occurs using a multiplicity of representational modes. It follows, then, that in order for students to learn the science content presented to them in science classes, and to move toward full participation in science discourse, they need to be able to negotiate and create representations in the "critical constellation of modes" (Airey & Linder, 2009, p. 20) typically used in communication about science, a contention supported by an ever increasing body of research (Airey & Linder, 2009; Lemke, 1998a).

Scientific Literacy

Being able to create and negotiate the modes of representation used in science discourse is a critical component of scientific literacy because "being literate in science…requires the ability to read and understand their literatures" (NRC, 2012, 74). Thus, to further the argument for the importance of teaching students how to negotiate and create science representations in multiple modes, a discussion of the purpose of science education in K-12 classrooms in the United States is in order.

Nature of scientific literacy. As previously stated, the overarching goal of science education today, as promoted by the current science education reform movement, is science literacy for all (AAAS, 1989; NRC, 1996). According to the NSES (NRC, 1996), a person who is scientifically literate has both a knowledge of science content and the ability to participate in science. This participation in science does not imply that all students should become professional scientists; rather, "Scientific literacy enables people to use scientific principles and processes in making personal decisions and to participate in discussions of scientific issues that affect society" (NRC, 1996, p. ix). Supporting this distinction between scientific literacy and becoming a professional scientist, Wellington and Osborne (2001) state:

> If being scientifically literate is to mean anything, it means that pupils need to learn both how to *read* and *write* science. This is not to say that we expect them to write research papers but rather that they become familiar, even in a very simplistic form, with some of the standard genres of writing that are used in science so that they are recognizable and less alien. (p. 64)

As students move towards scientific literacy, they should be able to apply scientific principles and ways of knowing to their lives and use these in daily decision making, negotiating popular media messages, and communicating with other people (Hand et al., 1999; Wellington & Osborne, 2001).

Norris and Phillips (2003) added greater depth to this conception of scientific literacy when they differentiated and intertwined two forms of scientific literacy: the fundamental sense and the derived sense. According to these authors, the fundamental sense of science literacy is the ability to read and write when the subject is science, while the derived sense of scientific literacy is "being knowledgeable, learned, and educated in science" (p. 224). The derived sense of scientific literacy includes science content knowledge, which has been defined as the "facts, concepts, principles, laws, theories, and models" of science (NRC, 1996, p. 23). Norris and Phillips (2003) make a strong argument that these two senses of literacy are not merely complementary in their relationship, but constitutive, each being an essential part of the other and unable to exist in independence.

While Norris and Phillips refer exclusively to reading and writing as the negotiation of written text, it has been suggested that this definition be expanded to include the many varied modes of representation used in science (Hand et al., 2009). This is in line with the work of other researchers (e.g., Draper & Siebert, 2010) who have proposed a broader scope of what it means to read and write that includes different modes. With this expanded definition, the fundamental sense of scientific literacy encompasses the ability to negotiate and create scientific messages in the critical modes of representation specific to the discourse of science (Draper & Siebert, 2010).

Norris and Phillips (2003) also contended that the fundamental sense of science literacy is neglected in the science classroom. “Focussing [sic] on the derived sense of literacy as knowledgeability in science,” they argue, “has…created a truncated and anemic view of scientific knowledge as facts, laws, and theories in isolation from their interconnections” (p. 233). To avoid promoting this shallow view of science, science teachers should ask students to negotiate and create a variety of texts and other modes in order to legitimately participate in the discourse of science (Hand et al., 2009; Prain, 2006). As Lemke (1998c) argued, “The goal of science education…ought to be to empower students to use all of these languages [or modes of representation] in meaningful and appropriate ways, and, above all, to be able to functionally integrate them in the conduct of scientific activity” (“Languages and Concepts in Science,” para. 16). In short, for students to be scientifically literate, they must have science content knowledge (part of the derived sense of literacy), *and* fluency in the representational modes used in science discourse (the fundamental sense of literacy). Teaching either sense of literacy in isolation is insufficient.

Access to scientific literacy. The goal of scientific literacy is not restricted to the traditionally successful student in science classrooms (Lee, 1997). Rather, reform documents are clear that scientific literacy is a goal for *all* students (AAAS, 1989; NRC, 1996). The NSES (NRC, 1996) explicitly declared,

> In a world filled with the products of scientific inquiry, scientific literacy has become a necessity for everyone. Everyone needs to use scientific information to make choices that arise everyday. Everyone needs to be

> able to engage intelligently in public discourse and debate about important issues that involve science and technology. And everyone deserves to share in the excitement and personal fulfillment that can come from understanding and learning about the natural world. (p. 1)

Interestingly, however, although equity is clearly an articulated goal of science education, my review of the extant literature has found no studies that have considered the effect of instruction aimed at supporting students' abilities with MMR in helping *all* students become scientifically literate. Instead, the existing studies aggregate all student data and have made no attempt to understand the impact on specific demographic groups (e.g., Adadan et al., 2009; Hand et al., 2009; Rosengrant et al., 2005).

This lack of research regarding how students of different demographic groups respond to the use of and instruction in MMR represents a significant gap in the existing knowledge available about the use of representations in science teaching and learning. This is particularly troubling given that a large body of literature suggests that students who are ethnic minorities, females, or low-SES, are underrepresented in the science professions (Oakes, 1990) and are less academically successful in science classes (Lee, 1997; Southerland et al., 2007; Suarez-Orozco, Pimentel, & Martin, 2009; Warren, Ballenger, Ogonowski, Rosebery, & Hudicourt-Barnes, 2001). In the following paragraphs I will outline three ways in which students from underrepresented groups, including ethnic minorities, females, and low-SES students, may be placed at a disadvantage when teachers do not explicitly teach how to negotiate or create the MMR used in science discourse or allow expression in MMR (Kress, 2000; Lemke, 1998c).

One reason for this inequity is that the meanings of modes are socially and culturally defined (Kress, 2010). For example, the meaning of gestures differs from culture to culture (Archer, 1997). One gesture that has different meanings across cultures is the “thumbs up” gesture, a wish of good luck or a congratulatory gesture in the United States and an aggressively obscene gesture in Iran (Archer, 1997). Due to this dependence on culture, students whose cultural backgrounds do not parallel the Western culture widely represented in U.S. science classrooms may be disadvantaged because these students would be less likely to understand the meanings of the various modes used therein (Kress, 2000).

A second reason that not teaching MMR explicitly may result in inequity is that the relative importance of different representational modes is also culturally dictated (Kress, 2010). Some cultures emphasize particular modes of representation more than other modes. For example, Western culture traditionally emphasizes the use of words to communicate (Kress, 2010). Indeed, the U.S. educational system has been accused of having a “verbal bias” (Coleman et al., 2011, p. 615), neglecting modes of representation that do not use words. For example, it has been found that secondary science teaching is “dominated by textbooks, teacher lectures, workbook exercises, and writing answers to questions” (Oakes, 1990, p. 193), which all occur primarily in modes of spoken words or written words. An additional example of the verbal bias of Western cultures is seen in an anecdote offered by Kress (2010) of a teacher explaining how blood circulates through the heart using a diagram, spoken words, and gestures. The gestures were apt for the meaning intended, but not entirely accurate. The words, however, were accurate. Kress points out that because of the verbal bias of Western culture the incorrect gesture in this case was not challenged, as words might have been. “‘Sir, but you *gestured*…’ does not have the same ontological weight as ‘Sir, but you *said*…’” (Kress, 2010, p. 86). Thus, if a student comes from a cultural background in which words are not as highly favored as they are in the US, that student will be at a disadvantage to his or her peers from Western cultures (Lee, 1997; Warren et al., 2001).

An additional potential cause of inequity created by not teaching MMR in the science classroom is described by Gee (2002), who argued that in order for a student to participate in a discourse, he or she must have become competent in other skills first, called *precursor domains*. This means that students who have had experience negotiating or creating representations like the ones used in science classroom discourse prior to entering the science classroom, will have an advantage over students who have not had exposure to such modes outside of class. For example, students who have had exposure and experience with graphs prior to using them in science class will likely be more successful in a science class that requires them to negotiate and create graphs. Therefore, differences in the previous experiences of students may contribute to varied success when learning science (see Lee, 1997; Warren et al., 2001).

Stating that students from diverse backgrounds may not be competent in the modes of representation used in science and favored in U.S. schools does not mean that students from diverse backgrounds are lacking competence in all modes of representation. In fact, researchers have found that students have nascent abilities related to participating in the discourse of science (Alvermann et al., 1996; diSessa, 2004; Warren et al., 2001). For example, diSessa's (2004) work found that students are remarkably capable of creating original representations and that children had basic, naïve competencies that guided their creation of representations. These competencies included a sense that space = space (if there is space in reality, there must be space in the representation); sensitivity to characteristics such as length, width, color, number, density, and brightness; and the intuition that to indicate more, you should represent more. According to diSessa (2004), these competencies for creating representations comprise a "free resource for further learning" (p. 294) that is not often tapped into in the classroom. Though these nascent abilities may reflect a student's "cultural and language environments" (Lee, 1997, p. 221) rather than the discourse of science, Warren et al. (2001) contended, "There seem to be few limits to the ways in which someone who is thinking hard and feels the freedom of his well-known ways with words can find to make them work" (p. 539).

In this vein, Southerland, Smith, Sowell, & Kittleson (2007) argued that to equitably teach diverse students, teachers need to think about the "linguistic and cultural resources these students bring with them into the classroom" (p. 57). Among these resources are the modes of representation favored in students' particular cultures. Kist (2000) argued that to reach *all* students, other modes of representation than those that are favored by the majority should be allowed in the classroom.

In sum, those students who are traditionally underrepresented in science should be better able to learn science if they received explicit instruction in the modes of representation in which science is communicated. Though this benefit is clearly predicted by the literature, no studies were found that examined how different groups of students were influenced by an explicit focus on modes of representation in science.

Benefits of Teaching MMR Explicitly

As indicated previously, the current overarching goal of science education is that *all* students will become scientifically literate by the end of their K-12 education (NRC, 1996). This goal involves students acquiring both fluency in the MMR used in science discourse and science content knowledge, which has been defined as the "facts, concepts, principles, laws, theories, and models" of science (NRC, 1996, p. 23). Explicit instruction here refers to intentional and overt instruction that will help students (a) understand what is meant by MMR, (b) identify various modes and distinguish their affordances and limitations, and (c) negotiate and create representations in the modes used in science discourse. This type of instruction is in direct contrast to ignoring MMR and leaving students to intuitively figure out these objectives on their own. (See Appendix B for some of the lesson plans used to explicitly teach MMR in this study.) The benefits of explicitly teaching students about using a variety of modes in representing science ideas are discussed in this section.

Knowing like a scientist. In addition to being fluent in the discourse of science, a student who is scientifically literate must have sufficient content knowledge to make "personal decisions and to participate in discussion of scientific issues" (NRC, 1996, p. ix.). Science content knowledge is critical to scientific literacy in that one's ability to negotiate scientific representations is influenced by one's content knowledge (Gee, 2004; Norris & Phillips, 2003). When discussing this need for content knowledge, Norris and Phillips (2003) indicated that reading text is not a matter of simply decoding the text; rather, "inferring meaning from text involves the integration of text information and the reader's knowledge" (p. 228). In other words, regardless of the words on the page, the meaning negotiated by the reader will be influenced by what he or she knows, by their content knowledge and experience. Similarly, the negotiation or creation of representations is limited or enhanced by a person's experience and content knowledge (Gee, 2004; Kress, 2000, 2010; Schonborn & Anderson, 2009).

Several studies have indicated that student learning is increased when students are required to use MMR (Adadan et al., 2009; Rosengrant et al., 2005, 2006). Adadan et al. (2009) conducted a quasi-experimental study involving high school chemistry students wherein they implemented an intervention that required students to negotiate multiple pictures in addition to the words used in the control group. The results were that the students who were required to negotiate both linguistic and pictorial modes of representation scored higher on a posttest than students that only negotiated linguistic representations.

Similarly, two studies by Rosengrant, Van Heuvelen, & Etkina (2005, 2006) found that when university physics students created representations in multiple modes, their test scores increased. The first study (Rosengrant et al., 2005) found that more students who correctly drew free-body diagrams (a diagram which represents an object as a point and the forces acting on the object as arrows) answered test questions correctly than those who did not draw correct free-body diagrams. As a result, these researchers indicated it is critical for physics students to be able to use, create, and understand words, diagrams, sketches, equations, and graphs. In the second study, Rosengrant and colleagues (2006) found that using MMR appeared important to students' ability to solve physics problems correctly. The most successful students in this study drew a picture, and then drew a free-body diagram. They were able to use this free-body diagram to set up their mathematical equations and evaluate their answers.

Communicating like a scientist. As argued previously, in order to become scientifically literate, a student must be able to participate in the discourse of science. Because scientific discourse is multimodal in nature, participation requires that students acquire some *fluency*, mastery such that use becomes second nature, in the modes used in science discourse. The idea of fluency in MMR can be tied to the work of three groups of researchers (see Airey & Linder, 2009; Gee, 2002; Kozma & Russell, 2005).

Gee identifies fluency as when the learner achieves "some level of mastery, not just rote knowledge" (Gee, 2002, p. 23). Gee continues by arguing that students should be learning to be fluent in a discourse, rather than simply learning facts. This is related to Norris and Phillips' (2003) argument that for students to become scientifically literate they need both senses of scientific literacy—the derived sense (facts, abilities) and the fundamental sense (ability to participate in the discourse of science). In order to gain this discursive fluency Gee (2002) argued that students need to (a) mimic the representational use of more experienced others (e.g., the teacher), (b) receive direct instruction regarding the negotiation and creation of representations, (c) "*produce* combinations of words, symbols, images, and/or artifacts" (p. 51), and (d) receive feedback. Thus, in order to become fluent in a discourse, students need explicit teaching, with opportunities to negotiate and create the modes used therein.

Discursive fluency is further explicated by Airey and Linder (2009). These authors describe discursive fluency as the point at which "handling a mode…becomes unproblematic, almost second-nature" (p. 10). Clearly, from this perspective reaching discursive fluency requires that students have opportunities to practice using the discourse. This suggests that students have opportunities to negotiate and create representations in the set of modes used in science discourse. Becoming fluent in the language of science, as with learning a foreign language, is easiest when there are opportunities to use the language (Airey & Linder, 2009). Along the road to discursive fluency, Airey and Linder describe a stage of discourse imitation: a stage in which students attempt negotiating and creating representations but do not fully grasp the depths of meanings communicated and their associated ways of knowing. Consequently, students need to have opportunities to practice negotiating and creating representations through multiple modes in order to achieve discursive fluency.

Kozma and Russell (2005) give the most detailed account of fluency in representations, though they use the term *representational competence*. Representational competence is the "skills and practices that allow a person to reflectively use a variety of representations…to think about, communicate, and act on chemical phenomena in terms of underlying, aperceptual physical entities and processes" (Kozma & Russell, 2005, p. 131). Among the skills and practices that comprise representational competence are being able to (a) use representations to signify the unperceivable, (b) select and create the most apt representation for a specific situation, (c) connect features across multiple representations (called translation), and (d) use representations in social situations. While the authors have focused on representational competence in chemistry, it seems that these principles are equally applicable to the other disciplines of science. To help student become representationally competent, Kozma and Russell (2005) recommend that teachers intentionally have students negotiate and create representations in many modes.

Embedding like a scientist. Researchers (McDermott, 2009; McDermott & Hand, 2010) found that when students were required to use MMR in their writing, they would write text then, to meet the requirement of using multiple modes, would add other modes to the side. Because of these results, follow-up studies required students to "embed" MMR, rather than creating separate representations in multiple modes (Gunel et al., 2006; Hand et al., 2009; McDermott, 2009; McDermott & Hand, 2010, 2012). *Embedding* is the practice of combining multiple modes into one representation for a collaborative meaning. To illustrate what is meant by embedding, consider the following example: In order to describe a plane landing on a runway, a scientist may write the words, "The plane will be landing at one hundred forty miles per hour," draw a picture of a plane landing on a runway, sketch arrows for velocities and forces acting on the plane, *and* write numbers with units representing the magnitude of those forces. These modes are embedded, all unified in accomplishing a communicative purpose.

The group of studies that have been conducted to determine the effect of embedding MMR, has found that student learning increased when students were required to embed MMR (Gunel et al., 2006; Hand et al., 2009; McDermott, 2009; McDermott & Hand, 2010, 2012). For example, in a study conducted by Gunel, et al. (2006), high school students were required to explain concepts from quantum physics using either text alone or a computer presentation with whichever modes they desired. The authors concluded that embedding MMR was beneficial for student learning. Hand and his colleagues (2009) results were very similar, though the experience for the students was quite different. In this study, high school physics students were required to write letters explaining concepts in electricity, with some students being limited to text and others being required to embed mathematics or a graph. Again, these results suggested the benefit of embedding MMR in learning science content. Likewise, in 2010 McDermott and colleagues found that embedding multiple modes of representation was positively correlated with increased student performance on an end of unit assessment in high school chemistry.

In each of these studies, the effect of embedding MMR was examined using groups of high-achieving high school chemistry and physics students. A search of the extant literature reveals that no research has been done in this area with younger students. And yet, a variety of modes of representing science ideas are typically used during science instruction with students of all ages. As a result, it would seem that if this type of instruction is beneficial for older students (based on the extant literature), the earlier explicit teaching of appropriate use of MMR in science is introduced to students, the more likely they are to acquire representational fluency within the discourse of science. Thus, this study sought to move this line of research into earlier grades, including a similar emphasis on embedding, but examining the effect on an ethnically diverse group of middle school students in chemistry, ecology, and geology.

In summary, embedding MMR is a characteristic of science discourse. Because teachers do not typically explicitly teach students how to negotiate or create these modes of representation, most students, especially those from minority backgrounds, may not learn how to communicate within the discourse of science. Explicitly focusing in the classroom on the MMR used in science discourse is expected to help students learn science content and embed multiple modes as they make sense of science concepts.

Chapter 3

Methods

The overarching purpose of this study was to determine the effect of explicit instruction of MMR on middle school students' understanding of science content and their use of multiple modes of representation. With this purpose in mind, a quasi-experimental research design was used. According to Creswell (2008), an experimental design allows researchers to determine the impact of a treatment by dividing the sample population into two groups—a control group and a treatment group. The treatment group receives some sort of intervention that will be tested, while the control group is left unchanged. The control group represents the typical conditions such that researchers can observe what happens without the intervention, thus allowing a standard of comparison. In a true experimental design, participants are randomly assigned to groups. However, when random assignment is not possible, a quasi-experimental research design, in which a study uses preexisting groups (classes, in this case) for treatment and control groups, is appropriate (Creswell, 2008). A quasi-experimental design is particularly suited for this study because the research questions are about the impact of a specific treatment, which is the purpose of an experimental design (Creswell, 2008), without disrupting the authentic educational setting of intact classrooms.

The specific research questions that were examined in this study were:

1. How well does explicit instruction in MMR, as well as ethnicity, SES, and gender, predict student gain scores on unit assessments?

2. Controlling for embeddedness prior to the instructional unit, how well does explicit instruction in MMR, as well as ethnicity, SES, and gender, predict embeddedness on a final unit test?

Setting and Participants

The site selected for this study was Westside Middle School (a pseudonym), a midsize, urban middle school located in the western United States. This site was selected, in part, because I was a teacher at the school. Additionally, this site was selected because the middle school students in science classrooms at this site are diverse in terms of ethnicity. This is significant because a majority of the existing research relative to students' use of MMR in science classrooms has been conducted with groups of high school or college students in chemistry or physics courses without regard for ethnicity (see Eilam & Poyas, 2008; Hand et al., 2009; Jaipal, 2010; Kozma et al., 2000; Rosengrant et al., 2005, 2006; Schonborn & Anderson, 2009; van der Meij & de Jong, 2006; Wu et al., 2001). In contrast to these existing studies, the participants for this study were middle school students (grades 7 and 8) of multiple ethnic backgrounds who were enrolled in integrated science discipline courses.

Students. During the 2009-2010 school year, the site school had 852 seventh and eighth grade students, including Asian, African American, American Indian, Caucasian, Hispanic, and Pacific Islander students (Utah State Office of Education [USOE], 2010). Of these students, 60.4% were White and 32.7% were Hispanic. Students who participated in free/reduced lunch comprised 53.1% of the total student population (see Table 1).

The sample of student participants in this study included 202 middle school students, which is roughly 80% of the total population of students who were enrolled in a science course at Westside Middle School at the time of the study. Sixty-one participating students were seventh graders; 141 were eighth graders. As demonstrated in Table 1, the sample population is clearly representative of the total school population along these indices.

Table 1

School Demographics of Westside Middle School in 2010 (N=852) and Study Participants (N=202)

	Percent of students (%)	
Group	2010 Population	Sample
White	60.4	61.9
Latino	32.7	32.2
Other ethnicities	6.9	5.9
Participating in free/reduced lunch	53.1	51.5

The participants in this study were enrolled in seventh and eighth grade Integrated Science. These courses are considered integrated in that they are not limited to teaching a single branch of science (e.g., physical science); rather, these “middle school science classes were designed to infuse all three major branches of science (life, physical, earth)” (Buchanan, 2009, p. 3). Thus, multiple scientific disciplines are taught in each course (e.g., physics and ecology), with the justification that “in the natural world, the common science disciplines are not isolated from each other or from other intellectual fields, as they are in school” and that “blending science instruction” is “a reflection of [science’s] true nature” (McComas & Wang, 2010, p. 340). Both courses have central themes as designated by the Utah State Office of Education. Seventh grade Integrated Science is centered on structure, specifically the structure of matter, cells, the earth, and classification systems (USOE, 2003). Eighth grade Integrated Science is focused on “change as an organizing concept to understand matter and energy” (USOE, 2003, p. 17). At Westside Middle School, seventh grade Integrated Science is a half-year course and eighth grade Integrated Science is a full-year course.

Teachers. Three middle-school science teachers participated in this study: Mrs. Ivy, Mrs. Pohaku, and me. Mrs. Ivy (a pseudonym) had taught seventh grade Integrated Science for twenty-three year at Westside Middle School, having spent her entire teaching career at the site. Mrs. Pohaku (a pseudonym) taught eighth grade Integrated Science and was in her twenty-third year of teaching, having taught a number of different science courses in multiple states. It was my third year of teaching, all at Westside Middle School teaching eighth grade Integrated Science.

Data Sources

Data sources included pre/post unit assessments and demographic data from official school records. These data sources will be detailed below.

Unit tests. Tests were created to assess student science content knowledge. In order to determine how much students learned during the instructional unit, the same test was given as a pretest and a posttest. Each teacher created his or her own test because each taught different science content. Teachers created their test using a test blueprint in order to encourage a rigorous, valid test and in order to improve the intentionality of the unit they planned (see Bridge, Musial, Frank, Roe, & Sawilowsky, 2003; Cantrell, Liu, Leverington, & Ewing-Taylor, 2007). A test blueprint is a tool used in test preparation to ensure that a test is cognitively challenging and focused on the most essential content from the unit. Teachers created the test prior to planning any of the unit instruction such that teachers had intentionally created a test to reflect the things they felt were the most important. This increased the likelihood that their instruction would be focused on what they felt was the most important. The majority of the items on each teacher's test were multiple-choice. Approximately 35% of the test items were short-answer questions (as required by the test blueprint). Short answer questions were intentionally constructed such that responses could be entirely in words, though the affordances of other modes of representation would be beneficial to communicating the answer. In this way, students were able to respond to short answer test items with one mode of representation or with embedded modes of representation. These tests yielded data in the form of gain scores and embeddedness scores.

Gain scores. In order to determine the effect explicitly teaching MMR had on middle school students' understanding of science content, this study used gain scores. Gain scores were calculated by standardizing pre and posttest scores on a 100-point scale, then subtracting the posttest score from the pretest score. Because students were not assigned to classes randomly, there was no guarantee that distributions between classes were random. In order to account for the differences that may have existed between the classes, gain scores were used in the final analysis.

Embeddedness scores. In order to determine the effect of explicitly teaching MMR on middle school students' use of MMR, an embeddedness score was calculated. To calculate this score, test items in which a student could have responded using more than one mode of representation were identified. Student responses to these questions were then coded as embedded if the response included more than one mode of representation, or not embedded if only one mode of representation was used. In contrast to other studies in which students were asked or required to use more than one mode in their responses and the researchers determined embeddedness by assessing whether the modes worked together to enhance meaning (e.g., McDermott, 2009), students in this study were not required to respond using more than one mode of representation. Rather, when students responded to test items using more than one mode of representation, it was by their own choice; students had decided that these modes were needed to communicate the desired message. Therefore, for the purposes of this study, a student response that included more than one mode of representation was considered to be embedded.

Once inter-rater reliability was established with a second coder, I coded all of student responses independently. The embeddedness score represented the proportion of questions that students embedded out of the possible number of questions available for more than one mode of representation, standardized on a 100-point scale. This score was calculated for both the pretest and the posttest.

School level data. Demographic information about students was collected from official school records. This included student ethnicity, gender, and participation in free/reduced lunch program. Ethnicities of students were classified into three categories: White, Latino, and Other Ethnicity. Students who were listed as White only were placed in the White group. Students who were listed with any Latino ethnicity were placed in the Latino group. The Other Ethnicity category included Pacific-Islanders, Native Americans, and others including mixed ethnicities. Gender was recorded as reported on the school records. Additionally, student participation in the free/reduced lunch program was recorded as indicated on school records.

Procedure

This study occurred in two phases: preparation and treatment. Each of these phases is described in detail in the following sections.

Preparation phase. Prior to the beginning of the school year, I introduced the other participating teachers to the principles and practices involved in teaching students about MMR. During this orientation, I taught lessons describing MMR and how they are used in science to the other participating teachers (see Appendix A). These were the same lessons that were prepared for the students in the treatment group classes. After these lessons were taught, all participant teachers engaged in a critique of the lessons in order to improve the lesson plans as well as the teachers' understanding of the creation and negotiation of MMR in science.

The teachers were then introduced to the concept of a test blueprint, which specifies the type of content and cognitive difficulty of test items, in order to improve the quality of the assessment and associated instruction. During this instruction, the teachers were taught how to use the test blueprint to construct unit tests and were charged with creating a test for an instructional unit of their choice. In order to do this, teachers first created a list of concept statements for their unit of study. Then, using this list, each teacher created a unit test.

Because each teacher taught different science content, the science topic and concepts included in each teacher's instructional unit were also different. I verified the unit tests to determine the extent of the evidence for validity, including appropriate content, formatting, and test item wording as described by Downing (2003) and Haladyna, Downing, & Rodriguez (2002). Additionally, each teacher and I discussed and modified the short-answer items intended to elicit embedded responses to confirm that students could answer some of the items on the tests with MMR.

After the unit tests were created, teachers developed lessons plans for their instructional unit that provided evidence that the teacher would teach science content and explicitly tie that content to MMR for the treatment group. These units varied in length by teacher from two weeks to four weeks (see Table 2). The content of the lesson plans for both groups was identical, excepting explicit references to the use of MMR in the treatment group lessons. As is appropriate in the discourse of science, MMR were used in all lessons (both treatment and control). The difference was that, in the treatment group classes, teachers made explicit references to the modes being used, and how to make sense of them. This explicitness with modes of representation was not present in control group classes, though the same modes were being used with both groups. I previewed the lesson plans to verify that lesson plans used modes other than words, referred to affordances and limitations of modes used, and had explicit instruction on how to use these modes in communicating science ideas.

Treatment phase. During this phase of the study, each teacher's classes were split into two groups: a treatment group and control group. The control group received science instruction as planned and delivered by the teacher as usual, without any explicit emphasis on the modes of representation that students were being exposed to. The treatment group received instruction that was nearly identical to that which was delivered to the control group. The difference was that the teacher made explicit efforts to highlight the modes of representation already being used in the instruction. The idea was that the teacher made a special effort to help students in the treatment group understand how to negotiate and create the modes of representation used in the lessons. At times, this involved the teacher explicitly teaching the students in the treatment group about the nuances of a representation (e.g., stating that when the line on a bar graph goes up, it indicates that the population of wolves is rising). At other times, modifications involved a brief discussion on the affordances/limitations of representations in use. While at other times, teachers allowed students to generate their own representations rather than requiring students to use the canonical representations.

The control group was composed of the classes occurring at the beginning of the day; the treatment group was composed of classes at the end of the day. Such a distribution has advantages and disadvantages. The primary advantage is to encourage fidelity of treatment. The teachers agreed in advance that it would be easier to keep the treatment and control classes separate if they were chunked and that teaching the first classes “normally” then adding an explicit emphasis on MMR would be easiest. The disadvantage is that there may be systematic differences in overall class achievement that depends on the class period (e.g., students being tired due to time of day, class composition due to other classes being offered that period). It is believed that the advantage of this chunking of classes outweighed the attendant disadvantages.

The treatment phase began with the pretest being distributed to all classes. The day after the pretest, the MMR lessons (see Appendix A) were taught to the treatment group, while the control group received other lessons not related to the content of the instructional unit in order to prevent the control group from receiving supplementary instructional time. These lessons were related to the previous instructional unit. Once the MMR lessons were completed, unit instruction proceeded for both groups. Specifics about unit length, topic, class periods, and class sizes are delineated in Table 2.

Table 2

Characteristics of classes by teacher

	Grade	Years Experience	Topic	Class periods (# of students)		Instructional weeks
				Control	Treatment	
Mrs. Ivy	7	23	Cell structure	2nd, 4th (27)	5th, 6th, 7th (34)	2
Mrs. Pohaku	8	23	Chemical changes	1st, 2nd (23)	4th, 5th (25)	4
Mr. Nixon	8	3	Ecology	1st, 2nd (55)	3rd, 6th (38)	4

Because fidelity of treatment is critical to being able to infer a causal relationship between variables (Lastica & O'Donnell, 2007), two actions were taken to ensure fidelity of treatment during the instructional units. The first of these actions was requesting that teachers fill out a daily questionnaire (Appendix B) for both treatment and control groups. On this questionnaire, teachers reported which representations they used in class that day and marked how explicit they had made each representation with each group. As a second action to ensure fidelity, an independent observer made classroom observations of each teacher near the beginning of the instructional unit. This observer was present for one control group class and one treatment group class for each teacher. Prior to these observations, the observer was given a brief training about how to complete the observation protocol, which was nearly identical to the questionnaire the teachers were asked to complete each day. Analysis of teacher questionnaires and observation protocols suggested that teachers did, in fact, make MMR more explicit with the treatment groups as compared to the control groups.

The treatment phase was completed with the administration of the posttest. Both the pretest and posttest were scored by the classroom teacher, and then delivered to me. The scores awarded the students by classroom teachers were accepted as suitable data measuring student knowledge of science content because the teachers graded for scientific accuracy. Each test was later coded for embeddedness.

Data Analysis

The overarching purpose of this study was to determine the effect of explicit instruction of MMR on middle school students' understanding of science content and their use of multiple modes of representation. In order to accomplish this goal, I used two ordinary least squares (OLS) multiple regression models.

The first model used gain scores as the dependent variable. Dichotomous independent variables included ethnicity (Latino, White, and Other Ethnicity), gender (female=1), participation in the free/reduced lunch program (participation=1), and whether students received explicit MMR instruction (treatment group=1).

The dependent variable in second model was the portion of questions on the final test in which a student responded using more than one mode of representation. The same independent variables of ethnicity (Latino, White, and other), gender (female=1), participation in the free/reduced lunch program (participation=1), and whether students received explicit MMR instruction (treatment group=1) were included in the second model. Additionally, the analysis controlled for the amount of embeddedness on the first test.

In the first model, ethnicity, gender, participation in free/reduced lunch, and whether students were in the treatment group class were regressed on gain scores. In the second model, these variables were regressed on embeddedness score from the posttest while controlling for the pretest embeddedness score. These methods were used for the purpose of determining the effect of explicitly teaching MMR on middle school students' understanding of science content and their use of multiple modes of representation. The results of these analyses will be reported in the following chapter.

Chapter 4

Results

The two multiple regression models examined the relationships between student gain scores and the amount of embeddedness on the final test, with receiving explicit instruction in MMR, demographic variables (ethnicity, gender, and participation in free/reduced lunch), and (in the second model) the pretest embeddedness scores. The results of each model will be described below.

Model 1: Gain Scores

The first regression model examined the relationship between student gain scores and receiving explicit instruction in MMR, ethnicity, gender, and participation in free/reduced lunch as a measure of SES. Surprisingly, this model was not statistically significant (see Table 3) and remained that way despite attempts to detect errors and strengthen the model. This surprising finding may have suggested that there was not enough variation in the gain scores to reveal a relationship. However, further investigation indicated that this was not the case. Thus, this analysis may indicate that students who received explicit instruction in MMR did not learn more than the students who did not receive this explicit instruction. Student improvement from pretest to posttest was largely the same whether the students received explicit MMR instruction or not. Similarly, no ethnicity, gender, or SES group stood out from the others. This finding is also very surprising in light of the existing literature, which often indicates differences in academic performance between demographic groups (Oakes, 1990).

Although the overall model was not significant, and thus not interpretable, the gain scores of Latino students did reveal an effect that is statistically significant. These

Table 3

Multiple Regression Analysis for Treatment Condition on Gain Scores and Embeddedness (N=202)

Scores	*Model 1: Gain Scores*		*Model 2: Embeddedness*	
Model Adjusted R^2	.000		.244	
Model F	.048		11.799***	
df	(5, 196)		(6, 195)	
	B (SE)	β	B (SE)	β
Constant	31.120*** (2.592)		9.263*** (2.941)	
Latino (White)	-6.126* (3.109)	-.154	7.620* (3.395)	.153
Other Ethnicity (White)	2.455 (5.718)	.031	1.458 (6.255)	.015
Free/reduced lunch (1=participates)	1.124 (2.915)	.030	-2.383 (3.188)	-.051
Gender (1=Female)	-.631 (2.651)	-.017	9.109** (2.898)	.195
Treatment (1=treatment)	.588 (2.678)	.016	-.944 (2.923)	-.020
Pretest embeddedness score			.434*** (.060)	.449

*p<.05, **p<.01, ***p<.001

students show lower scores as compared to White students, suggesting a possible effect that needs to be more thoroughly investigated.

Model 2: Embeddedness Scores

The second model aimed to examine how receiving explicit instruction in MMR, ethnicity, gender, and participation in free/reduced lunch, predicted how much students embedded on the final test, while accounting for how much students embedded on the first test. Overall, model fit statistics show that this analysis predicted 24.4% of the variation in the amount of embeddedness on the final test. Additionally, this model was significant at the .000 level.

In this model three predictor variables showed a significant relationship with the amount of embeddedness on the final test: ethnicity, gender, and the portion of responses a student used embedded modes on the first test. Latino students answered a greater proportion of questions with more than one mode of representation than White students. Specifically, Latino students scored 7.62 points higher as compared to their White peers. Female students also answered a greater proportion of questions with more than one mode of representation than male students. In fact, female students scored 9.11 points higher on embeddedness than male students. Also, as might be expected, students who embedded their responses on the first test also embedded more questions on the final test. However, this was a much smaller effect on embeddedness than ethnicity or gender; for each embeddedness point on the first test, students scored an additional 0.43 points in embeddedness on the final test. Although no relationship between explicit teaching of MMR and embedding on the final test was observed, these three factors appear to significantly impact the amount of embedding.

Summary

The efforts of the teachers to explicitly teach students how to negotiate and create the various modes of representation already used in their classes appeared to have no influence on student learning of science content or the extent to which students wrote in a way similar to that of scientists by embedding MMR in their test responses. This was unexpected. It was anticipated, based on the research, that being more clear about how the teacher is communicating and how the students are expected to communicate would increase student learning and appropriate communication. However, this was not the case. Also unexpected was that students of all ethnic groups, genders, and SES groups improved similarly. Generally, white, male, middle class students achieve higher scores than those of other groups (Suarez-Orozco, Pimentel, & Martin, 2009). Again, this was not observed in this study.

The most striking result of this study is that students of underserved groups, specifically Latinos and females, embedded more of their responses on the final test than students from other groups even when controlling for the amount of initial embedding. These two groups embedded significantly more than other groups, while classes that were explicitly taught regarding MMR embedded only as often as the classes that were not explicitly taught about MMR. Though students who embedded more responses on the first test embedded more responses on the final test, this relationship was very small. Therefore, these two groups, Latino and female students, were more likely to pick up on the practice of embedding MMR whether or not they received explicit instruction in MMR.

Chapter 5

Discussion

The overarching purpose of this study was to determine the effect of explicit instruction of MMR on middle school students' understanding of science content and their use of multiple modes of representation. The following sections will highlight and discuss the key findings of this study, beginning with those directly related to the research questions posed in this study, and ending with those findings related to challenges with measuring embeddedness. Finally, I will relate some of the key implications of these findings for classroom teachers and educational researchers.

Reflections on the Results

In this section I will reflect on the findings of this study directly related to the research questions. This will include with findings related to the effect of explicitly teaching MMR, and the differences in student learning based on ethnicity and gender.

Explicit teaching of MMR. One of the purposes of this study was to determine the effect of explicitly teaching MMR on middle school students' understanding of science content. In order to accomplish this objective, half of the students received instruction as usually designed and taught by their classroom teacher. The other half of the students received a three-day lesson intended to help students understand that communication in science occurs in many modes of representation, that these modes are selected because of their affordances or limitations, and that different modes are often embedded or used together to enhance communication. Additionally, this second group received explicit instruction on the modes of representation utilized in class that the other group of students did not. This explicit instruction was expected to be beneficial for student learning (as measured by the pre/posttest), and to increase the amount of responses in which students would embed representational modes. Interestingly, however, analysis indicated that the explicit teaching of MMR had no influence on either student gain scores or the amount of responses a student embedded on the final test.

One possible explanation for these surprising results is that one unit of instruction may not offer sufficient time for explicit instruction to make a measurable difference. This is not surprising, inasmuch as previous studies with older students that specifically addressed embedding have found that the impact of teaching students with an emphasis on representations is increased with repeated exposure to explicit representational instruction (e.g., Gunel et al., 2006; Hand et al., 2009; McDermott, 2009). These results suggest that a substantial amount of time is required to build competence with representations and embedding.

The results of this study also suggest that the manner in which students learn about representations may influence how much science content students learn. In this study, the only difference between the instruction the treatment group received and the instruction the control group received was the explicit focus on MMR. The treatment classes were given additional, explicit instruction and emphasis on representational use. Otherwise, the instruction was identical in each class. It is possible that this slight variation was not enough to create a measurable difference between the classes.

In contrast, previous studies that have focused on the effect of embedding on student learning included greater variation in the teaching strategies used in participating classrooms and more focused student interaction with the construction of representations using multiple modes (see Gunel et al., 2006 2006; Hand et al., 2009; McDermott, 2009;

McDermott & Hand, 2012). These studies, which attributed an increase in student learning to students' ability to embed, emphasized writing-to-learn activities in which students were required to create a product that included more than one mode of representation. Additionally, students in many of these studies were engaged in creating a list of essential components of embedding and were required to self-assess their own writing for embeddedness. Unlike these studies, the results of this study suggest that simply teaching three lessons about the use of a variety of modes of representing ideas in science and adding an explicit emphasis on MMR for one instructional unit, as was done in this study, may not be sufficient to create a measurable difference in student learning or their ability to embed. This conclusion is substantiated by the literature that describes the cognitive work required by negotiating or constructing multiple modes of representation as complex and challenging (e.g., Ainsworth, 2006; Schonborn & Anderson, 2009).

Ethnicity and gender. The results of this study showed that Latino students embedded more on the final test than White students, and females embedded more on the final test than males, regardless of the emphasis on MMR during instruction. Upon discovering this, I was curious and sought to determine if these differences existed prior to instruction. To do this, I created a regression model in which the variables of receiving explicit instruction in MMR, ethnicity, gender, and participation in free/reduced lunch were regressed on the amount of embeddedness on the initial test. This model was not significant, suggesting that Latinos and females did not embed more on the first test than Whites and males.

Interestingly, this analysis suggests that Latino students and female students were better at embedding MMR by the end of unit instruction regardless of receiving explicit instruction about MMR. This finding is particularly notable because Latino students and female students have traditionally been considered underserved populations in science classrooms (Lee, 1997; Warren et al., 2001). Yet, here they are shown to outperform their peers by embedding MMR more frequently. This is important because, as described above, embedding MMR is a hallmark of the discourse of science (Lemke, 2004). Therefore, Latinos and females in this study were shown to communicate more like scientists than their non-Latino and male counterparts.

This finding leads to further questions about why Latinos and females embedded more than Whites and males on the final test. Perhaps Latinos and females inherently prefer modes of representing ideas other than words, possibly because they find other modes more accessible. Additionally, it is possible that challenges with the words of science (such as vocabulary words) lead these students to avoid words alone and to use other modes to help them make meaning. Though the results of this study may suggest that Latinos and females are inclined to use MMR more than Whites and males, many U.S. classrooms overemphasize the use of words (Coleman et al., 2011). This may contribute to Latinos and females being underserved by the way science is currently taught and assessed in U.S. classrooms.

It should be noted, however, that during this study the bias in favor of words was likely diminished. The unit test had items that allowed students to express themselves in modes other than words. Likewise, teachers in this study specifically planned to include MMR in their teaching. Whether or not there was an explicit emphasis on how to make sense of the modes used in the classroom, they were present. It is possible that because of this more open acceptance of using a variety of modes to represent science concepts or ideas and greater modeling of using multiple modes, Latinos and females felt permitted to express themselves in modes other than words. If classroom activities and assessments do not accommodate the preference to communicate in modes other than words, students from underserved populations may be put at a disadvantage. If science classrooms encouraged communication in a variety of modes of representation, students of underserved groups may be better able to communicate (see Kist, 2000; Southerland et al., 2007) and construct what they know (see Airey & Linder, 2009).

Challenges with Measurement

Throughout the course of this study, some challenges with measuring embedded responses from students were discovered. These included the challenge of eliciting embedded responses from students on a unit test, and the challenge of distinguishing between one embedded response and another. Both of these findings will be detailed below.

Eliciting embedded responses. It has been suggested that the U.S. educational system favors words over other modes of representation (Coleman et al., 2011). This preference, called a verbal bias, was clearly observed during the preparation phase of this study as participating teachers constructed test items for the unit tests. As teachers developed the unit tests, we were intentional about creating test items that could be responded to with embedded modes of representation. Indeed, although there was not a requirement to include a specific number of questions on which students could embed, most of the short answer questions were created with this in mind. After examining student responses, however, it became clear that many of these questions were answered by all students using words alone. In the end, only two of the 20 questions on Mrs. Ivy's test, eight of the 32 questions on Mrs. Pohaku's test, and six of the 15 questions on my test elicited any embedded responses.

A representative example of a question that could have been answered using more than one mode of representation was Question 17 on my unit test. It was developed as an item that was expected to elicit embedded answers, but did not. The question stated: "Predict what would happen if you left a plant in an airtight jar for three months. Support your prediction by referring to photosynthesis or respiration." I anticipated that students would answer this question by writing words, drawing a picture of the closed jar system, and/or writing the chemical equation for photosynthesis. Embedding these modes could have added depth and meaning to the response that an answer in just written words could not convey. However, no student embedded his or her response on this item.

A significant part of the challenge with eliciting embedded responses is in the wording of the question. In the example provided above, notice that it leads students to "predict," and "[refer] to photosynthesis or respiration." This question implicitly directs students to use the mode of written words. Predicting happens in written words, and, in order to refer to photosynthesis, one is also likely to use written words. Phrasing a question like this further serves to reinforce the verbal bias that dominates the school system (Coleman et al., 2011). Including the instruction to "describe" or "explain" directs students to write words, since the mode of written words is the most suited for these tasks. The way questions were designed implicitly favored words over other modes even though we, as classroom teachers, were intentionally trying to avoid this bias.

One technique attempted by participating teachers to avoid phrasing questions that favored words was to avoid words such as “describe” or “explain” and, instead, to direct students to “draw or explain” their answer. While this may indicate that modes other than words are acceptable, it is still directing students to use one mode or the other—pictures *or* words—rather than asking them to embed responses.

To avoid directing students to use words or to use one mode alone, it seems that questions must be worded without stating what action the student should do. Instead of asking a student to *describe* the difference between the atoms in a solid and the atoms in a liquid, a test item should simply ask the question—What is the difference between atoms in a solid and atoms in a liquid of the same substance? This leaves students free to respond in however many, and whichever modes they deem appropriate.

Another way to address this issue can be found in the work of Treagust and his colleagues (2012). Upon discovering that students were disinclined to respond to test items in multiple modes, these researchers structured test items such that instead of asking one general question with the directive to use multiple modes, they asked multiple questions. Each of these questions were related and requested responses in a different mode (e.g., one item requested an equation and another requested pictures). While structuring the assessment in this way increased the number of modes used to answer a question, it is not asking for embedded responses and, in fact, discourages embedding by asking for a response in one mode or the other. Though this may be an initial step in encouraging students to use MMR, and in overcoming the verbal bias of assessments, these responses fall short of the depth of the embedded communication prevalent in the discourse of science.

Differentiating between embedded responses. Related to the difficulty of writing questions that elicit embedded responses is the challenge of interpreting the embedded responses that are given. McDermott and Hand (McDermott, 2009; McDermott & Hand, 2012) have attempted to create a rubric which would quantify embedded responses. This rubric attempts to account for the quantity of modes used, the correctness of the ideas communicated, and the extent to which the modes are used together (embeddedness). Because of the complexity of this rubric, I did not attempt such an analysis of student responses. Instead, responses in this study were simply coded as embedded if the student used more than one mode of representation in the response.

Even with the simplified analysis of embeddedness used in this study, I found it challenging at times to determine if a question were embedded or not. A key example can be seen in a question from Mrs. Pohaku's test. On this item, students were provided with data, and a grid on which to graph the data. To correctly create a graph, one must use written words (titles, labels), numbers (scale), and a type of diagram (the body of the graph). However, rather than counting a graph with all of these elements as embedded, I determined that a graph without these elements would not be meaningful. Therefore, though a graph has written words, numbers, and a diagram, I treated a graph as one mode of representation, rather than a combination of embedded modes of representation.

Additionally, this simplified analysis did not capture the depth of the differences between responses. Many responses were coded as embedded, though they differed in many different ways. For example, students were asked to indicate the path of energy from the sun to an eagle. A food web diagram that included the eagle was provided. One of the simplest embedded responses involved a student making a food chain diagram with pictures and then naming on of the organisms. This response includes two different modes: a diagram and written words. However, this response varies in complexity from that offered by a student who responded by drawing on the actual test diagram all seven paths from the sun to the eagle. Both are correct, and both use MMR, but the responses clearly vary in complexity and in the depth of understanding demonstrated.

Implications

The findings discussed in this chapter carry with them several implications for both classroom teachers and educational researchers. The first implication of this study for classroom teachers is that helping students become competent in MMR, which is a critical element of scientific literacy, will take time and ongoing effort. Classroom teachers should not anticipate their students taking up complex representational behaviors, such as embedding MMR, in a short period of time (e.g., one unit of study). Similarly, in working to help students become representationally competent, it seems important that classroom teachers provide students with multiple opportunities to create representations on their own, similar to the writing-to-learn activities described in the work of McDermott and Hand (2012) and others (e.g., Hand et al., 2009; McDermott, 2009). Additionally, it may be important for students to have multiple opportunities to critique the representations of others, such as creating a list of critical elements of embedded representations as in the work of McDermott (2009). Finally, classroom teachers should work to encourage students to express themselves in MMR, acknowledging that some students are more apt to express themselves in MMR than in words alone. Messages about the preeminence of words over other modes can be sent implicitly as well as explicitly, so care needs to be taken. Classroom teachers should encourage their students to express their understanding in whatever modes are most apt.

Based on the findings of this study, educational researchers are encouraged to be mindful of the length of time spent on an intervention. Because changes in student learning due to instruction about MMR seem to require more than one instructional unit, educational researchers should design studies spanning more than one instructional unit. Additionally, educational researchers must take into account the potential for differences to exist across groups of students. Although past studies have neglected to examine how the ethnicity, gender, and SES of participating students might relate to their ability to negotiate and create MMR (e.g., Gunel et al., 2006; Hand et al., 2009), educational researchers should seek to determine if students from a variety of groups respond differently in studies regarding MMR. In addition, educational researchers should take care when attempting to assess student learning with MMR. Designing assessments that elicit embedded responses is challenging (see Hand et al., 2009; Treagust et al., 2012) and requires that educational researchers be deliberate in designing test items.

Further research in this area is needed to better understand how to help all students become scientifically literate. In general, this work should focus on how to help students to be better able to negotiate and create embedded representations like scientists do. As students become more competent with modes of representation, they will be become more scientifically literate (see NRC, 1996) and be better able to participate in the practices of science (see NRC, 2012). Accomplishing this goal requires a better understanding of how scientists embed MMR in their communication. Additionally, this requires that educational researchers better understand exactly how students use different modes together. Thus, a qualitative look at both the quantity and the quality of embedded representations in student responses seems important.

Furthermore, work is needed to determine the feasibility of this emphasis on representations in schools. Part of this work would be to establish the impact of increasing students' representational competence on high stakes tests, which is a study that is in currently in progress as an extension of the current research. Likewise, an examination of the verbal bias in U.S. schools could inform researchers and educators of the state of our education system and may help educators work towards reaching all students.

Though the teachers in this study attempted to help one group of their students become more competent in the representations used during instruction, no differentiated effect was measured as a result. Rather, regardless of explicit instruction, two underrepresented groups, Latinos and females, began communicating more like scientists do, by embedding their responses to test items. Students of these groups are of specific concern in the quest to help all students become scientifically literate because these groups are often underrepresented in science. Science educators must help students be able to communicate in the discourse of science if all students are going to scientifically literate. In order to help students communicate in the discourse of science, teachers must help them negotiate and create the specialized modes of representation that comprise that discourse.

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Appendix A

Lesson plans

MMR Lesson 1

OBJECTIVES
Students will read all representations.
Students will answer questions in multiple representations—selecting them based on their various limitations and affordances.
Students will know that MMR is critical for science communication, as each mode of representation has varied limitations and affordances

PROCEDURE
INTRO

1. One of the main things I want to do this year is to move you closer to being scientists.
2. This is why I focus so much on how to do experiments.
3. Today our focus will be on how scientists communicate, though that might not be clear for a while.

GOLDILOCKS TEXTS

1. First, pull out your notes.
2. Draw a line down the middle of the page.
3. At the top of one column write "SAME" and at the top of the other write "DIFFERENT."
    a. Point out that everything you write in the "Same" column should be things that are the same about both pages. The things that are different between the two pieces should go in the "Different" column.
4. I have here for you two different ways of representing information.
5. You're going to get with your table buddy, read these two things, and then fill out your list of things that are the same and things that are different. You should have at least four things listed in each column.
6. Hand out the Goldilocks stories (one with words and pictures, one without pictures).
7. Pick on a student:
    a. What are we supposed to do? (student responds)
8. Let them read and work.
    a. Encourage those who are stuck to look for differences and similarities in meaning, presentation, how interesting it is, how easy it is to understand. Do not lead too much.
9. Discuss as a class.
    a. What are the similarities?
        i. About the same topic. Words. About the same length.
    b. What are the differences?

i. Pictures, diagrams.
ii. What do those add? Why are they there?

MODE OF REPRESENTATION

1. One of the main differences here is that different modes of representation are used.
    a. Write "mode of representation" on the board.
2. Identify the modes of representation in the previous examples.
    a. Goldilocks modes: pictures, words, color
3. Let me show you another example of what I mean by "mode of representation."
4. Project smiley face examples up on the board.
        i. Photograph of a smiley face
        ii. Draw a picture of a smiley face
        iii. Pull a student up—have them smile
        iv. :)
    a. Each of these are a different mode of representation (or, way of showing the same idea, or way of representing the same idea or thing)
        v. Photograph
        vi. Drawing
        vii. Live person
        viii. Text emoticon
    b. How is the meaning communicated by each of these different?
5. Let me show you another example. If you wanted me to tell you how to get to Fresh Market, how could I do it?
    a. Project representations as students respond.
        i. Draw a picture.
        ii. Show you a map.
        iii. Describe it with words.
            1. First you have to go out of the school onto 200 N. Once you are on 200 N you need to walk towards the mountain—which is east. When you get to 600 W turn right (south). Go one block that direction and turn left (on 100 N). The building there on the corner is the one Fresh Market is a part of. Walk around to the front of the building. Fresh Market is on the south end of the building.
        iv. Go with you and guide you.
    a. Each of these is a different mode of representation.
        v. Image
        vi. Map
        vii. Words
        viii. Motion
6. Talk with your partner and come up with something that can be communicated with more than one mode of representation. You have 30 seconds until some of you will be sharing with the class.
7. Let them go.

8. Share.

RESTRICTED MODE GAME

1. We're now going to play a game.
2. It's a lot like Pictionary or Charades. In both of those games, you're restricted on which modes of representation you can use.
3. Let me tell you how this game works.
4. You'll be split up into teams of 3-4. Each team will play against one other team (multiple games occurring simultaneously). One person from each team will be in charge of making the representation.
5. So—you'll have two people in front of your teammates. Each of them will make the representation. The first team to guess it gets the point.
6. Follow the instructions on the card—each team will not be using the same mode of representation. Just follow the instructions.
7. We'll go until there are 15 minutes left today.
8. Split them into teams. Have them read the instruction card out loud and let them play.

PROCESSING

1. I want you to think about the game you've just played.
2. At the bottom of the notes you used at the beginning of class, write a paragraph on:
    a. What was the effect of changing the mode of representation you could use?
    b. If unclear, restate the question as:
        i. How was your ability to communicate changed by the mode of representation you used?
        ii. Were you able to get your team to win in some modes than others? Why?
3. Let them write. Collect.

MATERIALS

Goldilocks texts (one copy of each for each group)

Power Point/Computer/Projector

For each game

Play-Doh
Drawing stuff (markers, paper/markers, dry erase board)
Game cards
Game instructions page

MODE OF REPRESENTATION GAME

INSTRUCTIONS

You will be competing against one other team. Each team will have one person who makes the representation. Both of these people will step to the front and look at the card, making sure no one else can see the word. While these people make the representation, the team members will hurry to guess the word as represented by their team member. The first team to guess the word correctly earns a point. The team that has the most points at the end of the game wins.

MODES OF REPRESENTATION

Below are the rules for each mode of representation.

- Picture: Draw a picture.
- Gesture: Move your body and hands. You may not use objects or sounds.
- Play-Doh: Make shapes (not words/numbers) out of Play-Doh.
- Spoken word: The person up front says one word (not the word the team is trying to guess). The team can then guess. If the team does not get it, the person may make say one more word, followed by the team guessing one more time. One word, one guess. One more word, one guess.
- Choice: You may pick ONE of the above modes of representation to help your team guess the word.

SCORE KEEPING

Keep score in the boxes below.

TEAM A	**TEAM B**

CARDS

WORD: House TEAM A TEAM B Picture Picture	WORD: Jump TEAM A TEAM B Play-Doh Spoken word
WORD: Climb TEAM A TEAM B Gesture Gesture	WORD: Friends TEAM A TEAM B Spoken word Picture
WORD: Fly TEAM A TEAM B Picture Gesture	WORD: Love TEAM A TEAM B Choice Choice
WORD: Run TEAM A TEAM B Gesture Play-Doh	WORD: Old TEAM A TEAM B Choice Choice

MMR Lesson 2

OBJECTIVES
Students will be able to identify the strengths and weaknesses of various modes of representation.
Students will be introduced to the idea of embedding.

PROCEDURE
STRENGTHS AND WEAKNESSES
1. Pull out your paper from yesterday.
2. Take a moment and read to your table buddy your answer to the question we ended with yesterday.
3. So does it matter which mode of representation you use? Why?
    a. Expected answers:
        i. It's harder/easier to communicate to negotiate/create
        ii. Makes my team guess right faster/slower
    b. When? Always?
    c. Is it always easier to use words? When? Is it always harder to use ___? When?
4. Each mode has strengths and weaknesses.
5. Let's compare two common modes: spoken words and pictures.
    a. What are strengths/weaknesses of words/pictures? (brainstorm, list on board)
        i. Spoken words (think about talking on the phone):
            1. Strengths: can respond to people, quick to say, can be very specific about things
            2. Weaknesses: hard if you don't know the words, hard if you are talking about a lot of things, if they haven't seen it, can't be real specific about things (size, shape, color) or it takes a long time to describe.
        ii. Pictures:
            1. Strengths: don't have to know the word, can be very specific (size, shape, color), spatial orientation and relationship
            2. Weaknesses: long time to draw or find, sometimes doesn't look enough like the thing to know what it is
6. Every mode of representation has strengths and weaknesses.
7. In order to communicate clearly, you choose a mode, or a combination of modes, based on the strengths and weaknesses of each mode.

MODE SORT
1. I'm going to hand out a set of cards that have some possible modes of representation on them.
2. I will tell you something that needs to be communicated and I want you to sort them in order of the best mode to the worst mode to use to communicate that idea.

3. You'll work with your partner.
4. Hand out cards.
5. Make sure the students understand what is meant by each mode.
    a. Show examples if unclear.
6. Have a student verify the instructions.
7. Go!
    a. Situations (teacher select about three)
        i. How to make a peanut butter sandwich
        ii. How to find you on Facebook
        iii. Your phone number
        iv. Order of planets starting at the sun
        v. The percent of students that own a Wii
        vi. How to get to the lunchroom from your classroom (or how to get to school from their home)
8. Share and discuss their sorting after each situation. Then continue to the next situation.
9. Why have I given you cards? What's the strength of using the mode of cards? (can move them easily) What's a weakness? (not permanent—no record of what you were thinking so I can't give you points and you can't take it home to show your Mom)

MODE SORT PART 2

1. I have one more thing I want you to do with the cards.
2. On a paper I want you and your partner to pick three modes of representation.
3. For each of those three modes, I want you and your partner to write one specific situation (like the ones we've already talked about) when using that mode of representation would be best.
4. Go!
5. Have a few students share their examples and discuss why it would be ideal. Have a student not in the group explain why that mode of representation would be ideal.
6. Gather up the cards.

INTRO INTO EMBEDDING (Toy Story Trailer)

1. Who can summarize what we've learned so far?
    a. Guide them to something like: We communicate in multiple modes of representation. We choose the mode based on the mode's strengths and weaknesses.
2. We rarely communicate in one mode of representation. Almost always, modes are combined to help us understand what people are communicating.
3. This is called embedding—using multiple modes of representation together to communicate something.
4. Embedding is very common.
5. Let me show you an example. As we watch this, I want you to pay attention for three things:
    a. The modes of representation used

    b. The strengths and weaknesses of each mode
    c. The combined meaning of each of the modes
6. Watch Toy Story 3 Trailer.
7. Which modes were used?
    a. Written words
    b. Gesture
    c. Spoken words
    d. Pictures (moving, in this case)
8. Strengths and weaknesses
    a. Written words (information about upcoming movie)
    b. Gesture (communication between characters)
    c. Spoken words (shows communication between characters, introduces movie)
    d. Pictures (shows who, what, where)
9. How is the meaning enhanced by using all of these modes of representation?
    a. It would take a lot of words to share all this information.
    b. If the pictures did not move we would not be able to imagine them as alive.
    c. With just the video it would be hard to communicate when the video was coming out.
10. This is embedding. Using multiple modes of representation together to communicate.

MATERIALS

Mode sort card set (for each partnership)

Computer
Projector
Toy Story 3 trailer

MODE SORT CARDS

Picture
Gesture
Spoken words
Written words
3D model
Graph
Chart
Diagram
Video
Sound
Math

MMR Lesson 3

OBJECTIVES
Students will see that multiple modes of representation are embedded in science.
Students will practice embedding multiple modes of representation.

PROCEDURE
INTRO

2. Remind us of some things we've learned about multiple modes of representation.
    a. Guide them to something like: We communicate in multiple modes of representation. We choose the mode based on the mode's strengths and weaknesses.
3. Today, I'm going to show you a few examples of messages with embedded modes of representation and then you will have an opportunity to create a message in multiple modes.

WEATHER REPORT

1. This is a fairly common example in many of your lives.
2. A weather report.
3. As we watch this, I want you to pay attention for three things:
    a. The modes of representation used
    b. The strengths and weaknesses of each mode
    c. The combined meaning of each of the modes
4. Watch Weather Report (from 3:29 in to 3:55—just the Wasatch front forecast).
    a. Repeat it a few times.
5. Tell me some of the modes of representation used in the little clip.
    a. Picture
    b. Gesture
    c. Spoken words
    d. Written words
    e. Graph
    f. Chart
    g. Video
    h. Sound
    i. Math
6. Pause throughout the movie to point out the different modes.
7. What if it was just one of these modes? For example, spoken words? Cover the projector and replay the video clip (so nothing can be seen).
8. How is it different without the other modes of representation? (not as much information)

BOOMING SANDS

1. Scientists almost always embed multiple modes of representation when they communicate about a science idea. One mode is almost never enough to communicate what they want to communicate.
2. I have a science video to show you.

3. As we watch it, I want you to write down the modes of representation present in this video and I want you to think about how the modes are used together to communicate a message or idea.
4. I will be pausing it now and then to point out the different modes of representation.
5. Watch.
6. Pause when a new mode of representation appears. Why did the makers of the video choose that mode of representation? What are the strengths of that mode of representation?

    Sound (so we can hear the booming)
    Voice (communicate information efficiently)
    Moving picture (shown locations, people, events)
    Diagram of sand dune (show layers under the sand—make clear what is not seen on surface)
    Arrow (shows movement)
    Graph of potential and kinetic energy (shows changes in energy which cannot be seen)
    Graph of sound (spike shows which frequency is the main frequency)
7. Were any of these modes of representation used by themselves?
    a. No! They were always combined. They shared the message.

SCIENCE TEXTBOOK

1. Even our textbook embeds multiple modes of representation (or uses more than one mode to help the reader understand the concept or idea).
2. Show page 28 in the textbook on the projector.
3. Take a moment and read—watching for multiple modes of representation.
4. Why did they choose that mode of representation? What are the strengths of that mode of representation?
    a. Chemical symbols (specific about which element)
    b. Atomic drawings (shows what the chem symbols mean—e.g., two symbols)
        i. Color and size (show a difference, detail about element)
    c. Chemical equations (show a reaction happening at the element level—how they combine, etc.)
    d. Highlighted numbers (emphasis)
    e. Bolded words (emphasis)
    f. Words (explanation)
5. Were any of these modes of representation used by themselves?
    b. No! They were always combined. They shared the message.

FIND YOUR FAMILY

1. This is last activity of the day.
2. Keep in mind the ideas of using multiple modes of representation and embedding.
3. I'm going to tell you a situation and ask a question. Then I want you to take a moment and prepare to answer in three embedded modes of representation.
4. Do you understand what we're doing?

5. Say I'm going into a crowded room and I need to find your family. You are not with them, and I've never seen them before.
    a. How would I know it is your family?
6. Take a moment and prepare to answer that question in three embedded modes of representation. Three modes used together.
7. Give them time.
8. Share.
9. Which modes? Why did you pick them? How embedded were they (i.e., did each mode add to the overall meaning of the message)?
    a. Modes likely to be used:
        i. Words (written or spoken)—names, height, colors, gender
        ii. Image—size, shape, colors, hair style, distinguishing features
        iii. Numbers—number of family members, ages, size/height

MATERIALS

Computer
Projector
MMR Lesson 3 Keynote presentation
Textbook pages (1 for each group)

Appendix B

Teacher Questionnaire

DAILY REFLECTION SHEET Teacher: ________________________________

Date: ________________________________

Representation 1

Description:	*Presence in Control*	*Presence in Treatment*
o Text o Picture o Graph o Table o List o Diagram o Math		

Representation 2

Description:	*Presence in Control*	*Presence in Treatment*
o Text o Picture o Graph o Table o List o Diagram o Math		

Representation 3

Description:	*Presence in Control*	*Presence in Treatment*
o Text o Picture o Graph o Table o List o Diagram o Math		

Add more on back if needed...

PRESENCE KEY: 1 – Present 2 - Talked about 3 - Reinforced

Date: ________________________________

Representation 1

Description:	*Presence in Control*	*Presence in Treatment*
o Text o Picture o Graph o Table o List o Diagram o Math		

Representation 2

Description:	*Presence in Control*	*Presence in Treatment*
o Text o Picture o Graph o Table o List o Diagram o Math		

Representation 3

Description:	*Presence in Control*	*Presence in Treatment*
o Text o Picture o Graph o Table o List o Diagram o Math		

Add more on back if needed...

PRESENCE KEY: 1 – Present 2 - Talked about 3 - Reinforced