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Use of Metaconceptual Scaffolding in the Science Classroom to Promote Conceptual Change

Erin Duez
Seattle Pacific University

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By

ERIN DUEZ

A dissertation submitted in partial fulfillment

Of the requirements for the degree of

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Dedication

This work is dedicated to my daughters, Ellie and Mary, may they continue to love learning.

Acknowledgements

First and foremost, I would like to thank my family, friends, and students for their support and love through this process. I could not have done this without the unwavering support and love of my husband, Mike. My husband who did almost all of the household chores for the last 3.5 years, read countless drafts, and told me I could not give up. My family and friends who stepped in to watch my girls when I was locked away typing. My amazing students who cheered me on throughout the process. Thank you all.

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The focus of this dissertation is on conceptual change in the science education. I was first introduced to this topic as an undergraduate at Bryn Mawr College taking a "Pedagogies in Math and Science Education" course. My experiences in that course encouraged my thinking in how students learn science and prompted my career as a science teacher. I am thankful to Dr. Donnay for providing that life changing opportunity. I am also thankful to Dr. Francl and Dr. Burgmayer for modeling how to teach chemistry well.

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Abstract

The purpose of this study was to analyze the effects of providing metaconceptual awareness questions on the conceptual change and metaconceptual awareness of students in the chemistry classroom. This quasi-experimental study with a repeated-measures design analyzed the effects of providing metaconceptual awareness questions on the conceptual change and metaconceptual awareness of high school chemistry students. The intervention consisted of providing metaconceptual awareness questions nine times to the experimental group over a three-week period. The chemistry conceptual knowledge of both groups was assessed three times: pretest, posttest, and a delayed retention test. The metaconceptual awareness of the students was assessed twice with a pretest and a posttest. An ANOVA with repeated-measures was performed for both the chemistry conceptual knowledge data and the metaconceptual awareness data. A significant between subject-effect of $F(1,98) = 10.17$, $p = .002$, $\eta_p^2 = .10$ indicates that 10% of the variance in chemistry scores was explained by the intervention. The average posttest scores were significantly higher for the experimental group with a Cohen's *d* of .63. The retention test scores were also significantly higher with a Cohen's *d* of .85. The ANOVA with repeated-measures did not indicate a significant effect of the intervention on metaconceptual awareness scores. These findings indicate more research is warranted for the intervention of providing metaconceptual awareness questions in the science classroom.

Keywords: metaconceptual, framework, conceptual change, metaconceptual awareness, science education

Chapter 1

Introduction

Background

Recently, in 2015, John Hattie updated his meta-analysis data on education interventions that increase student learning to include conceptual change interventions. He calculated conceptual change interventions to have an effect size of 1.16 and a ranking of 5 out of 195 influencers on student achievement (Hattie, 2015). This effect size of conceptual change interventions is far higher than many other influencers including reciprocal teaching at .74 and direct instruction at .6 (Hattie, 2015, p. 82). Hattie's meta-analysis focused primarily on the use of conceptual change curriculum in the science classroom. His subsequent 2017 meta-analysis included conceptual change with an effect size of .99 (Hattie, 2017). Even though Hattie's addition of conceptual change programs to his meta-analysis of instructional programs is recent (Hattie, 2015), the term "conceptual change" has been around in educational research since the 1970s (Hattie, 2015; Vosniadou, 2007). Much research has been done in both psychology and education on conceptual change, including the definition of a "concept," the importance of conceptual change for students, and the best instructional methods for facilitating conceptual change for students (Yürük et al., 2008). Conceptual change is different from other areas of learning such as skill acquisition (basic algorithms) or acquiring new facts (names of capitals or math facts) (diSessa, 2014).

Purpose

The purpose of this study was to examine how using metaconceptual scaffolding questions in the science classroom impacts conceptual change and students' metaconceptual awareness. Several science education researchers claim that metaconceptual awareness is a prerequisite for conceptual change to occur (Carey, 2009; Vosniadou, 2014). In fact, lack of metaconceptual awareness has been identified as a cause for students reverting back to inaccurate preconceptions after time has passed (Huang et al., 2016). However, few empirical studies have addressed increasing a student's metaconceptual awareness as an intervention to increase student's science conceptual understanding. Only recently has an instrument been developed to measure students' metaconceptual awareness, the Metaconceptual Awareness and Regulation Scale (MARS) (Kirbulut et al., 2016).

Significance

In 1978, Driver and Easley published a seminal paper on students' inaccurate science preconceptions and their resistance to change despite teaching students scientifically accurate information. Since that paper, decades of science education research have been devoted to understanding and facilitating conceptual change in the science classroom (Kirbulut et al., 2016; Taasoobshirazi et al., 2016). Science students revert back to their initial science preconceptions when their ideas are not conceptually changed (Mason et al., 2017; Syuhendri, 2017). Therefore, much attention has been given to facilitating conceptual change in the science classroom. Recently, there has been a shift in conceptual change research in science education from classical conceptual change (where the student's prior alternate conception is replaced) to a theoretical framework that acknowledges that the student will retain their prior alternative theory. More detail will follow in the chapter two literature review regarding this shift of understanding of conceptual change, including recent neuroscience findings regarding conceptual change.

This modern theory of conceptual change, known as Framework Theory, was first put forth by Vosniadou in 2007. In 2017, Vosniadou was the keynote speaker at the National Association for Research in Science Teaching (NARST) where she presented research supporting the claim that students arrive in science class with a framework theory of how the world operates. Furthermore, she discussed the need for students to possess metaconceptual awareness as a prerequisite for conceptual change (Vosniadou, 2017). Secondly, she discussed that student's theories are not replaced when new scientific knowledge is learned but rather when they no longer offer students the greatest explanation (Vosniadou, 2017). Few researchers have tried to increase student's metaconceptual awareness as a way of facilitating conceptual change, with no studies occurring in high school chemistry. This study explored the effects of metaconceptual prompts on students' conceptual change. The effects of using metaconceptual prompts on metaconceptual awareness were also analyzed.

Questions and Hypotheses

This study examined the effect of utilizing metaconceptual scaffolding on conceptual change in high school chemistry students. This study also examined the correlation between using metaconceptual prompts and metaconceptual awareness.

Research Question 1: Is there a statistically significant difference in chemistry conceptual knowledge between students who receive metaconceptual scaffolding questions and students who receive the same chemistry instruction for three weeks without metaconceptual scaffolding questions?

H_0 = There is a statistically non-significant difference between groups (metaconceptual treatment and nontreatment) on chemistry conceptual knowledge as measured by the American Association for the Advancement of Science (AAAS) conceptual chemistry assessment.

H_1 = There is a statistically significant difference between groups (metaconceptual treatment and nontreatment) on chemistry conceptual knowledge as measured by the AAAS conceptual chemistry assessment.

Research Question 2: Does the use of metaconceptual scaffolding increase students' retention of chemistry concepts over time?

H_0 = There is a statistically non-significant difference between groups (metaconceptual treatment and nontreatment) on delayed posttest on chemistry conceptual knowledge as measured by the AAAS conceptual chemistry assessment four weeks after the study.

H_1 = There is a statistically significant difference between groups on posttest and retention posttest on chemistry conceptual knowledge as measured by the AAAS conceptual chemistry assessment four weeks after the study.

Research Question 3: Is there a statistically significant difference in metaconceptual awareness for students who receive metaconceptual scaffolding questions when compared to students who receive the same chemistry instruction for three weeks without metaconceptual scaffolding?

H_0 = There is a statistically non-significant difference between groups (metaconceptual treatment and nontreatment) on metaconceptual awareness as measured by the Metaconceptual Awareness and Regulation Scale (MARS).

H_1 = There is a statistically significant difference between groups (metaconceptual treatment and nontreatment) on metaconceptual awareness as measured by the MARS.

Defining Terms

Metaconceptual Awareness: learners ability to understand, monitor, and evaluate their conceptual learning, this includes the awareness of existing and preexisting conceptual understanding (Yürük et al., 2008)

Conceptual Change: change of understanding from a prior, naive, conception to a scientific conception widely held by the scientific community (Nadelson et al., 2018).

Assumptions and Limitations

This study had several assumptions and limitations due to the natural classroom setting of the study. Assumptions include that the experimental and comparison groups contain similar student learners. The four intact chemistry classes are the same level of high school chemistry with the same math and science prerequisites. Pretests were administered to all students and results analyzed for significant differences between groups. In using an analysis of variance (ANOVA) with repeated measures, several assumptions must be met including normality of data, no significant outliers, homogeneity of variance, categorical independent variable, and continuous dependent variable (Field, 2013). This study had several limitations inherent in a natural classroom setting including nonrandom assignment of participants. Instead the study has random assignment of intact classes to the experimental and comparison groups. Student absences due to illnesses and fire drills were unavoidable interruptions of instruction that occurred. However, these interruptions occurred at the same rate in the experimental group as the comparison group.

Structure of Dissertation

The remainder of this dissertation is divided into four subsequent chapters. The organization of these chapters follows.

Chapter Two examines the historical development of conceptual change research in science education. This chapter also contains a summary of Framework Theory, which is the theoretical framework used in this study. A summary and analysis of empirical studies focused on metaconceptual awareness and neuroscience conceptual change studies are also included.

Chapter Three describes the methodology used in this quasi-experimental study. The design of the study including sample, instrumentation, and data collection is presented.

Chapter Four presents the results of this study. Descriptive and inferential statistics are included. A summary of results is presented in both narrative and table form.

Chapter Five provides a summary and the author's analysis of the findings organized by research question. Limitations of the study including internal and external threats to validity are also discussed. Finally, recommendations for future study are provided.

Chapter 2

Review of Literature

Conceptual change research in science education spans more than four decades (Kirbulut et al., 2017). Conceptual change research remains very relevant today despite its long research history. Stella Vosniadou was the keynote speaker on her Framework theory for conceptual change at the National Association for Research in Science Teaching 2017 Conference. In recent neuroscience studies, researchers have gathered data supporting the coexistence of conceptions, both pre-existing alternative and scientifically accurate conceptions within students (Potvin et al., 2015). This recent development varies widely from the largely held replacement theories from the 1990s and 2000s (Dawson, 2014; Posner et al., 1982). Empirical studies from the last five years support the need for metaconceptual processing as students conceptually change the way they view natural phenomena (Huang et al., 2016; Sackes & Trundle, 2017).

The current study focused on using metaconceptual scaffolding to facilitate conceptual change for chemistry students. This chapter includes the theoretical development of conceptual change in science education, neuroscience findings linked to conceptual change, background on an instrument to measure conceptual change, and empirical research on the relationship between metaconceptual processes and conceptual change. The review of empirical research is narrowly focused on the relationship between metaconceptual processes and conceptual change, the focus of this current study.

Background Theory Development for Conceptual Change

Scientific historian Thomas Kuhn first used the phrase “conceptual change” in 1962 to describe when concepts change their meaning due to a shift in theories and those concepts are part of an overall framework that also changes (Kuhn, 2012). Conceptual change research can be traced back to the mid-20th century study of the nature of scientific discovery (Vosniadou, 2014). Two competing explanations emerged to explain the process of scientific discovery. One explanation was put forth by Kuhn (2012) in "The Structure of Scientific Revolutions," where he argued that scientific discovery did not progress in a linear nature. Additionally, he identified different periods of scientific discovery, including normal science, paradigm shift, and revolution. During periods of normal science, puzzle solving takes place and problems are solved within the current field of knowledge (Kuhn, 2012, p. 181). Kuhn wrote "the most striking feature of normal research problems we have encountered is how little they aim to produce major novelties, conceptual, or phenomenal" (p. 185).

Kuhn coined the term "paradigm shift" to describe when there is a scientific crisis and a revolution occurs. In Kuhn's follow-up postscript to "Structure of Scientific Revolutions," he offered a response to a lack of understanding of what a paradigm was and further defined it by retitling paradigm as a "disciplinary matrix." Kuhn felt that readers were understanding the paradigm as he named it to be similar to a scientific theory or set of theories which he felt was too limited and not all-encompassing, thus leading him to retitle paradigm as disciplinary matrix (Kuhn,2012, p 181). The disciplinary matrix describes the area within which scientists operate during a Normal Science period, including symbolic generalizations, metaphysical models, values, and exemplars (Kuhn, 2012). According to Kuhn, scientists operate within this disciplinary matrix (paradigm) until there is an anomaly, an observation that does not fit within the paradigm and thus a crisis commences. The response to this crisis leads to a paradigm shift which Kuhn writes is "the changes in which these discoveries were implicated were all as destructive as they were constructive" (p. 66). Kuhn writes that for a paradigm shift to occur the old disciplinary matrix must be replaced with the new disciplinary matrix or paradigm. He further states that a paradigm shift is "like the gestalt switch, it must occur all at once or not at all" (p. 149). He also wrote that when the new paradigm was incommensurable with the older paradigm, the two could not be compared because the new understanding represents a completely different worldview, a different disciplinary matrix (pp. 195-198).

One such paradigm shift as described by Kuhn is the transition from Ptolemaic to Copernican Astronomy (p. 68). The Copernican system no longer allowed the scientists to engage in “normal science” puzzle-solving as they discovered more and more anomalies between the Copernican system predictions and their planetary observations. The abundance of discrepancies led to a scientific crisis as more and more corrections were made to the Copernican system and yet it still did not accurately predict planetary motion (Kuhn, 2012, pp. 68-69). Copernicus wrote of the failing of the current system, thus a crisis, in the preface of his “De Revolutionibus,” where he explained his revolutionary theory for planetary motion (Copernicus, 1543). The shift from Ptolemaic to Copernican Astronomy demonstrates Kuhn's insistence that the new paradigm is incommensurable with the old paradigm and that it is a completely new worldview, not a continuation of the normal science period puzzle-solving.

Following Kuhn’s work, the “Structure of Scientific Revolutions”, Stephen Toulmin wrote “Human Understanding” in 1972. Toulmin rejected the coherence of Kuhn's paradigm (disciplinary matrix), viewing knowledge that evolves through selection and evolution rather than revolution (Toulmin, 1972). He also argued against Kuhn's incommensurably between the new and old paradigms due to a lack of coherence within each paradigm. Toulmin maintained that scientific change was a process, not a gestalt switch (diSessa, 2014). Toulmin stated "this change of approach [away from strong coherence] obliges us to abandon all those static, 'snapshot' analyses. Instead, we must give a more historical, 'moving picture' account" (Toulmin, 1972, p. 85). Toulmin also described each person having a "conceptual ecology" in which concepts form based on the intellect and the physical environment of the person (Toulmin, 1972). So, when a person encounters new concepts, they fit into the conceptual structure the person already possesses (Posner et al., 1982; Toulmin, 1972). Posner et al. (1982), along with other more recent conceptual change theorists, continue to use and define conceptual ecology (diSessa, 2002).

Classical Conceptual Change Theory

Kuhn's work in "The Structure of Scientific Revolutions" has become the basis of what is known as the classical approach to conceptual change (Vosniadou, 2014). In the classical approach, students, like scientists, have an understanding of the world that when confronted with an anomaly that does not fit into their worldview**;** they will reject their prior conception, and adopt the new way of thinking (diSessa, 2002, p. 144). This classical approach to conceptual change led to misconceptions research in the 1980s through the early 1990s (diSessa, p. 144). One example of this is the *Private Universe* research and videos by the Harvard-Smithsonian Center for Astrophysics (Shapiro, 1987). These video segments highlight the enduring science misconceptions that students have from middle school through college graduation. Before showing Harvard students displaying misconceptions, the narrator says, “Even the brightest students in the class have false ideas based on enduring misconceptions that traditional instructional methods cannot overcome” (Shapiro, 1987). The project shows teachers using traditional teaching methods unable to overcome middle school students’ science misconceptions and is an example of a project based on the classical conceptual change approach.

Susan Carey, a developmental psychologist, supports Kuhn’s incommensurability work stating that a key difference between enrichment and true conceptual change for both scientists and children is that the new understanding is incommensurable with the previous understanding (Carey, 2009, pp. 413-480). Carey wrote, “Incommensurability arises when episodes of conceptual development have required conceptual change” (p. 471). Carey’s earlier work in 1986 bridged Kuhn’s theory of how scientists undergo conceptual change with how children undergo conceptual change while learning science, especially biology (Carey, 1986). Carey described how children learn science as very similar to how Kuhn described the crisis scientists undergo before a paradigm shift and the transition between normal science and revolutionary science. Carey postulated that children strive for internal consistency and a coherent basis of facts. When their predictions fail and they detect inconsistency, they undergo a conceptual change within that domain (Carey, 2009). Carey’s most recent work in “The Origin of Concepts” (2009) proposes a method she calls “Quinian bootstrapping” for how students are able to bridge the gap between their incommensurable naive theories and advanced scientific theories (p. 20). In Quinian bootstrapping students use symbols and model phenomena for which they initially have partial meaning**;** then, through the process of modeling and exploration they develop more meaning and new symbols. Carey writes that metaconceptual awareness is the ability to monitor one's conceptual change, including the ability to recognize multiple conceptual representations, and is important for the conceptual change process. Exploration and hypothesis testing are needed for Quinian bootstrapping and the conceptual change process (p. 479). Carey's early work in 1986 explained the parallel between Kuhn's "Structure of Scientific Revolutions" and students making conceptual changes in the classroom. Her later work, "The Origin of Concepts", explains the mechanism for conceptual change (Carey, 2009).

Theory-Theory

Closely linked to Kuhn's "Structure of Scientific Revolutions" is theory-theory (Vosniadou, 2014). It is named theory-theory because it is the theory that children and adults hold intact theories of science phenomena explanations before receiving formal instruction in that scientific domain, similar to how scientists have theories to explain scientific phenomena (diSessa, 2016). Carey (2009) stated that she endorses theory-theory although she does not think its current form explains the conceptual change process in its entirety. Theory-theory follows Kuhn's model with a "normal science period" when students operate within their initial theory and conceptual change occurs when their previous conceptions are challenged, thus they must acquire a new theory (Posner et al., 1982). Posner et al. (1982) utilized Toulmin's conceptual ecology in their model and described it as a collection of previous conceptions used by the learner to organize questioning of the new phenomenon (p. 211). Theory-theory states that first the learner "assimilates" new knowledge, then when the learner is unable to maintain their current conceptual knowledge, they replace and accommodate new knowledge (p. 212).

Posner et al.(1982) described four conditions needed for a learner to undergo accommodation and achieve conceptual change:

1. Dissatisfaction with prior conception, similar to Kuhn's anomalies
2. A new concept must be intelligible
3. A new concept must seem plausible
4. A new concept must be fruitful for future pursuits and can be extended into other areas

Instructionally, Posner et al. (1982) wrote that students must have a "Kuhnian state of crisis" so that they can accommodate this new knowledge (p. 224). In this way, Posner and other conceptual change theorists who subscribe to theory-theory utilize both Kuhn's Structure of Scientific Revolutions and Toulmin's conceptual ecology. Theory-theory emphasizes the need for more time during instruction for assimilation and accommodation of concepts by students with less emphasis on the quantity of science material content coverage (p. 225). Theory-theory supports the need for cognitive conflict in demonstrations, lectures, and labs that produce anomalies for students (p. 226). Although Posner said that his four conditions for rational conceptual change were theoretical and did not provide a model for instruction, many teachers have organized teaching units around these and some have explicitly taught them to students as steps to follow (diSessa, 2016).

Framework Theory

The modern framework theory of conceptual change has roots from classical change theory and Kuhn's Structure of Scientific Revolutions. As such, there are many similarities between modern framework theory and classical conceptual change theory

(Vosniadou & Skopeliti, 2014). Most notably, the framework theory is based on the notion that students' scientific knowledge is coherent and makes up a framework to explain how the world operates (Vosniadou, 2014). Framework theory postulates that all children develop naïve theories for how the world operates. Vosniadou (2007) writes that children's naïve theories are different from scientific theories in that they are neither shared by a community nor a tested theory but rather an explanation based on individual experiences.

Differing from classical conception theory, framework theory states that the initial preconceptions (naïve theories) children have are different from synthetic conceptions that children develop after they are taught new knowledge in school. Formal schooling creates misconceptions and fragmentation when the new scientific knowledge learned in school does not fit into students' naive theory framework. Vosniadou and Skopeliti (2014) wrote that "misconceptions can form when students distort the scientific information given to them." This new formal science information is incompatible with their existing knowledge base and does not lead to an instantaneous conceptual change (Vosniadou & Skopeliti, 2014). Instead, conceptual change is a slow process that requires students to have increased metaconceptual awareness so that they better understand their naïve beliefs and where the formal science knowledge they are learning fits in. Framework theory is constructivist in nature in that new scientific information is building on student's existing knowledge structure. Framework theory does not posit that their initial naïve theory should be replaced but rather students should be taught metaconceptual awareness so that they can positively integrate scientific information from formal schooling. Framework theory is very different from classical conceptual theory which states that the preconception is replaced. In framework theory, cognitive dissonance and later conceptual change do not lead to a complete replacement but rather an integration of the new knowledge (Vosniadou, 2014).

Framework theory has many instructional implications, including the importance of a teacher's awareness of the student's naïve theories to better facilitate conceptual change and the difficulties students experience when encountering new scientific information that does not fit these naïve theories. The introduction of formal knowledge may lead to a fracturing of student's previous conception of how a phenomenon works and lead to misconceptions as they attempt to fit this new knowledge into their previous framework (Vosniadou & Skopeliti, 2014). Students must be taught to identify areas of their naïve theory that can be built on and areas needing revision. This is a gradual building of knowledge that requires long-term planning by the teacher to utilize a student-centered curriculum with student-generated modeling, questioning, and experimentation (Vosniadou, 2017). Within a framework theory view, students should not be told their naïve theories are wrong**;** rather that they are from one perspective and there are other perspectives that can explain more. For example, in 2001, Vosniadou et al. conducted an experiment with different methods of science instruction to teach the evidence that the Earth was round and not flat. When students were shown a globe and told the Earth is round, they did not have long-term conceptual change. However, when they learned that their perspective caused them to think the Earth was flat and they played with models and watched pictures taken by astronauts in space, they understood why they had that perspective but there were other perspectives that could explain more. Many researchers have explored the instructional implications of framework theory since it was first proposed by Vosniadou (Kirbulut et al., 2016; Ozdemir & Clark, 2007.

Recent Neuroscience Connections to Conceptual Change

Within the past several years there have been many neuroscience studies that provide evidence that students do not replace their original conception when they undergo conceptual change but rather hold onto both conceptual understandings, the original and the scientifically accurate understanding (Dawson, 2014). When students are presented with information that is consistent and inconsistent with their previous understandings, different portions of their brain activate according to functional MRI (fMRI). When consistent data is shown to students, caudate and parahippocampal gyrus show increased activation. However, when data that is inconsistent with student's initial conceptions is introduced, the anterior cingulate, precuneus, and dorsolateral prefrontal cortex (DLPC) are activated. These areas activated by inconsistent data exposure are areas associated with error detection and conflict monitoring. Functional MRI studies were done on physics and non-physics students. Both groups of students were exposed to computer simulation of unequal balls falling at the same rate. Non-physics students who had incorrectly answered that the balls would fall at different rates had the anterior cingulate preferentially activate when they saw the balls of uneven size falling at the same rate. However, physics students who had correctly answered that the balls of uneven size would fall at the same rate, had the same area, the anterior cingulate activate when they viewed the same computer simulation. Even though the physics students had the scientifically accurate conceptual knowledge that the balls would drop at the same rate, they had held on to their prior concept and had them both simultaneously.

Similar studies have been done with reaction time and learners classifying items as living or nonliving; teenagers took longer to classify moving nonliving items such as cars and celestial bodies (Mareschal, 2016). These studies suggest that when students learn conceptual change, they do not replace their prior naive theory but rather hold onto both. These neuroscience studies support Vosniaudou's framework theory that student's naive theory is held onto rather than replaced, such as in classical change and theory-theory. Framework theory informs this study on conceptual change. The metaconceptual scaffolding questions used in the intervention acknowledge that students hold onto their initial naive theory. Rather than the questions focusing on replacement of theory, students analyze the differences in theories both initial naive and learned theories and their explanation of the natural world.

Metaconceptual Awareness and Regulation Scale

Recently, Kirbulut et al. (2016) developed a Metaconceptual Awareness and Regulation Scale (MARS) to assess student's metaconceptual awareness and regulation. This is the first instrument of its kind designed to assess student's metaconceptual awareness and regulation. Previously, researchers had used videotaped interviews and coding in an effort to measure student's metaconceptual awareness and regulation. Metaconceptual awareness is required for conceptual change to occur (Saçkes & Trundle, 2017; Vosniadou & Skopeliti, 2014). However, researchers have not been able to measure metaconceptual awareness quantitatively. Instead, those researching metaconceptual interventions have provided interventions to facilitate metaconceptual processes and only measured the resulting conceptual change using science conceptual assessments. This MARS instrument is an important development in learning more about facilitating metaconceptual processes and ultimately increasing conceptual change.

The MARS instrument was designed within the chemistry context with a sample of 349 tenth-grade chemistry students for the pilot study and 338 students for the validation study. The study was conducted within public high schools in Turkey. The preliminary instrument had 17 items which were reduced to 12 after careful analysis and feedback from panels of science, statistics, and education experts. Further refinement was done by interviewing 10th graders and seeing how they responded to the questions and if they understood what the questions were asking. For the pilot study, the 12-item MARS was administered to 349 high school chemistry students. Following the administration, an Exploratory Factor Analysis utilizing principal components and direct oblimin rotation was conducted. The Kaiser-Meyer-Olkin measure for sampling adequacy was .84, which indicated the sample size was large enough for factor analysis (Field, 2013). Bartlett's test for sphericity was significant at ($\chi^2(66) = 961.02$, $p < .001$) indicating that the correlation matrix is significantly different from the identity matrix (Field, 2013). The scree plot and parallel analysis indicated two primary factors. The metaconceptual regulation factor accounted for 33% of the total variance and the metaconceptual awareness factor accounted for 11.9% of total variance, combined the two factors accounted for 44.9% of total variance in MARS scores. All factor loading coefficients were greater than .3. Two items expected to load to metaconceptual awareness factor instead loaded to metaconceptual regulation factor. These items were thus eliminated resulting in a 10-item instrument.

The MARS is a 10-item instrument using a six-point Likert scale from “never” (1) to “always” (6) to assess metaconceptual awareness and metaconceptual regulation. Metaconceptual awareness was assessed with four items and included sample statements such as “I know what I did not understand about this chemistry topic” and “I know what I have learned about this chemistry topic.” The Cronbach’s alpha for these four items was .71 (95% CI [.65, .75]) which is satisfactory (Field, 2013). Metaconceptual regulation was assessed with six items including statements such as “While learning the chemistry topic, I monitored the changes in my ideas related to the topic” and “I questioned whether my prior knowledge related to the chemistry topic is plausible.” The Cronbach’s alpha coefficient was calculated to be .75 (95% CI [.70, .78]) which again was satisfactory (Field, 2013).

A validation study was then conducted using the MARS with 338 high school chemistry students. A confirmatory factor analysis, CFA was used to assess the two-factor structure of the instrument. Skewness and kurtosis were assessed for each of the ten items indicating univariate normality. Multivariate normality was also indicated by data analysis. To evaluate how well the data fit the prior model Comparative Fit Index (CFI), Root Mean Square Error of Approximation (RMSEA), Normed Fit Index (NFI), and Non-Normed Fit Index (NNFI) were used. The results for the fit analysis (RMSEA = .07; CFI = .97; NFI = .96; NNFI =.96; 90% CI [.05, .08]) demonstrated that there was a satisfactory fit (Kirbulut et al., 2016). The Cronbach’s alpha reliability coefficients for the metaconceptual regulation and metaconceptual awareness factor scores were calculated as .80 (95% CI [.67, .77]) and .72 (95% CI [.67, .77]) respectively which are above the .7 satisfactory threshold (Field, 2013).

The MARS instrument was used in the current study to assess students' metaconceptual awareness and regulation in addition to the chemistry conception as a pretest and a posttest. This instrument piloted and validated with high school chemistry students was a good fit in this current study with a sample of high school chemistry students. One limitation of this instrument is like any self-report instrument, relying on participants to give an accurate assessment of their metaconceptual level. The MARS provides a way of assessing metaconceptual awareness and metaconceptual regulation of students learning chemistry. Further research is needed to analyze if and how this instrument can be adapted for different science disciplines and student ages. However, for this current study, the instrument was applied to a similar participant population of high school chemistry students.

Empirical Studies on Metaconceptual Awareness and Conceptual Change

Explicit Metaconceptual Prompting During a Computer Simulation.

One quasi-experimental study investigated the effect of providing metaconceptual scaffolding questions to 8th graders during a computer-based inquiry simulation (N = 138) on conceptual change. More science classrooms are using computer simulations for inquiry learning, particularly in physical sciences. Rather than allowing students to explore computer simulations unguided, structure and guidance provided by the instructors to the students during computer simulation inquiry increase learning outcomes (Huang et al., 2016).

In this research design, all students were provided with structure and guidance consistent with the predict, observe, and explain (POE) framework. The experimental group was presented with additional elaboration and prediction question prompts. The lesson focused on force and motion: position, velocity, acceleration, balanced, and unbalanced forces. This experiment utilized Phet simulations, online HTML computer simulations from the University of Colorado. Two Phet simulations were used: Moving Man and Forces. Phet simulations allow students to make predictions and pause and replay the motion. Both groups, experimental and control, were given the POE scaffolding guide in electronic form and had to answer the POE prompts in a text box to move on to the next part of the simulation ensuring students interacted with it rather than merely play with the simulation. The experimental group received the additional elaboration and prediction prompts in their electronic form, including:

- What is the reason for your answer? Please explain.
- If your prediction is different from what you found from the simulation, are you ready to give up your prediction and accept what you found from the simulation?
- Based on what you found from the simulation, what is your theory about the velocity graph for at rest objects? (Huang et al., 2016, p. 83).

Effects from the additional elaboration and prediction prompts were measured both with multiple-choice pretest and posttest (15 questions) and conceptual mapping of forces and speed. (Huang et al., 2016). Both the multiple-choice posttest and the conceptual mapping assessment were given immediately, at ten days, and 30 days after the intervention. The treatment group which received metaconceptual scaffolding performed significantly better both at 10-day and 30-day posttest, $F(1, 111) = 15.96$, $p < .01$, $\eta^2 = .13$ with differences in pretests accounted for (p. 90). On the conceptual mapping assessment done at 10-day and 30-day posttest, there was no significant difference between the students who received the metaconceptual treatment and the control group (Huang et al., 2016, p. 93).

The metaconceptual scaffolding had a significant positive effect on students' conceptual knowledge as assessed by the multiple-choice test at the end of the instructional period. However, conceptual mapping did not demonstrate a significant difference. Authors Huang et al. (2016) speculate that conceptual mapping is an indicator of broader knowledge and that the metaconceptual scaffolding questions focused too narrowly on a few concepts rather than a broader, more holistic overview (p. 93). Metaconceptual scaffolding is an exciting new addition to computer-based inquiry simulations and in order to increase effectiveness, more research is needed. One limitation of this study was how narrowly focused the content was in this study and the brief length of the intervention. The study lasted seven 45-minute periods. Longer term studies and on different content areas are needed on metaconceptual scaffolding.

Contribution of Metaconceptual Awareness in Learning Science Concepts.

This longitudinal study examined how metaconceptual awareness affected preservice teachers' conceptual understanding and the durability of science concepts (Saçkes & Trundle, 2017). Sixteen preservice teachers were interviewed to assess their understanding of lunar phases as a pretest, posttest, and a delayed 15-week posttest. Students' metaconceptual awareness was also assessed immediately following six hours of total lunar phases instruction during the four class periods. Students' conceptual understanding and metaconceptual awareness were both assessed through videotaped interviews. The Conceptual Understanding Interview Protocol (CUIP) was used to measure students' understanding of lunar phases. Students were asked what caused the lunar phases; models of the sun, moon, and earth were provided to aid their verbal explanations. Students were also asked to put eight primary lunar phase pictures in the proper order.

Participants' metaconceptual awareness was assessed using a Metaconceptual Awareness Interview Protocol (MAIP) designed for the study (Saçkes & Trundle, 2017). Participants' use of metacognitive strategies was used to validate this interview protocol. The MAIP utilized six questions to assess their metaconceptual awareness, two in each of the following categories: metaconceptual awareness of changing understanding, metaconceptual awareness of contradiction between new and past understanding, and metaconceptual awareness of strategies used and experience. Interviews were videotaped and responses coded, disagreements in coding were discussed until consensus was reached.

With the limited sample size ($N = 16$), the scores deviated from normality. The Kruskal-Wallis test was used as a nonparametric equivalent of an analysis of variance, ANOVA (Saçkes & Trundle, 2017). The Kruskal-Wallis test was followed by the Mann-Whitney U procedure. Seven of the 16 participants were categorized as having high metaconceptual awareness, six with moderate conceptual awareness, and three with low metaconceptual awareness. Students with high metaconceptual awareness were able to explain how their understanding had transitioned from their initial model to a more scientifically accurate model. They were able to describe the metacognitive strategies they used to process the knowledge from instruction. Additionally, they could explain how their learning experiences influenced their conceptual understanding. Conversely, students categorized as having low metaconceptual awareness were not able to describe their initial model of lunar phases or how it has changed. They were not able to communicate awareness of the differences between their initial lunar phase model and the scientific lunar phases model. Students with low metaconceptual awareness were not able to describe how learning experiences influenced their conceptual understanding.

Students' understanding of lunar phases was grouped into three categories: "decay or stability", "continuous growth", or "stability and growth." The students in the "decay or stability" group either kept their initial inaccurate understandings or their scientific understanding declined over the course of the study. There was a statistically significant difference in metaconceptual awareness between "decay or stability" and the "growth and stability" groups ($Z = 2.62$, $p = 0.009$) with an effect size of $r = .77$. There was not a statistically significant difference in metaconceptual awareness between the "growth and stability" and the "continues growth" groups. Metaconceptual awareness was a predictor of both the student's conceptual change and the durability of the conceptual change.

While the data from this study strongly supports the link between metaconceptual awareness and conceptual understanding and durability, there are some important limitations on this study. This study only had 16 participants, all female and all preservice elementary teachers. This limits the generalizability of the study to other populations. Additionally, the independent variable was not manipulated in this study, rather the association between metaconceptual awareness and conceptual understanding was examined. The results from this study suggest further research is warranted in metaconceptual awareness and conceptual change.

Refutation Text to Elicit Metaconceptual Change.

Mason et al. (2017) examined whether including a refutation graphic with refutation text had a positive effect on long-term conceptual change and metaconceptual awareness for students. The refutation graphic used displayed a common misconception visually and an explanation of why it was inaccurate. In this study, the team included a refutation graphic showing the tilted Earth closer to the Sun during the Italian summer in the Northern Hemisphere and highlighted the Southern Hemisphere experiencing winter at the same time. The refutation graphic was labeled "No," and the correct standard graphic was labeled "Yes." The research team also examined whether including refutation text increased the metaconceptual awareness of the student, a necessity of long-term conceptual change as indicated by Carey (2009) in “The Origin of Concepts.” Science textbooks often contain graphics and the authors were curious if adding a refutation graphic to the standard graphic would demonstrate the same effect that refutation text has (Mason et al., 2017, p. 277). Two experimental studies were conducted, both with 80 Italian 12th graders. Both studies had four randomly assigned groups, $n = 20$ (p. 276). Treatments of the four groups were: standard text & standard graphic, standard text & refutation graphic, refutation text and standard graphic, and refutation text and refutation graphic (p. 276). Student group composition did not differ in reading comprehension, spatial ability, or prior science achievement. The students were assessed on the reasons for seasonal change with a pretest, immediate posttest, and a posttest delayed by fifteen days. In addition, all students were asked questions to assess their metaconceptual awareness, such as:

> Did the text contain information that contradicted what you knew about seasonal change?

Yes or No? If you responded yes, please indicate what information contradicted what you knew about seasonal change.

Do you think you have changed your conception about season change after reading the text and observing the illustration? If you have responded Yes, please indicate why you changed your understanding about seasonal change. (Mason et al., 2017, p. 279).

For the second part of the study, everything remained the same as the first study, the same number of students and conditions, except all participants were given the instructions "the illustration is important to understand the topic. Read the text and carefully observe the illustration" (Mason et al., 2017, p. 283).

The results from both the first and second part of the study indicated that the refutation text significantly increased student conceptual learning both for the immediate posttest and delayed posttest, $p < .001$. The refutation graphic did not have a significant effect on conceptual learning when paired with standard text or with refutation text. The second study, where all participants were instructed to look at the illustration, demonstrated a higher effect on conceptual learning for the refutation graphic during the immediate posttest but not for the delayed posttest. Both the first and second study showed that refutation text had a significant effect increasing students' metaconceptual awareness, $p = .005$, whereas standard text and refutation graphic did not, $p = .502$. Both of these studies were congruent with prior research showing that refutation text increased conceptual change and slightly increased metaconceptual awareness. However, the authors' hypothesis that the inclusion of refutation graphics would aid conceptual learning was not supported by their two studies.

Further research needs to be done in refutation graphics to determine if the age of the participants impacts the effect of refutation graphics on conceptual learning and metaconceptual awareness. For example, Tippet found that students in grades 3-10 benefitted the most from refutation text, while students in K-2 showed no benefit from refutation text over traditional expository text (Tippet, 2010). Perhaps students in younger grades would benefit more from a refutation graphic; recall that Mason's refutation graphic study only had 12th-grade participants. Besides, this study utilized only one graphic as the refutation graphic, a somewhat unclear diagram showing the Earth slightly closer during the summer. Perhaps a different graphic, one that is more clear, would show a similar effect to refutation text. Additionally, perhaps a different scientific concept, such as genetics or photosynthesis, would lend itself more to a refutation graphic than placement of the Earth during seasons.

Conceptual Change Texts Enriched with Metaconceptual Processes.

Yürük and Eroglu (2016) examined the effects of conceptual change texts enriched with metaconceptual scaffolding questions on the conceptual change of 105 pre-service science teachers. This study had an experimental design, with random assignment into three treatment groups: control group, experimental group with refutation text, and experimental group with conceptual change text including metaconceptual prompts (p. 3). This study utilized a heat and temperature concept test as the pre-test administered one week prior, post-test one week after reading, and delayed post-test nine weeks after intervention.

Three types of texts were used in this study, including expository for the control group, refutation text for experimental group one, and conceptual change text enriched with metaconceptual questions for experimental group two (Yürük & Eroglu, 2016). The conceptual change text enriched with metaconceptual questions (CCTMP) was written by the researchers and read and reviewed by both professors and university students the same age as those in the study. The CCTMP included opportunities for students to reflect on their existing conceptual knowledge and past experiences with it, monitor how their conceptual understanding was changing including inconsistencies between their new understanding and prior understanding, and evaluate both competing conceptions (prior and new) in how they explain physical phenomenon (p. 4). In addition to the metaconceptual prompts, CCTMP included conceptual change text which included both common alternative conceptions and scientifically accepted conception regarding heat and temperature. Part of the CCTMP included reminding students that their prior conceptual understanding of natural phenomena may sometimes be different than scientifically accepted conceptions (p. 4). Elicitation prompts were designed for students to identify gaps and weaknesses in their conceptual understanding. Students were asked if they fully understood the science concept and if not were directed to reread the text.

The experimental group assigned to the refutation text (RT) had texts that contained both scientifically accurate conceptual knowledge as well as widely held alternative science conceptions regarding heat and temperature (Yürük & Eroglu, 2017). The refutation text covered the same concepts and utilized the same examples that were in the CCTMP but did not facilitate metaconceptual processes (Yürük & Eroglu, 2017). No questions in the refutation text were directed at the reader. The control group received expository text that covered the same concepts, heat, and temperature, that were in the CCTMP and the RT. The expository text (ET) contained the same examples that were in both the CCTMP and the RT but did not contain any comparisons to widely held alternative inaccurate science conceptions. All participants read their assigned texts in the same large lecture hall. They were instructed to take as much time as they needed and not to interact with each other or the researchers (p. 6).

The pretest did not show any significant difference in understanding heat and temperature concepts between the three groups. All groups increased their average scores from pretest to posttest. The experimental group which read the CCTMP had the highest posttest mean of 23,342, compared to the ET mean of 16,942 and the RT mean of 19,828 (p. 6). An analysis of variance, ANOVA was performed to analyze differences between groups post-test scores resulting in ($F(2,202) = 28.238$, $p < .05$). A post-hoc Scheffe test was used to analyze differences between all groups and found significant differences between the performance of all groups. Eta squared was calculated at .356 indicating a large effect size (p. 7). The delayed, by eight weeks, post-test was given the same statistical analysis. This time the Scheffe test showed the statistical mean difference between the scores of the CCTMP ($M_{CCTMP} = 19{,}457$) and RT ($M_{RT} = 15{,}857$) and CCTMP and ET ($M_{ET}=14{,}485$), but no significant difference between RT and ET. This shows that the positive effects of RT diminished over time but the positive effects of CCTMP endured.

This study utilizing metaconceptual prompting in combination with conceptual change text is significant. Prior studies had utilized refutation text and had shown an increase in conceptual change. However, this study not only used refutation text similar to prior studies but additionally included an experimental group that had refutation text with prompts to facilitate metaconceptual processes. This study was well-designed with random assignment of students to control and experimental groups with the same conditions for reading and assessments utilized for each group. Additionally, by performing a delayed post-test, long term effects on durability of conceptual change could be analyzed. While this study has many advantages, there are limitations including the generalizability to K-12 classrooms due to the participant sample used of university students who were studying to be preservice teachers. Secondly, the study did not permit the students to interact with one another or an instructor while reading or after reading which does not represent a typical K-12 science classroom situation.

Empirical Studies Influence on Current Study

Students need to engage in metaconceptual processes to gain new conceptual knowledge. The current study relies on Framework theory developed by Vosniadou which posits that conceptual change is a process that relies on metaconceptual processes (Vosniadou & Skopeliti, 2014). Conceptual change is not an instantaneous switch as discussed by earlier researchers but a slow process as learners incorporate new information into their existing frameworks and create new structures for understanding (Vosniadou, 2017). Students utilize required metaconceptual processes to create this new understanding, their naive theories still exist but they have recognized the limitations of these theories in explaining natural phenomena (Vosniadou & Skopeliti, 2014).

Empirical studies on conceptual change and metaconceptual awareness have demonstrated that students with a higher metaconceptual awareness were more likely to have higher rates of conceptual change and longer lasting accurate conceptual knowledge (Saçkes & Trundle, 2017). In both the computer simulation study and the textbook reading study, metaconceptual prompting was provided to the student via text and had a significant effect on conceptual change (Huang et al., 2016; Yürük & Eroglu, 2016. However, both studies did not utilize direct instruction of a classroom teacher, unlike the proposed study, instead relied solely on text passages or computer simulations. This study utilizing a standard high school chemistry unit including direct instruction, Process Oriented Guided Instructional Learning (POGIL), group work, and laboratory experiences will be more similar to a typical classroom environment than those previous studies. The intervention in this study aims to increase the metaconceptual awareness of the students in the experimental group through metaconceptual prompting and will similarly follow with a science concept post-test and a delayed post-test. Different from previous studies, this study will also administer the Metaconceptual Awareness Regulation Scale (MARS) in addition to the science concept tests. This study builds on previous studies demonstrating the positive effects of metaconceptual awareness on conceptual change while also directly measuring metaconceptual awareness through metaconceptual prompting utilizing the MARS.

Chapter 3

Methodology

The primary purpose of this study was to analyze the effect of using metaconceptual scaffolding questions during instruction on chemistry students' conceptual knowledge as measured on a posttest and delayed retention test. Secondly, this study analyzed the effects of using metaconceptual scaffolding questions on students' metaconceptual awareness as measured by the Metaconceptual Awareness and Regulation Scale. Prior research has demonstrated a significant correlation between metaconceptual awareness and science conceptual change. However, there are a lack of studies using metaconceptual scaffolding questions as an intervention to increase conceptual change in a high school science classroom. Prior studies, as noted in chapter two, have included using metaconceptual prompts with computer simulations in a middle school science classroom and using metaconceptual prompts with preservice educators in a college environment.

This chapter describes the methods and statistical methods that were used in this study. The metaconceptual questions were adapted from prior studies (Huang et al., 2016; Yuruk et al., 2008. The research questions and hypotheses are stated followed by a description of the participants. The research design for this study including experimental groups and testing procedures are explained. Instruments including the Metaconceptual Awareness and Regulation Scale and the AAAS Science assessment are described. Finally, descriptive and inferential analysis statistical procedures are reported.

Methodology

The following research questions and hypotheses were explored in this study:

Research Question 1: Is there a statistically significant difference in chemistry conceptual knowledge for students who receive metaconceptual scaffolding questions when compared to students who receive the same chemistry instruction for three weeks without metaconceptual scaffolding questions?

H_0 = There is a statistically non-significant difference between groups (metaconceptual treatment and nontreatment) on chemistry conceptual knowledge as measured by the American Association for the Advancement of Science (AAAS) conceptual chemistry assessment.

H_1 = There is a statistically significant difference between groups (metaconceptual treatment and nontreatment) on chemistry conceptual knowledge as measured by the AAAS conceptual chemistry assessment.

Research Question 2: Does the use of metaconceptual scaffolding increase students' retention of chemistry concepts over time?

H_0 = There is a statistically non-significant difference between groups (metaconceptual treatment and nontreatment) on delayed posttest on chemistry conceptual knowledge as measured by the AAAS conceptual chemistry assessment four weeks after the study.

H_1 = There is a statistically significant difference between groups on posttest and delayed posttest on chemistry conceptual knowledge as measured by the AAAS conceptual chemistry assessment four weeks after the study.

Research Question 3: Is there a statistically significant difference in metaconceptual awareness for students who receive metaconceptual scaffolding questions when compared to students who receive the same chemistry instruction for three weeks without metaconceptual scaffolding?

H_0 = There is a statistically non-significant difference between groups (metaconceptual treatment and nontreatment) on metaconceptual awareness as measured by the Metaconceptual Awareness and Regulation Scale (MARS).

H_1 = There is a statistically significant difference between groups (metaconceptual treatment and nontreatment) on metaconceptual awareness as measured by the MARS.

Design of Study

A nonequivalent control-group design with repeated measures was used in this study. This quasi-experimental study utilized four intact college prep chemistry classes taught by the investigator. For all three investigative questions the independent variable was the use of metaconceptual questions in the classroom. Paper and pencil metaconceptual questions were administered nine times during the three-week study. The metaconceptual scaffolding questions used in this study were adapted from previous metaconceptual experimental studies (Huang et al., 2016; Yuruk, et al., 2008. The dependent variable for research questions one and two were scores from a conceptual chemistry test designed by the American Association for the Advancement of Science to elicit students' understanding of conservation of matter during chemical reactions. The dependent variable for research question three was scores from the Metaconceptual Awareness and Regulation Scale (AAAS, 2018). The AAAS instrument was administered before treatment (pretest), directly following treatment (posttest) and again four weeks later (retention test). Additionally, the Metaconceptual Awareness and Regulation Scale (MARS) was administered as a pretest and as a posttest to measure metaconceptual awareness and metaconceptual regulation (Appendix A). Refer to Table 1 for an overview of the study.

Table 1

Quasi-Experimental Design

Group	Pretest (AAAS & MARS)	Intervention	Posttest (AAAS & MARS)	Retention Test (AAAS)
N1	O	X	O	O
N2	O		O	O

Participants and Context

The research participants consisted of 112 tenth- and eleventh-grade students from four college prep chemistry classes. The high school's prerequisites for enrolling in college prep chemistry include passing biology and algebra with a C or better. The school offers an honors chemistry class which is composed of 30% of students taking chemistry. This study focuses on the college prep chemistry classes which is composed of the remaining 70% of students taking chemistry. This college prep chemistry class fulfills the "d" laboratory credit for the University of California a-g admission requirements.

The research participants in this study attended a public high school that has approximately 1,500 students with 54% qualifying for free and/or reduced-price lunch (California Department of Education, 2014). The school location is described as "town, remote" by the National Center for Educational Statistics (NCES, 2019). The town only has one public high school and is located more than two hours from the nearest large city, Los Angeles. The town does not have any other significant high school options, public or private. The town has a total population of 36,370 with a median income of $59,720

(NCES, 2019). Of the total high school students enrolled, 5.5% self-report as Black or African American, 6.3% as Asian, 25.7% as Hispanic or Latino, 1.7% as Native Hawaiian or Pacific Islander, and 58.6% as White. About 12.5% of students in the school receive special education services and 4.2% of students currently receive English Language Learner services.

For this convenience sample, 112 students from four different intact chemistry classes participated. The sample was composed of 62 students self-identified as female (55.3%) and 50 students self-identified as male (44.6%). Four students (3.5%) are currently designated as an English Learner level one (emerging) or two (expanding). Proficiency level descriptors for level one emerging include “limited receptive English skills” and for level two expanding “producing basic academic language” (California Department of Education, 2014). Twenty-three students (20.5%) have previously received English Learner services in elementary or middle school but are now designated as Reclassified Fluent English Proficient (RFEP). Five students (4.5%) in the sample receive special education services for disabilities ranging from autism to an auditory processing disorder. The sample was a mix of 10th and 11th graders with 88 of the students (78.6%) in 10th grade and 24 of the students (21.4%) in 11th grade. Table 2 provides information regarding gender, grade, and ethnicity in the sample.

Table 2

Demographic Information of Sample

		Frequency	Percentage
Grade			
	10	88	78.6%
	11	24	21.4%
Gender			
	Male	50	55.3%
	Female	62	44.6%
Ethnicity			
	White	53	47.3%
	Hispanic or Latino	36	32.1%
	Black or African American	11	9.8%
	Native Hawaiian or Pacific Islander	4	3.6%
	Asian	8	7.1%

Assignment to Groups

The experimenter flipped a coin to designate classes as part of the experimental group receiving intervention or the control group. The experimental group consists of 58 students and the comparison group consists of 54 students. Table 3 displays the characteristics of both groups by gender. Both of the periods assigned to the control group meet before lunch. Of the two periods assigned to the experimental group, one meets before lunch and one meets after lunch. Although this represents a threat to internal validity, it is unavoidable due to school scheduling.

Table 3

Gender of Sample Groups

Group	Male	Female	Total
Comparison	21	33	54
Experimental	29	29	58
Total	50	62	112

Protection of Participants

There are no risks to participants beyond normal chemistry class and laboratory activities. The intervention introduced slight variation in instructional practices between the two groups with the inclusion of metaconceptual scaffolding questions for the experimental group. All other teaching practices were the same between the comparison and the experimental groups. The multiple-choice instrument administered as a pretest, posttest, and retention test from the American Association for the Advancement of Science (AAAS) is commonly used by science teachers in the classroom. Therefore, this AAAS instrument did not present additional adverse impact. The second instrument utilized is the Metaconceptual Awareness Regulation Scale (MARS). This instrument is a 10-question Likert scale instrument that asks questions to assess their metaconceptual awareness and regulation. Although this instrument has not been routinely used in chemistry classrooms, the risk of adverse effects is minimal. The questions ask about how students learn the subject chemistry and students will answer using a Likert scale, limiting the amount of personal data collected.

Although the risks to students are minimal, the researcher asked students and guardians to consent to participate in the study. Student data was coded with a random number by a colleague of the researcher so that the students' identifying information is not on the pretests, posttests, retention tests, or MARS.

Instrumentation

This study utilized two different instruments, the AAAS conceptual chemistry test and the MARS. The AAAS conceptual chemistry test was from the Project 2061 AAAS Science Assessment database. The questions were developed to include common science misconceptions as possible answer choices along with the correct answer choice. Development of the AAAS assessment included both national field and pilot testing between 2006-2010. During field testing, students answered the multiple-choice assessment and explained why they chose their answers. They were also asked if they understood the question or if there was any confusion. Based on the feedback from the field testing, questions were modified for a national pilot testing with 1000 students. Based on statistical analysis of the field test data, the test developers eliminated problematic questions. The researcher obtained permission from Dr. George DeBoer, principal investigator, to use the assessment in this study.

The second instrument used is the Metaconceptual Awareness and Regulation Scale (MARS). The MARS was developed in Turkey to assess the metaconceptual awareness and regulation of high school chemistry students. The MARS is a 10-item Likert scale that measures two factors: metaconceptual awareness and metaconceptual regulation. The pilot study consisted of 349 public high school 10th graders (158 females, 188 males, 3 did not indicate) and the validation study consisted of 338 eleventh graders (157 females, 169 males, and 12 did not indicate)((Kirbulut et al., 2016). Following the pilot study, an Exploratory Factor Analysis was conducted. The Kaiser-Maeyer-Olkin measure for sampling adequacy was .84 indicating a large enough sample size (Field, 2013). Scree plot and parallel analysis indicated two primary factors. After the validation study the Cronbach's alpha reliability coefficients were calculated as .72 (95% CI [.68, .77]) for metaconceptual awareness and .80 (95% CI [.77, .83]) for metaconceptual regulation. A more detailed account for this instrument's development is in the chapter two literature review. The researcher for this study obtained permission from the lead author Dr. Zubeyde Demet Kirbulut to utilize the MARS in this study.

Procedure

The intervention discussed in this paper lasted for three weeks, is composed of 15 instructional periods, with twelve periods lasting 56 minutes and three periods lasting 51 minutes due to the late start Wednesday schedule. The three-week instructional unit focused on the conservation of matter and energy during chemical reactions and is centered around the NGSS HS-PS1-4 and HS-PS1-7 performance expectations (NGSS Lead States, 2013). All participants took the AAAS conceptual chemistry assessment and MARS as a pretest on the first day of the intervention. The students took the AAAS assessment on Chromebooks and MARS on paper. The resulting data was exported to google sheets where the student names were removed and replaced with numbers by another teacher. The classroom teacher continued to teach the unit on conservation of matter and energy for the next three weeks. During these three weeks both groups, experimental and comparison, participated in normal high school chemistry classroom activities such as two labs, POGIL, lecture, small group problem sets, and individual work time. At the end of the three weeks, both groups took the AAAS chemistry conceptual assessment and the MARS. Four weeks following the intervention both groups retook AAAS chemistry conceptual assessment as a retention test. By having students take the same conceptual chemistry assessment three times, pretest, posttest, retention test, there was an increased threat of test sensitization (Gall et al., 2007). Both the experimental and comparison groups took the AAAS measurement three times to minimize the threat to validity.

Intervention

The experimental group received metaconceptual questions included in their assignments three times a week for a total of nine times. The comparison group had received a few additional practice problems instead. The teacher did not provide feedback on the metaconceptual questions but did provide feedback on other parts of the assignments. The rationale for not providing teacher feedback for the students' answers to the metaconceptual awareness questions include that the questions are reflective in nature and are intended for the student to self-reflect and not write to an outside audience. Furthermore, in prior research using metaconceptual questions, teacher feedback was not provided (Huang et al., 2016). The included metaconceptual questions were adapted from the metaconceptual prompt work of Yürük et al. (2008) and Huang et al. (2016) referenced in chapter two. The metaconceptual questions were designed to increase metaconceptual awareness, monitoring, and evaluation. Examples of the metaconceptual questions are in Table 4.

Table 4

Metaconceptual Questions

Metaconceptual Awareness	• In your opinion, what does it mean to conserve mass? Can you explain it in your own words? • In your opinion, what does it mean to conserve energy? Can you explain it in your own words? • Based on what you did in the lab, what is your current theory of what happens to the mass during the reaction? • Based on what you did in the lab, what is your current theory of what happens to the energy during the reaction? • What is the reason for your prediction? • Can you give an example of mass being conserved in a reaction? • In your mind, is energy and temperature the same thing, or are they different? Explain your idea. • Are you sure about your predictions? • Are you very sure about your current idea?
Metaconceptual Monitoring	• Students will be asked to judge whether an idea from others was right or wrong. They were asked to explain and justify their reason. • Was there something new presented that is different from your original prediction? • Does the lab data support your prediction? • Write down the difference between your original idea regarding what happens to the energy and what your found in lab. • Is the scientists' difference between energy and

	temperature the same as your written explanation from earlier? • Think back to your initial understanding of energy. Overall were there any changes to your initial understanding? If so, explain the biggest change.
Metaconceptual Evaluation	• At the end of the unit, • If your prediction is different than the data gathered from the labs, which prediction do you think best explains the flow of energy? why?

Descriptive Data Analysis

The researcher utilized SPSS to analyze the data. Because intact classes were used without random assignment, a preliminary t-test was conducted to ensure no significant difference on the pretest between the experimental group and the comparison group (Field, 2013). The data was checked to make sure normal parametric assumptions are met (including normality, skewness, and kurtosis) before inferential analysis (Field, 2013).

Inferential Statistics

The hypotheses in this study were written non-directionally in the two-tailed form as recommended by Field (2013). A repeated-measures analysis of variance (ANOVA) was used in this study to minimize Type 1 error (Field, 2013). The ANOVA with repeated-measures examined the main effects of the independent variable over time between the two groups. There was one within-subjects factor: sequence of test: pretest, posttest, and retention test. There was one between-subjects factor: group with two levels: experimental and comparison group. The resulting F ratio indicated the amount of variation due to treatment and from other sources. A Bonferroni adjustment for post-hoc tests was used to reduce possible Type 1 error (Field, 2013).

The third research question and resulting hypothesis examined if there was a significant difference between those students who received and did not receive metaconceptual questions on their metaconceptual awareness level as measured by the MARS. A repeated-measures ANOVA was performed to analyze the effect of the metaconceptual questions intervention. Both the comparison and the experimental group took a 10-item MARS as a pretest and posttest to ensure any differences in metaconceptual awareness and regulation are due to the intervention and not preexisting levels.

Chapter 4

Results

This chapter reports the results from this experiment in order of each research question posed by the investigator. The first two research questions will be grouped together since the same instrumentation, the American Association for the Advancement of Science (AAAS) conceptual chemistry assessment, was used for both. The data from the third question which used the Metaconceptual Awareness and Regulation Scale (MARS) will be reported next. Data analysis will include both descriptive and inferential analysis. Finally, a research summary will be presented at the end of this chapter.

Research Questions One and Two

First Research Question: Is there a statistically significant difference in chemistry conceptual knowledge for students who receive metaconceptual scaffolding questions when compared to students who receive the same chemistry instruction for three weeks without metaconceptual scaffolding questions?

Second Research Question: Does the use of metaconceptual scaffolding increase students' retention of chemistry concepts over time?

Descriptive Statistics.

The AAAS Conceptual Chemistry assessment was given as a pretest, immediate posttest, and a retention test four weeks after the conclusion of the unit. The resulting test scores were analyzed for normal parametric assumptions including outliers, kurtosis, skewness, and normality. Table 5 includes the descriptive statistics for the pretest, posttest, and retention test. Ten students' data was excluded from the final data due to missing an excessive number of instructional periods, three or more absences, during the

15-day instructional period. In reviewing the pretest scores, one score was found to be an extreme outlier with a score of 50. Upon further investigation, the student had taken chemistry the year prior and was repeating chemistry due to earning a D in the last year. The student's data was eliminated from the dataset. All other students' transcripts were examined to ensure this was their first year taking high school chemistry. Three other outliers were identified, one score in the pretest (score of 45) and two outlier scores in the retention test data, (95 and 100). The researcher was concerned that the outlier retention scores biased the data in the direction of confirming the second hypothesis (Field, 2013). The researcher performed an Analysis of Variance (ANOVA) with repeated-measures with and without the outliers. There was a significant difference with and without the outliers, therefore the outliers were removed.

The sample size of $N = 100$ was large enough to assess the hypotheses without those outlier data. A power analysis was performed utilizing G*Power with power set to .8, effect size .2, and $p < .05$ (Field, 2013). The sample size needed for the AAAS dependent variable with three measurements and two groups was 42. The sample size needed for the MARS dependent variable with two repeated measures and two groups was 52. See Appendix B for G*Power outputs.

The kurtosis and skewness values fell within the accepted range of normality of plus or minus one (Field, 2013). The Kolmogorov-Smirnov and Shapiro-Wilk tests for normality were utilized on all three sets of data. The normality tests were non-significant indicating normal data (Field, 2013). Furthermore, Analysis of Variance (ANOVA) is a robust test that can withstand slight differences from normality (Field, 2013).

Table 5

Descriptive Statistics for AAAS Assessment

	N	Mean	*SD*	Range	Kurtosis	Skewness
Pretest	100	19.55	7.69	30	-.18	.73
Posttest	100	51.60	13.98	55	-.86	-.03
Retention Test	100	38.40	15.92	70	-.72	.35

The AAAS conceptual chemistry pretest administered prior to instruction had a mean of 20.00 out of a possible 100. Table 6 summarizes the data by group. Both groups, comparison and experimental, scored similarly on the pretest (M = 19.90 and M = 20.10) respectively. A t-test was performed to ensure there was not a significant difference between the conceptual chemistry AAAS scores of the two groups. Those in the comparison group had an average slightly higher pretest score (M = 19.90, SE = .99) than the experimental group (M = 19.17, SE = 1.20). However, the difference of .73 is not significant, $t(98) = .48$, $p = .634$.

Table 6

Descriptive Statistics for AAAS Assessments by Group

Time	Group	Mean	*SD*	*N*
Pretest	Comparison	19.90	7.11	52
	Experimental	19.17	8.34	48
Posttest	Comparison	47.88	12.30	52
	Experimental	55.63	14.68	48
Retention Test	Comparison	32.79	13.81	52
	Experimental	44.48	15.95	48

Inferential Statistics.

A repeated Analysis of Variance (ANOVA) with repeated-measures was used to analyze the three test scores for the two groups. The researcher utilized IBM SPSS version 26 to first assess that ANOVA assumptions were met. The within-subjects factor was time as both the comparison and experimental groups were tested with the AAAS instrument three times. The between-subjects factor was the treatment of metaconceptual questions that were asked of the experimental group on nine different occasions. Levene's test of Equality of Error Variances was conducted resulting in no violations of the assumption of homogeneity of variance (Table 7). In addition, the Mauchly's Test of Sphericity was not significant, $p > .05$, indicating that the data did not significantly violate the sphericity assumption.

Table 7

Levene's Test of Equality of Error Variances

	F	*df 1*	*df 2*	*p*
Pretest	3.00	1	100	.086
Posttest	3.26	1	100	.074
Retention Test	3.52	1	100	.063

The ANOVA with repeated-measures analysis indicated a significant between-subjects effect, $F(1,98) = 10.17$, $p = .002$, $\eta_p^2 = .10$. The intervention of asking the students metaconceptual questions had a significant effect on their posttest and retention test scores. The first research question asked if there was a significant difference in posttest scores for the two groups, comparison and experimental. The mean posttest scores from the experimental group were 7.74 higher than the comparison group. The difference was significant, $p = .005$ with an effect size of $d = .63$. The Cohen's *d* value of .63 indicates a medium effect size (Thompson, 2013). In Figure 1, the experimental group and the comparison group estimated marginal means are shown over time.

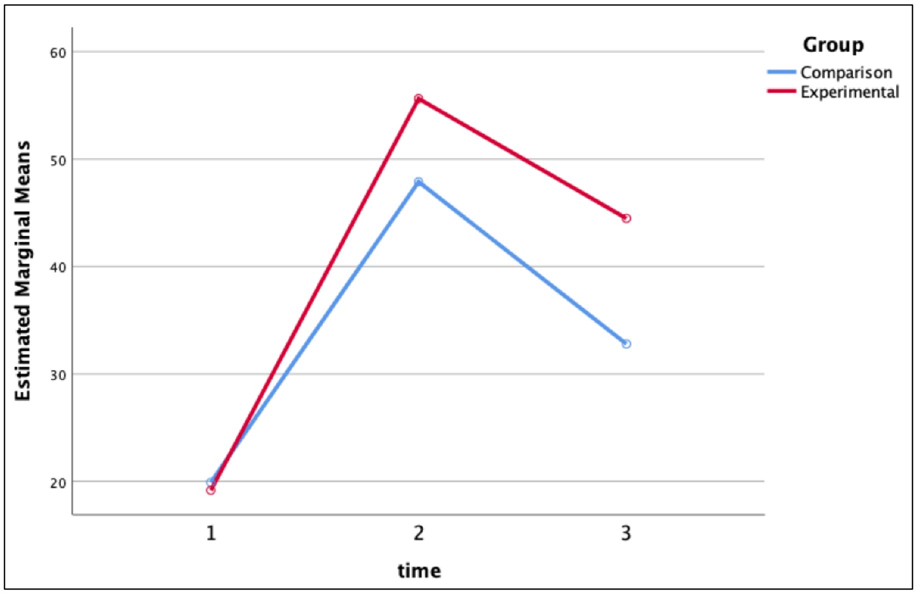

Figure 1. Estimated Marginal Means of AAAS Scores Over Time

The second research question focused on the retention of conceptual chemistry knowledge over time. The retention test was administered one month after the posttest. As shown in Figure 1 both groups mean scores decreased over time. The mean difference for the comparison group was -15.10 and for the experimental group was -11.15. Also, overall the mean scores on the retention test were higher for the experimental group (M = 44.48, SE = 2.30) and the control group (M = 32.79, SE = 1.92). The difference of 11.69 is significant $p < .001$ with an effect size of $d = .85$. This effect size is large in magnitude (Thompson, 2013).

Research Question Three

Is there a statistically significant difference in metaconceptual awareness for students who receive metaconceptual scaffolding questions when compared to students who receive the same chemistry instruction for three weeks without metaconceptual scaffolding?

Descriptive Statistics.

The Metaconceptual Awareness Regulation Scale (MARS) was administered two times as a pretest and posttest to both groups: experimental and comparison. The range of scores was between 1-60. The scores were assessed for normality, skewness, outliers, and kurtosis. Table 8 includes the descriptive statistics for the MARS pretest and posttest. The skewness and kurtosis values fell within the recommendation of an absolute value of 1. (Field, 2013). The Kolmogorov-Smirnov and Shapiro-Wilk tests for normality were both nonsignificant indicating that the assumptions for normality were met (Field, 2013). Descriptive statistics are displayed in Table 9. An independent t-test confirms that there was no significant difference between groups on MARS pretest. Those in the comparison group had, on average, a slightly higher score ($M = 37.33$, $SE = 8.37$) than the experimental group ($M = 36.10$, SE = 6.917). However, the difference of 1.23 is not significant ($t(100) = .792$, $p = .430$).

Table 8

Descriptive Statistics for MARS Pretest and Posttest Data

Time	*N*	Mean	Range	*SD*	Kurtosis	Skewness
Pretest	102	36.79	35	7.11	-.21	-.43
Posttest	102	40.84	34	7.53	-.12	.09

Table 9

Descriptive Statistics for MARS by Group

Time	Group	Mean	*SD*	*N*
Pretest	Comparison	37.33	8.37	52
	Experimental	36.10	6.92	50
Posttest	Comparison	39.98	7.85	52
	Experimental	57.40	7.18	50

Inferential Statistics.

An ANOVA with repeated-measures was used again to analyze the effect of the metaconceptual intervention. However, for hypothesis three, rather than using the AAAS conceptual chemistry test that was done for hypotheses one and two, the Metaconceptual Awareness and Regulation Sale (MARS) scores were utilized. The within-subjects factor was time as both the comparison and experimental groups were tested with the MARS two times. The between-subjects factor was the treatment of metaconceptual questions being asked. Levene's Test of Equality of Error Variances was conducted resulting in no violations of variation, refer to Table 10.

Table 10

Levene's Test of Equality of Error Variances

	F	*df1*	*df2*	*p*
Pretest	1.65	1	100	.203
Posttest	3.26	1	100	.353

The ANOVA with repeated-measures analysis did not indicate a significant between-subjects effect, $F(1,100) = .03$, $p = .874$, $\eta_p^2 = .000$). There was insufficient evidence that the intervention of asking the students' metaconceptual questions had an effect on their MARS posttest scores. The Tests of Within-Subjects Contrasts showed a significant interaction between time and treatment $F(1,100) = 5.34$, $p = .023$, $\eta_p^2 = .05$). In Figure 2, the experimental group and the comparison group estimated marginal means are shown over time, MARS pretest and MARS posttest four weeks later.

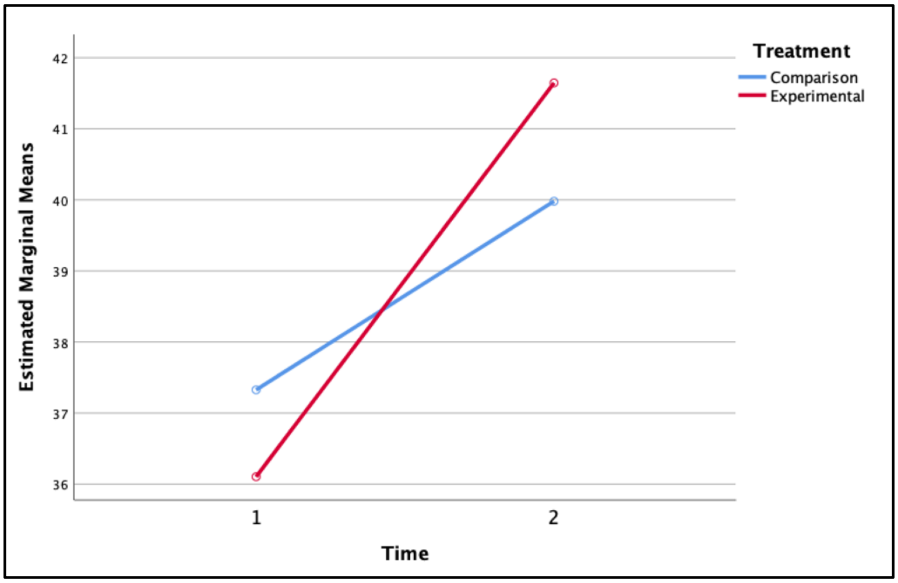

Figure 2. Estimated Marginal Means of MARS

Summary

This research study utilized two different instruments: AAAS conceptual chemistry assessment three times (pretest, posttest, and retention test) and the MARS two times (pretest and posttest). Two groups of students, experimental and comparison, took the same assessments for the same number of times. The resulting data from these assessments was reviewed to see if it met normal parametric assumptions (skewness, kurtosis, normality, and absence of outliers). The AAAS data contained four outliers in the pretest, posttest, and retention test. Due to the large sample size, $N = 103$, the outliers were removed. The other parametric assumptions were met including skewness, kurtosis, and normality. The scores from the MARS assessment met all parametric assumptions.

Three research questions guided this study and subsequent data analysis. The first research question asked whether using metaconceptual questions had an effect on students' conceptual chemistry knowledge as measured by the AAAS assessment. An ANOVA with repeated-measures was used to analyze the data and indicated that the use of metaconceptual questions had a significant effect, $F(1,98) = 10.17$, $p = .002$, $\eta_p^2 = .10$. Furthermore, Cohen's *d* was .63, $p = .005$ indicating a medium sized effect. The second research question focused on the effect of using metaconceptual questions on the retention of chemistry conceptual knowledge. While both groups, experimental and comparison groups mean scores declined from the posttest to the retention test, the comparison group declined more. The significance of this difference was not determined. The difference in decline was 3.95, with the comparison group declining a mean of 15.10 and for the experimental group a mean of 11.15. In addition, the retention test scores of the experimental group ($M = 44.48$, $SE = 2.30$) were significantly higher than those of the control group ($M = 32.79$, $SE = 1.92$), $p < .001$ with an effect size of $d = .85$.

The third research question examined if using metaconceptual questions would have an effect on students' metaconceptual awareness as measured by the MARS assessment. Again all scores were reviewed for normal parametric assumptions including kurtosis, skewness, normality, and absence of outliers. The data met all normal parametric assumptions. An ANOVA with repeated-measures was performed indicating that using metaconceptual questions had no significant effect on student performance on the MARS posttest, $F(1,100) = .03$, $p = .874$, $\eta_p^2 = .00$).

Chapter 5

Discussion and Conclusion

This study focused on how using metaconceptual scaffolding questions in the science classroom affected students learning of chemistry concepts including their retention of chemistry concepts overtime. The treatment of metaconceptual scaffolding questions was designed to increase the metaconceptual awareness of the students thus increasing their conceptual chemistry knowledge and retention of the knowledge. Metaconceptual awareness is a prerequisite for conceptual change to occur for science learners (Carey, 2009; Vosniadou, 2014. Without metaconceptual awareness students often revert back to their scientific inaccurate preconceptions (Huang et al., 2016; Vosniadou & Skopeliti, 2014).

Research Methodology

This quasi-experimental study utilized four intact high school chemistry classes, two were randomly assigned to the comparison group and two were assigned to the experimental group. The independent variable was providing the students with metaconceptual scaffolding questions. The dependent variables were conceptual chemistry knowledge and metaconceptual awareness and regulation. The experimental group was provided metaconceptual scaffolding questions for three weeks similar to those provided in previous conceptual change empirical studies (Huang et al., 2016; Yürük et al., 2008). Both groups took a pretest, posttest, and retention test on chemistry concepts. Both groups also took a pretest and posttest using the Metaconceptual Awareness Regulation Scale (MARS). An ANOVA with repeated-measures was utilized to analyze both the AAAS and MARS scores.

Discussion of Results

Research Questions 1 and 2.

Rather than discussing the findings from research questions one and two separately, they will be discussed together as they utilized the same assessment and are related to the same empirical studies. The first research question asked if there is a statistically significant difference in chemistry conceptual knowledge for students who receive metaconceptual scaffolding questions when compared to students who receive the same chemistry instruction for four weeks without metaconceptual scaffolding questions. The second research question asked if the use of metaconceptual scaffolding questions increase students' retention of chemistry concepts over time.

An ANOVA with repeated-measures indicated a positive significant effect from the metaconceptual treatment, $F(1,98) = 10.17$, $p = .002$, $\eta_p^2 = .09$. Previous empirical studies have also indicated a positive significant effect of utilizing metaconceptual scaffolding questions to increase science conceptual knowledge. Huang et al. (2016) utilized metaconceptual scaffolding questions during an online simulation study for 8th grade science and found the treatment also had a significant effect, $F(1, 111) = 15.96$, $p < .01$, $\eta^2 = .13$. While the current chemistry study was similar to that of Huang, Ge, and Estereyel there were a few differences. Most notably, the computer simulation study relied solely on an interactive computer simulation to teach the content. Students in the computer simulation study did not interact with each other during class time nor receive instruction from the instructor. However, the current chemistry study more closely replicates a typical science classroom environment. In this chemistry study, groups of students, experimental and comparison, engaged in typical chemistry high school instruction including direct teaching, cooperative learning, laboratory experiments, and group POGIL exercises. During typical chemistry instruction students discuss work, discuss lab results with their partner, and write conclusions where they discuss results in the context of their hypothesis. Both the experimental and comparison groups performed these typical science classroom tasks. However, the experimental group had metaconceptual scaffolding questions instead of additional practice problems that the comparison group had. While the partial eta squared value was slightly smaller for the present chemistry study compared to the computer simulation study, only accounting for 9.4% of variance, it still indicates a positive effect on learning for a typical science classroom.

The second empirical study that also focuses on the effects of metaconceptual scaffolding questions was done in a university setting with science text (Yürük & Eroglu, 2016). The university text study was similar to the current chemistry in that a pretest, posttest, and retention test for science conceptual knowledge were used. However, there were also three main differences between the two studies. The university text study had an additional experimental group that received refutation text. Refutation text is positioned within the theory-theory framework while metaconceptual scaffolding questions fits within the framework theory, which provides the theoretical background for this current study (Posner et al., 1982). The second main difference is the methodology. The university text study allowed random assignments of participants and did not rely on intact classes. The students in the university text study read the texts, sat apart from each other, and were encouraged not to interact with anyone else in the room. The third difference between the two studies is the participant sample. The university text study was done with university preservice science teachers while the current chemistry study utilized high school students. The eta squared for metaconceptual treatment, .36, $F(2,102) = 28.24$; $p < .05$, from the university text study was much larger than .09 in the current high school chemistry study. The differences in methodology, including typical classroom activities as mentioned in the previous paragraph, may have minimized the amount of variance solely attributed to the metaconceptual treatment.

The average score of the experimental group ($M = 55.63$) was significantly higher than the comparison group ($M = 47.88$), $p = .005$ with medium effect size $d = .63$. The data from this study supports the hypothesis that there is a statistically significant difference between the two groups on the conceptual chemistry posttest. This study's result of significant difference in posttest means is similar to the two previous studies mentioned, both the computer simulation study and the university text study had higher posttest means for the group who received metaconceptual scaffolding questions. The computer simulation study provided the means of 9.09 for the experimental group and 6.15 for the comparison group on a 10-point scale; the significance is not provided (Huang et al., 2016). The university text study indicate a significant mean difference, $p < .05$, between the groups' posttest scores (Yürük and Eroglu, 2016).

Research question two explored the retention of conceptual chemistry knowledge over time. In the current chemistry study, the group who received the metaconceptual questions on average scored significantly higher than the group who did not receive the treatment by 11.69, $p < .001$ with an effect size of $d = .85$. This difference in retention scores between groups is similar to those in the previous mentioned studies. Both the computer simulation study and the university text study also showed higher average mean scores for those received metaconceptual questions.

Research Question 3.

This study's third research question asked if there was a statistically significant difference in metaconceptual awareness for students who receive metaconceptual scaffolding questions when compared to students who did not. Metaconceptual awareness was measured by the Metaconceptual Awareness and Regulation Scale (MARS). The ANOVA with repeated-measures did not indicate a significant effect $F(1,100) = .03$, $p = .874$, $\eta_p^2 = .00$. The MARS instrument was developed in Turkey within the context of high school chemistry. The MARS instrument has not been utilized in studies in the United States.

There are many possible reasons why the MARS results did not indicate a significant effect from the metaconceptual treatment. There is the possibility that although the metaconceptual scaffolding questions increased the chemistry conceptual posttest and retention test scores, the questions did not increase metaconceptual awareness. There is also the possibility that, although the MARS was a good fit for the Turkish chemistry high school students, it was not a good fit for the United States chemistry students and was not able to assess their metaconceptual awareness. The MARS included terms such as "plausible" are not commonly used words by the 10th and 11th grade students in this class. Because the words used in the MARS were not commonly used by these high schoolers, there is a high possibility that did not accurately measure their metaconceptual awareness.

Thirdly, the format of the MARS is very different from the AAAS conceptual chemistry test. The MARS was administered as designed by the original authors and features all ten questions on one page. The AAAS conceptual chemistry test was administered via computer presenting one question per page, often with a graphic that must be answered before the student can move on. Although the same instructions were given during both assessments, “take your time and try your best,” the instructor noted that the students finished the MARS in a small amount of time, many circling quickly as they scanned the questions. Further research needed for metaconceptual awareness scales will be discussed in a later section.

Limitations

There are several factors that could limit the internal validity and generalizability of this research including research method, participants, and methodology. Most of these limitations are inherent in studies that take place in natural school settings. Previous studies on utilizing metaconceptual scaffolding did not mimic a natural school setting. While this study may have more limitations due to this quasi-experimental design it is also more applicable to science classrooms.

***Research Method*.**

This quasi-experimental study was done in a high school with intact classes. Although intact classes were randomly assigned to the experimental and control group, individuals were not. Therefore, there was not true randomization of the population. Although all four chemistry classes had the same prerequisites, sometimes due to placement of other advanced classes, high-achieving students can be clustered together. Because of this limitation, pretests were administered to both groups of students. A t-test was conducted to ensure that there was no significant difference between the groups both on the AAAS pretest and the MARS pretest. No significant difference was found.

Participants.

A convenience sample of high school chemistry students was used in this study. The sample used in this study may not be representative of all science students. The prerequisites for entrance into high school chemistry at this school include passing high school algebra. Although both groups, comparison and experimental, had the same prerequisites this may limit generalizability. More demographic information regarding participant sample is located in chapter three. The data from ten participants were excluded from the sample due to excess absences, three or more absences during the 15-day instructional period. There were a high number of absences due to confirmed cases of influenza. However, removing students' data who missed school may have altered the population.

Methodology.

In this study, the AAAS was administered three times to both the comparison group and control group while the MARS was administered twice to both groups. By administering the same assessment more than once, this may possibly improve scores because the students become "test-wise" (Gall et al., 2007). Both groups were exposed to the same number of assessments so that test exposure would not benefit one group over the other. Another possible limitation is compensatory rivalry, when those in the experimental group outperform those in the control group because they perceive they are in the experimental group and thus need to outperform the control group (Gall et al., 2007).

Although students were never told which group their class period belonged to and periods were randomly assigned, there is a chance student may have inferred which group they were in. The IRB process necessitated a brief description of the experiment for both the consent and assent forms. Students in the experimental group may have noticed that they were answering questions similar to those described in the IRB. Students in the experimental group could have possibly discussed their metaconceptual questions with other students outside of class including those in the comparison group thus exposing them to the treatment. However, the instructor did not witness any discussion of which study group the students belonged to or what the questions were. These high school chemistry students, like many high school students, tend to focus on social aspects outside of class time. Between classes and at lunch the instructor only witnessed social discussions that were of no relevance to high school chemistry.

Prior to this study the instructor commonly used open-ended and reflective questions during classroom discussion and written work. However, the previously used questions were not used as routinely as in the intervention for this study or worded with a focus on metaconceptual awareness. During this study, the comparison group continued to take part in normal classroom activities including discussion and open-ended questions. They did not receive the intervention of metaconceptual questions. Nonetheless, the reflective nature of this classroom environment could have a ceiling effect on the effect size of the intervention. In classrooms or experimental studies that do not have reflection as part of the normal classroom activities, the intervention of asking students metaconceptual awareness questions may have more of an effect size. The intervention in these environments would provide more of a difference and thus potentially a much larger effect size.

Finally, this study did not provide feedback or extrinsic rewards such as points for completing the AAAS, MARS, or the metaconceptual scaffolding questions throughout the treatment. The previous metaconceptual scaffolding studies mentioned also did not provide feedback or extrinsic motivation for completing the assessments or metaconceptual questions. The metaconceptual questions are reflective in nature and are not intended to be written to an outside audience. The students in this study are accustomed to not receiving points for most of their practice work. Instead, the focus is on better understanding the content. However, this lack of feedback or points could limit the generalizability in a classroom that did assign points for all assignments.

Suggestions for Further Research

Conceptual change research, specifically within the framework theory, provides many further avenues for research. Although conceptual change research has been ongoing for decades, framework theory and metaconceptual scaffolding are relatively new. Vosniadou (2001) began writing about framework theory as an alternative to the more classical conceptual theories within the past 20 years. Recent neuroscience studies have brought forth evidence supporting her framework theory (Dawson, 2014; Mareschal, 2016). Given the newness of framework theory there has not been many empirical studies that have used it.

More research is needed in the effectiveness of classroom interventions that utilized framework theory. There are very few quantitative studies that utilize metaconceptual scaffolding questions to increase conceptual knowledge and retention of knowledge. This study was done within a high school chemistry classroom and the prior study, that utilized a computer simulation, was done in 8th grade science. The researcher could not find quantitative studies that utilized metaconceptual questions within elementary science though there are a few qualitative studies with small sample sizes. The current high school chemistry study utilized a shortened timeframe of one month for retention. Further studies that utilize six months to a year for retention testing are warranted. Lastly, this study was performed in a high school chemistry class. Other sciences, such as life sciences, should also be explored to see if there are similar effects.

Implications for the Classroom

This intervention of utilizing metaconceptual scaffolding questions in the high school science classroom does not take an exceptional amount of time or resources. Students were able complete the metaconceptual scaffolding questions within 5-8 minutes and answered them in lieu of additional practice problems. The classroom instructor did not have to spend additional time by providing feedback for the questions. This relatively easy intervention had a high effect size of $d = .85$ on retention of conceptual chemistry knowledge. Furthermore, it has been well researched that when students do not undergo conceptual change they revert back to their original preconception (Huang et al., 2016; Vosniadou & Skopeliti, 2014). This intervention of providing metaconceptual questions is an easy one that science instructors can use to facilitate their students' retention of conceptual knowledge.

The purpose of this study was to analyze the effects of using metaconceptual questions on students' conceptual change within the science classroom. Conceptual change has been a prominent science education research focus for many decades.

However, recent conceptual change research has shifted from classical conceptual change to the framework theory, which necessitates students having increased metaconceptual awareness. Without metaconceptual awareness students revert back, over time, to their original and often inaccurate preconceptions. Recent science education studies have demonstrated the positive effect of using metaconceptual questions to increase the retention of conceptual knowledge. However, this study is the first quantitative study to utilize a natural school setting, with an instructor teaching, to analyze the effect of the intervention. By asking students metaconceptual awareness questions in chemistry class, students in this study were better able to retain conceptual chemistry knowledge. The large effect size of d = .85 is noteworthy for this classroom intervention. More exploration of this intervention at the classroom level is needed.

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Appendix A

Metaconceptual Awareness and Regulation Scale (MARS)

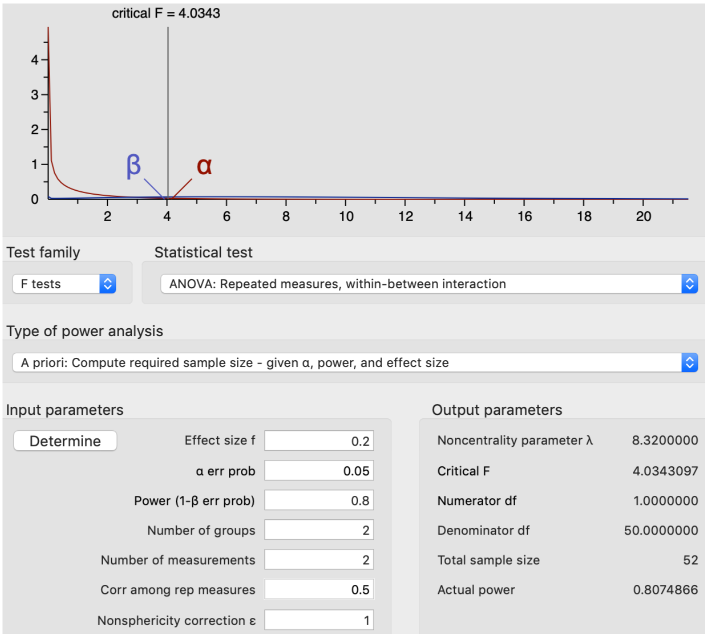
Direction: This scale aims to understand your ideas related to learning. While answering this scale, please focus on your learning about a chemistry topic. Please read each statement and circle only one number reflecting your opinion. There are no right or wrong answers. Your answers will be kept confidential. Thank you for your participation.	Never	Rarely	Occasionally	Frequently	Very frequently	Always
1. While learning chemistry topics, I compare whether my ideas are consistent with the ideas coming from my friends, teacher or other sources (book, journal, etc.)	1	2	3	4	5	6
2. While learning a chemistry topic, I monitor the changes in my ideas related to the/that topic.	1	2	3	4	5	6
3. I consider if I can use the knowledge I learned recently in the chemistry course in various topics.	1	2	3	4	5	6
4. I question whether my prior knowledge related to a chemistry topic is plausible.	1	2	3	4	5	6
5. I know what I did *not* understand about a chemistry topic.	1	2	3	4	5	6
6. I know what I learned about a chemistry topic.	1	2	3	4	5	6
7. While learning a chemistry topic, I compare my prior knowledge with the new knowledge.	1	2	3	4	5	6
8. I use my prior knowledge related to a chemistry topic.	1	2	3	4	5	6
9. I become aware that I understood a topic related to chemistry.	1	2	3	4	5	6
10. I evaluate whether the ideas coming from my friends, my teacher, or other sources (book, journal, etc.) related to a chemistry topic are plausible or not.	1	2	3	4	5	6

Used with permission from Dr. Kirbulut

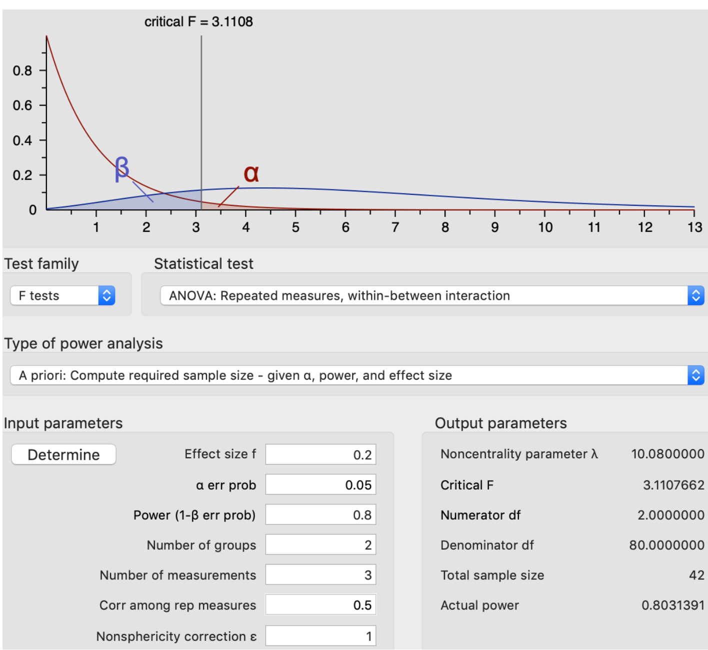
Appendix B

G*Power Output

MARS



AAAS



Appendix C

Student Assent

Engaging the culture, changing the world®

Seattle Pacific UNIVERSITY

INFORMED ASSENT

Effects of Metaconceptual Scaffolding on Conceptual Change

Investigators: Erin Duez, (760) 499-1800, dueze@spu.edu
Faculty Sponsor: Dr. Nyaradzo Mvududu,(260) 281-2000 nyaradzo@spu.edu

PURPOSE

You are invited to take part in a research study. Ms. Erin Duez is studying the effects of teaching strategies on learning science. The purpose of this study is to examine the effects of asking students questions about how their science understanding is changing. The approximate number of students in this study is 120. All students in Ms. Duez's chemistry classes are eligible for the study. All students will continue to have regular chemistry instruction from Ms. Duez.

PROCEDURES

At the start of the unit, all students will take a brief 20-item pretest on chemistry concepts and a survey on how they learn chemistry. During the 3- week unit, students in some sections will be asked additional reflection questions regarding how their understanding of chemistry is changing. Two of Ms. Duez's four chemistry sections will be randomly selected to receive the additional reflection questions. All students will receive regular chemistry instruction. At the end of the 3-week unit all students will take a posttest on the chemistry concepts, similar to what they usually take in chemistry class. They will also repeat the survey regarding how they learn chemistry. Four weeks later they will take another brief assessment to see if they retained the knowledge. All assessments will be deidentified, names will be removed, and assigned a random number so that students' data can remain confidential.

RISKS and BENEFITS

All students will receive the same chemistry instruction from Erin Duez
Potential risks to students:

- Risks to students will not be greater than they normally experience in chemistry class, same pretest and posttest format.
- Students may feel unease while answering pretest and posttest chemistry. questions. Students will be instructed to try their best, if they do not know the answer it is okay, and students may stop if they feel uncomfortable.

Potential benefits to students:

- Through the use of questioning regarding their understanding of chemistry, students may better understand chemistry.
- Students in the intervention group may gain greater metaconceptual awareness with the use of additional prompts. In the next chemistry unit, all students will receive the additional intervention.

Potential benefits for your chemistry teacher and teachers generally:
Learn better strategies to teach chemistry

PARTICIPATION AND ALTERNATIVES TO PARTICIPATION

There are no alternatives to engaging in the classroom activities measured in the study, as the students will be engaged in the typical curriculum as prescribed by the School District and required per the guidelines for High School Graduation. If you decide to be a 'NON-participant', you will remain engaged in the regular classroom activities; however, your data will not be collected for the study.

CONFIDENTIALITY

The information in the study records will be anonymous. All names will be removed and coded with a random number. The coded, anonymous data will be stored securely and will be made available only Erin Duez and Dr. Nyaradzo Mvududu. There will be no way to link any work or score to you.

Your de-identified data may be used in future research, presentations or for teaching purposes by the Principal Investigator listed above.

SUBJECT RIGHTS

If you have questions at any time about the study or the procedures, you may contact the Principal Investigator, Erin Duez, at (760) 499-1800. If you have questions about your rights as a participant, contact the SPU Institutional Review Board Chair at 206-281-2201 or IRB@SPU.edu .

CONSENT

Your signature on this form indicates that you have understood to your satisfaction the information regarding participation in this research project and agree to participate in this study. In no way does this waive your legal rights nor release the investigators, sponsors, or involved institutions from their legal and professional responsibilities.

I have read the above information and agree to participate in this study. I have received a copy of this form.

Participant's name (print) ______________________________	**Researcher's name (print)** ______________________________
Participant's signature ______________________________	**Researcher's signature** ______________________________
Date ____________	**Date** ____________

Copies to: Participant Principal Investigator

Appendix D

Guardian Consent

Engaging the culture, changing the world®

Seattle Pacific UNIVERSITY

INFORMED CONSENT

Effects of Metaconceptual Scaffolding on Conceptual Change

Investigators: Erin Duez, (760) 499-1800, dueze@spu.edu
Faculty Sponsor: Dr. Nyaradzo Mvududu,(260) 281-2000 nyaradzo@spu.edu

PURPOSE

Your child is invited to take part in a research study during normal chemistry class time. Ms. Erin Duez is studying the effects of teaching strategies on learning science. The purpose of this study is to examine the effects of asking students questions about how their science understanding is changing. The approximate number of students in this study is 120. All students in Ms. Duez's chemistry classes are eligible for the study. All students will continue to have regular chemistry instruction from Ms. Duez.

PROCEDURES

At the start of the unit, all students will take a brief 20-item pretest on chemistry concepts and a survey on how they learn chemistry. During the 3- week unit, students in some sections will be asked additional reflection questions regarding how their understanding of chemistry is changing. Two of Ms. Duez's four chemistry sections will be randomly selected to receive the additional reflection questions. All students will receive regular chemistry instruction. At the end of the 3-week unit all students will take a posttest on the chemistry concepts, similar to what they usually take in chemistry class. They will also repeat the survey regarding how they learn chemistry. Four weeks later they will take another brief assessment to see if they retained the knowledge. All assessments will be deidentified, names will be removed, and assigned a random number so that students' data can remain confidential.

RISKS and BENEFITS

All students will receive the same chemistry instruction from Erin Duez

Potential risks to students:

- Risks to students will not be greater than they normally experience in chemistry class, same pretest and posttest format.
- Students may feel unease while answering pretest and posttest chemistry. questions. Students will be instructed to try their best, if they do not know the answer it is okay, and they may stop if they feel uncomfortable.

Potential benefits to students:

- Through the use of questioning regarding their understanding of chemistry, students may better understand chemistry.
- Students in the intervention group may gain greater metaconceptual awareness with the use of additional prompts. In the next chemistry unit, all students will receive the additional intervention.

Potential benefits for your child's chemistry teacher and teachers generally:

- Learn better strategies to teach chemistry

PARTICIPATION AND ALTERNATIVES TO PARTICIPATION

There are no alternatives to engaging in the classroom activities measured in the study, as the students will be engaged in the typical curriculum as prescribed by the School District and required per the guidelines for High School Graduation. If your child or you decide to be a 'NON-participant', your child will remain engaged in the regular

CONFIDENTIALITY

The information in the study records will be anonymous. All names will be removed and coded with a random number. The coded, anonymous data will be stored securely and will be made available only Erin Duez and Dr. Nyaradzo Mvududu. There will be no way to link any work or score to you.

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If you have questions at any time about the study or the procedures, you may contact the Principal Investigator, Erin Duez, at (760) 499-1800. If you have questions about your rights as a participant, contact the SPU Institutional Review Board Chair at 206-281-2201 or IRB@SPU.edu .

CONSENT

Your signature on this form indicates that you have understood to your satisfaction the information regarding participation in this research project and agree to participate in this study. In no way does this waive your legal rights nor release the investigators, sponsors, or involved institutions from their legal and professional responsibilities.

I have read the above information and agree to participate in this study. I have received a copy of this form.

Participant's name (print) ______________________	**Researcher's name (print)** ______________________
Participant's signature ______________________	**Researcher's signature** ______________________
Date __________	**Date** __________

Copies to: Participant Principal Investigator

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JAN 2020
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Expires_______