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Investigating the Pedagogical Content Knowledge of Georgia 6-12 Science Teachers in Relation to Conservation of Mass

Lyric Portwood
ldc8881@students.kennesaw.edu

Investigating the Pedagogical Content Knowledge of Georgia 6-12 Science Teachers in Relation to Conservation of Mass

by

Lyric Danielle Curtis Portwood

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Dedication

This dissertation is dedicated to my three sons, Kaden, Kason, and Kolson. You are my drive and reason for pushing so hard to accomplish this lifetime goal. Remember that you can do anything you set your mind to as long as you never give up and always persevere through anything life throws at you.

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Abstract

The Law of Conservation of Matter is a crosscutting concept in science that has implications for all disciplines of science. Conservation of Matter concepts are interwoven into all middle school and high school science courses both within the Next Generation Science Standards (NGSS) and the Georgia Standards of Excellence (GSE). For students to become scientifically literate, teachers of science must be able to articulate the content accurately to students and anticipate student difficulties and misconceptions in understanding the content. In order to ensure that students successfully learn said content, science teachers must possess both content knowledge and pedagogical content knowledge. Strengths and limitations in the CK and PCK of science instructors within various populations must be identified so that interventions can be designed to help these teachers improve and enhance the PCK of the scientific community as a whole. This study utilized a mixed method design to investigate the correlation between content knowledge, pedagogical content knowledge, and instructor demographics, as well as discover the way that teachers address student misconceptions in class. Middle school and high school science teachers in Georgia participated in the administration of a concept inventory and semi-structured interviews relating to the concept of Conservation of Matter. The concept inventory data investigated indicated that there is no correlation between content knowledge and pedagogical content in the area of Conservation of Matter for these teachers. However, it was found that the content knowledge and teaching an honors level class influenced the pedagogical content knowledge score of these teachers. Interview data suggests that teacher misconceptions in regard to Conservation of Matter exist within this population. These misconceptions specifically were found in regard to the splitting of atoms during chemical reactions and matter cycling in biological systems. Teachers were both proactive and reactive to the presence of student misconceptions in class. Another finding from this study indicates that teachers make alterations to their curriculum due to misconceptions. While the modifications to the curriculum varied from adding/changing activities, adding additional instructional time, and incorporating more discussions and questioning, a high percentage of teachers interviewed did modify their curriculum due to misconceptions being present. This study highlights the CK and PCK of teachers related to conservation of matter and can be utilized in order to develop interventions and professional development for teachers that allow for development in these areas.

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Chapter 1: Introduction

Background of the study

Science literacy is indispensable in the contemporary technologically advanced world. Science literacy satisfies society's need for objective and open-minded citizens and appropriate labor market skills. In order to produce scientifically literate citizens teachers must be competent and effective in the classroom. Quality instruction in the classroom allows students to become more scientifically literate due to exposure to and ability to decipher scientific concepts and information in the manner that a scientist would. As a result, pedagogical content knowledge of teachers (PCK) has continued to receive significant attention since the mid-1980s (Bond-Robinson, 2005). PCK is one of the seven categories Shulman highlighted in the U.S.-centered debate on teaching profession competency. Sadler (2013) reiterated that teachers would be unable to assist children if they do not understand the content themselves. For science teachers, possessing science matter knowledge was identified as critical to students' learning of science. Science matter knowledge (SMK) also known as Content Knowledge (CK) is defined as the general conceptual understanding of the subject area and the ability of the teacher to complete the coursework (Sadler, 2013). Based on Sadler's (2013) findings, the current study will investigate the Content Knowledge and Pedagogical Content Knowledge of science teachers regarding the Law of Conservation of Mass.

Teacher's content knowledge and pedagogical content knowledge help students to learn and assess new ideas effectively. According to Grossman (1990), content knowledge and pedagogical content knowledge are teachers' main ideas, and their mastery ensures that the concept will be understood by different students and thus enhance successful learning. In chemistry, the content expertise comprises the ability to understand various chemical reaction principles occurring at macroscopic and submicroscopic levels. Moreover, to achieve the multiple levels of understanding, one must apply various techniques to obtain specific insight into obtaining the teachers' numerous weaknesses and strengths (Bayram-Jacobs, 2019). The various concept inventories are usually the assessments primarily derived from detailed scientific research. They are mainly used to identify the countless misconceptions the different students have in their daily lives. Researchers utilized traditional concept inventories to gain a specific insight into understanding better what previous knowledge students often bring to their classes.

Statement of the problem

The development of PCK is one of the primary goals of teacher education. However, there is need for more studies to explore the outcomes when the teacher explicitly introduces new ideas or content to students. For instance, the Law of Conservation of Matter is a "cornerstone" in modern chemistry development (Ozmen & Ayas, 2003). Furthermore, it is described as one of the fundamental laws of science and an empirical law by Ozmen and Ayas (2003). Paixao and Cachapus (2000) describe the law as indispensable in the entire understanding of chemistry in subsequent studies, including and beyond the study of chemical reactions. This law states that matter cannot be created or destroyed but only rearranged during a chemical reaction. The mass of all reactants is equivalent to the mass of all products before and after a chemical reaction. The study of chemical reactions and conservation of mass is problematic for many chemistry students and is a central theme for 14-15-year-old pupils (Ozmen & Ayas, 2003). Since this concept is central and challenging for students, teachers should be aware of student difficulties in this area. This law appears in each of the middle school and high school discipline standards under the NGSS (Next Generation Science

Standards). In addition, the law is present in seven core science courses at the secondary level in Georgia as listed in the Georgia Performance Standards.

National science reform documents call for more advanced pedagogical practices and cohesive science teaching. Pedagogical content knowledge and content knowledge are developed and intimately correlated in successful science teachers (Grossman, 1990). One of the tenets of Pedagogical Content Knowledge is the knowledge of assessment and the ability of teachers to predict student difficulties and misconceptions within the curriculum and concepts being taught. This ability allows teachers to plan the curriculum to address these misconceptions and help students overcome these misconceptions during instruction (Pompea & Walker, 2017). Based on these ideas, the current study will examine the purposeful application of PCK in teaching science concepts specifically the Law of Conservation of Mass. The study will help researchers to understand how teachers develop content for positive science learning outcomes that rely on the Law of Conservation of Matter. Past studies found that various teachers widely use pedagogical content knowledge to ensure that they have successfully trained the different students on the main concepts in both theory and practice. In this study, our interest is to understand the various ways through which the PCK will assist the teachers on the multiple ways to help the student understand the science concept of mass conservation. Investigating the CK, PCK, and self-reported demographic data differences between various populations allows for these differences to become more apparent and therefore targeted interventions can be researched and developed for this specific population.

Research objectives and questions

The study attempted to answer the following questions:

1. Is there a relationship between content knowledge, pedagogical content knowledge, and teacher demographics collected?
2. How do teachers use their knowledge of common student misconceptions related to conservation of mass to address student needs for this concept of the curriculum?

The study collected data from concept inventories and semi-structured interviews regarding both PCK and CK to answer the research questions, as they are related to mass conservation. The research fulfilled specific study objectives including:

i. To examine the relationship between PCK and CK of 6-12 science teachers in Georgia regarding conservation of mass
ii. To examine the relationship between PCK and self-reported teacher demographics.
iii. To investigate teachers use of PCK in designing learning experiences about the Law of Conservation of Mass

Purpose and significance of study

The purpose of the study was to investigate varying levels and experiences of science teachers CK and PCK as it relates to conservation of matter concepts through a conservation of mass concept inventory and semi-structured teacher interviews. Through this, the effect of varying levels of CK and PCK on each other and teacher demographics was investigated. This enabled the researcher to discern the relationship between CK and PCK and teacher demographics. If teachers hold misconceptions, they will likely pass these on to their students (Yip, 1998). Strengths and weaknesses in CK and PCK of science teachers within different populations must be identified so that interventions can be devised to help these teachers improve and to improve the PCK of the entire scientific community.

Knowing which populations of teachers are most at risk of having less developed CK and PCK will also aid in the community's development of resources and interventions targeted towards science teachers. Elsewhere, the ability to define both the weaknesses and strengths in CK and PCK using various populations is identified to ensure that the interventions are devised. The interventions provide that teachers have improved together with the entire community who are studying science—moreover, familiarizing ourselves with noting the population of teachers who are less developed in both CK and PCK aids in the development of community intervention and resources. Furthermore, the ability to utilize the existing inventories aids in determining the PCK of the teacher when related to a particular topic.

Local context

The participants are all located within the state of Georgia. The study was conducted with teachers that have varying levels of experience, background, preparation programs, and degrees. These teachers teach middle school earth science, middle school life science, middle school physical science, secondary physical science, secondary biology, secondary life science, secondary chemistry, secondary physics and AP/IB biology, life science, physics and chemistry. There were at least eight teachers per subject area.

Conceptual framework

Shulman (1987) categorized teacher knowledge into several categories. Content knowledge and PCK are two of the essential types of teacher knowledge. Content knowledge is comprised of understanding the actual subject matter that is to be taught to the students. Within a science classroom, this constitutes the understanding of the chemical principles occurring at the submicroscopic level and the manifestation of these at the macroscopic level (Sadler, 2013). Measuring content knowledge can be achieved in many ways to gain insight into the strengths and weaknesses of teachers in terms of content. However, understanding science is not the only component that a teacher must possess when facilitating student learning.

On the other hand, the concept of PCK has been defined as "the knowledge used to transform subject matter content into forms more comprehensible to students" (Park & Oliver, 2008, p. 262). Grossman (1990) describes science PCK as both subject matter knowledge and general pedagogical knowledge and beliefs. In addition, this idea was expanded upon by Magnusson, Krajcik, and Borko (1999) as they described the components of PCK for science teaching. PCK for science teaching consists of orientations towards science teaching, knowledge and beliefs about science curriculum, knowledge and beliefs about students' understandings of specific topics, and knowledge and ideas about assessment in science. Researchers have reported difficulty measuring and quantifying science PCK, supporting its reported multifaceted and complex framework (Loughran, 2001).

Concept inventories are assessments that are derived from scientific research to identify misconceptions of students (Hestenes, 1992). Concept inventories are traditionally utilized to gain insight into what prior understanding students are bringing to the classroom. They are then administered again after the unit of instruction is complete to understand what learning has occurred. Sadler (2013) used concept inventories to measure CK and PCK of physical science teachers finding that teachers that could identify the most common student misconception achieved higher student gains in the classroom. Salder (2013) argue that a teacher's ability to identify the most common wrong answer on multiple-choice items is a measure of pedagogical content knowledge. Therefore, utilizing existing concept inventories can help determine a teacher's PCK related to a specific topic in a more time-efficient manner. In addition, concept inventories can simultaneously collect data on a teacher's content knowledge by looking for the correct responses to the questions within the inventory.

From these findings and theories, the proposed conceptual framework for the current study will be constructivist. Constructivism rests on the tenets of Piaget, which states that knowledge is constructed through experiences (1977). This study is based on the idea that students come to the classroom with prior experiences and conceptions, some of which may not agree with scientifically accepted thoughts. These misconceptions were constructed due to previous experiences inside and outside the classroom. Some students' prior conceptions may disagree with the ideas that teachers present in class (Solis, 2018). Therefore, teachers must help students to construct their knowledge in scientifically agreed ways so that their conceptions include scientifically accepted ideas about how the world works.

Organization of study

The rest of the dissertation is organized into the literature review, methodology, results, discussion, and conclusion chapters. The literature review presents critical studies of different aspects of content knowledge and pedagogical content knowledge in teaching science subjects. The methodology chapter describes the methods and procedures that the researcher will apply to attain the objective of the research. Results and discussion present the findings and their interpretations. Finally, the concluding chapter will offer a summary of the study and implications on theory and practice.

Chapter 2: Literature Review

Introduction

Teachers cannot help students learn and understand concepts that they themselves do not understand (Sadler, 2013). The knowledge that teachers must have in order to be effective in teaching concepts such as conservation of matter is a key topic of interest. A review of the existing literature reveals varied opinions regarding the kinds of knowledge that are essential to enhance good teaching. In acknowledging the significance of subject matter knowledge (SMK) for teaching, Shulman (1987) introduced the concept of PCK which encompasses teachers' knowledge and is based on the manner in which teachers link their pedagogical knowledge to their subject matter knowledge. Some studies have argued that there is no significant difference between PCK and SMK because SMK is a source to be transformed for teaching (Ozden, 2008). Teachers with inadequate and inaccurate knowledge about a subject or topic may transfer their misconceptions to their students. This may further increase the burden on students in understanding the concepts taught by their teachers.

According to Kaya (2008), there exists a link between teachers' pedagogical knowledge and the subject matter. Other researchers concluded that content knowledge had influence on PCK (Depaepe, 2013; Halim & Meerah, 2002; Loughran, 2008). Van Dooren, Onghena, & Verschaffel, 2002) observed that when teachers without subject matter knowledge taught topics that they did not understand well, they tended to dominate the discourse, talking more frequently, longer, and asking more low-level cognitive questions. Students were less likely to be the originators of questions or discussion topics. The authors also found that teachers' content knowledge also affected their assessment of students' solution strategies.

The literature review section addresses key aspects related to the study objectives. The key areas covered in this section include theoretical framework (constructivism); relationship between CK and PCK; components of PCK; and measuring PCK.

Guiding Study

This research is based on the study conducted by Sadler (2013), which focused on the influence of teachers' knowledge on student learning. The content knowledge possessed by teachers and their pedagogical content knowledge are critical in helping students learn and comprehend the concepts being taught. Given that the primary purpose of this study is to investigate the varying levels and experiences of science teachers in using their CK and PCK to enhance the teaching of conservation of matter concepts, the findings by Sadler (2013) will help guide this study.

The purpose for conducting this study is influenced by the need to understand the knowledge that science teachers should have to be effective in teaching the different science concepts. The existing literature provide diverse opinions concerning the kinds of knowledge that are essential for effective teaching. However, rigorous empirical studies to support the knowledge that science teachers should possess are still few. Sadler (2013) also observed that the available studies of teacher effectiveness mainly depend on proxies for teacher subject matter knowledge and teacher self-reports.

The key aspects that will be drawn from Sadler's (2013) when investigating how PCK can assist science teachers to promote students' understanding of the science concept of conservation of matter include subject matter knowledge and knowledge of student misconceptions.

Theoretical Framework

Constructivism

A guiding assumption of this study is that teacher knowledge is significant because it influences classroom instruction and student learning. The conceptualization of teacher knowledge in this study fits in the tradition started by Shulman (1986) which identifies distinguishable interacting knowledge bases. Many models in this tradition focus on pedagogical content knowledge (PCK), a form of professional knowledge that enables teachers to make subject matter comprehensible for students.

One of the key theoretical models that promotes PCK as a form of professionals to enhance learning among students is constructivism. Constructivism is based on the idea that people actively construct or make their own knowledge, and that reality is determined by your experiences. Constructivism is important for teachers because it influences the way they present content to students. Teachers and instructors that understand the constructivist learning theory understand that their students bring their own unique experiences to the classroom. Teachers are able to use constructivist learning theory to help their students understand the different science concepts such as conservation of matter (Makgato, 2012).

There are many specific elements and principles of constructivism that shape the way the theory works and applies to students. Constructivism holds that knowledge is constructed. This means that knowledge is built upon other knowledge. Students can build on their teachers' pedagogical content knowledge to enhance their understanding of the science concepts presented to them in class.

In Cognitive constructivism from the work of Piaget, a students' reactions to experience lead to learning (Amineh & Asl, 2015). From the work of Vigotsky, social constructivism plays an important role in the construction of meaning from experience. According to the constructivism framework, learning is a social activity in which learning is directly associated with students' connection to their teachers and this impacts their learning. Progressive education recognizes that social interaction is key to learning and thus uses conversation, interaction, and group applications to help students retain their knowledge.

Teachers should have an understanding of constructivist theory, principles and pedagogy in order to provide effective teaching and learning in the science classroom. In implementing a constructivist classroom, the teacher should; influence or create motivating conditions for students; take responsibility for creating problem situations; foster acquisition and retrieval of prior knowledge and; create the process of learning, not the product of learning (Palmer, 2005). The proponents of the constructivist framework provided the following principles for effective teaching and learning. The first principle is that teaching should begin with content and experiences familiar to the students, so they can make connections to their existing knowledge structures. New knowledge should be presented in the context of real-life applications, rather than abstract. Knowledge should be presented in a manner that does not change students' cognitive models drastically. This principle deals with the content knowledge the teacher possesses for teaching content on conservation of matter in the classroom.

Secondly, teaching should enable students to fill the gaps and extrapolate information and materials presented by the teacher on conservation of matter. The goal should be to empower learners with skills to be independent, and access and use relevant information from various sources to understand the concepts regarding conservation of matter.

The framework requires that teachers should understand subject matter if they are to make it comprehensible for students (McConnell, 2013). While this understanding must be transformed or integrated with other knowledge bases to develop PCK, Subject Matter Knowledge (SMK) is distinguishable from PCK. SMK refers to the knowledge of the discipline’s body of concepts, procedures, and processes or specific knowledge to be shared within the content for the students (Adler & Venkat, 2020). To understand how the teacher’s content knowledge of conservation of matter predicts student gains, it is important to understand the three domains of SMK – core content knowledge, specialized content knowledge, and linked content knowledge. Core content knowledge consists of the fundamental concepts of the scientific discipline the teacher is responsible for teaching. Specialized content knowledge comprises the scientific knowledge required to accomplish a teachers’ work, including the scientific understanding required to make sense of student responses. Linked content knowledge includes the connections that relate scientific concepts.

Subject Matter Knowledge (SMK)

Shulman (1986) described subject matter knowledge as the general conceptual understanding of a subject area possessed by a teacher, which is obtained by completing the required coursework. SMK is a foundational component of PCK and important for teaching. Rollnick (2008) found that teachers’ SMK influenced their methods of representing the subject matter to students, their design of assessment tasks, and their choice of instructional strategies. In the model that emerged from their findings, SMK was found to be one of the four fundamental domains of knowledge for teaching. In a study conducted by Chan & Yung (2015) to investigate the development of PCK during classroom instruction it was found that SMK facilitated the development of new instructional representations.

Wilson (1987) indicated that SMK involves the substantive and syntactic structures of discipline. The authors went ahead to explain that substantive structures comprise the ideas, concepts of the subject or topic, facts, and the relationships among those ideas, facts, and concepts. It was suggested that substantive structures provide diverse ways in which teachers can incorporate and organize the basic concepts and principles of the topics taught in class. Syntactic structure on the other hand provides a means by which teachers can establish truth and falsehood. Wilson (1987) stated that syntactic structure comprises knowledge of the ways in which teaching creates and evaluates new knowledge.

There has been increasing interest in examining the significance of SMK for teaching. Research has shown that SMK of science such as chemistry includes the knowledge of chemistry and knowledge about chemistry. For instance, when handling the topic about conservation of matter, teachers need to have an understanding of the principles of conservation of matter as well as the nature of the knowledge involved in understanding the topic. The teachers' role is to help students to develop a proper understanding of the subject matter (conservation of matter). To effectively help the students, teachers need to have a solid knowledge of the subject matter. Teachers with solid knowledge in teaching chemistry (and specifically the knowledge of conservation of matter) are more capable of helping students achieve a meaningful understanding of the subject matter.

Similarly, research has shown that the most basic level of subject matter is 'knowing that and knowing why'. 'Knowing that' involves the knowledge, rules, and concepts that are related to specific topic of study. 'Knowing that' is critical for teaching because it includes a basis for adequate PCK. 'Knowing why' comprises the knowledge pertaining the underlying meaning and understanding of why things are the way they are, and as such, it facilitates better pedagogical decisions (Even & Tirosh, 1995). According to Even & Tirosh (1995), 'knowing why' affects the

decisions made by teachers about the presentation of the subject matter. The concepts 'knowing that and knowing why' are critical for making good pedagogical decisions for teaching.
SMK is important because it enable teachers to indicate why particular statement is necessary to be considered or be demonstrated, why it is worth knowing, and how it relates to other statements in theory and practice (Usak, 2011). With proper SMK, a teacher has the capacity to identify the different ways of organizing and presenting the contents of a specific topic. Teachers can also outline the pedagogical grounds for selecting the approaches they use to present subject content under different circumstances.

Evidence from various studies show that SMK plays a key role in influencing classroom practice (Davis, 2006; van Driel, 2014). Findings from a study conducted to investigate the science teachers as they taught their area of certification and experience and as they taught in a new subject area for which they were not certified and had taught less than twice found that teachers acted like novices when teaching a new subject area. For examples, teachers struggled to respond to student questions about the science content and relied more on closed instructional strategies such as lecture or seatwork compared to their instruction in their specialty subject. In related studies, it was found that teachers who used the right mathematical knowledge in teaching experienced significantly larger student gains in their classrooms. More studies are still required to conclusively determine whether teacher SMK can influence student learning gains.

van Driel (2014) stated that science teachers should understand the subject matter they teach including knowledge of the concepts of their discipline and concepts from other related disciplines. In addition, teachers need to understand the processes and practices associated with their pedagogical practice. These dimensions of SMK play an important role in influencing the instructional decisions made by teachers in a science classroom and it also influences student learning (Abell, 2013).

In a study conducted by Diamond (2014), it was shown that the SMK of teachers improves as they interact more with the curriculum and engage in professional development programs. Teachers have to put more effort to understand the subject matter if they are to make it easy for their students to understand. The teachers' understanding of SMK must be integrated with knowledge bases to develop PCK (Jin, 2015). Großschedl (2015) provided evidence to show that classroom experience leads to the development of science teachers' PCK. In their study which involved prospective biology teachers, it was found that teachers with greater teaching experience (over 10 lessons taught) had higher PCK scores than the teachers without teaching experience.

To further demonstrate the importance of classroom experience in enhancing teachers' SMK and PCK, Chan & Yung (2015) explored how experienced teachers developed their PCK while teaching. The authors found that the teachers developed new instructional representations as they tackled unexpected student questions, faced unexpected student responses, or encountered other stimuli in the classroom. Classroom experience was also shown to influence additional forms of teacher knowledge. In a study to compare the knowledge of teachers with and without classroom experience in an alternative certification program, Friedrichsen (2009) found that teachers with classroom experience had improved and integrated SMK and pedagogical knowledge than those without classroom experience. As teachers planned and enacted lessons, their SMK and pedagogical knowledge became more coherent. The SMK of teachers with classroom experience is highly structured and organized. Arzi & White (2008) conducted a study in which they monitored 22 Australian secondary science teachers over 15 years, and in the process documented their SMK using concept maps. The authors found that the teachers' SMK became more comprehensive and coherent for topics that they taught regularly. Some studies have linked poor SMK in teachers to poor content instruction at the university level. A study conducted in Spain found that teachers hold misconceptions about their subjects or topics similar to those observed in students. Quilez (2004) explored teachers' explanations of chemical equilibrium changes in gaseous systems. The findings showed that a few teachers were able to provide the correct explanations, with the majority incorrectly drawing on Le Chatelier's Principle. The teachers attributed their incorrect explanations to their university content coursework. More research is needed to examine the link between coursework and teacher SMK because the scientific knowledge taught in university coursework is in most cases different to the scientific knowledge needed for teaching. Luft (2015) attempted to explain this disparity by indicating that professional development programs are focused on general pedagogy and are not designed to help teachers develop their science SMK.

Students' understanding of conservation of matter

Conservation of matter is a critical fundamental law in science and many students face difficulty understanding this concept. The law of the conservation of matter as described by Antoine Lavoiser states that matter cannot be created nor destroyed. As such, mass remains constant regardless of the various changes in the system. Atoms rearrange during a chemical reaction with the sum of the beginning reactants having the same mass as the sum of the ending products of the reaction. Pomper (1962) explained that Lavoiser was conducting a series of experiments to support the law of conservation of matter. The preservation of matter is the basic foundation of modern chemistry.

Studies have demonstrated the widespread misconception of students on the concepts of conservation of matter. The students' misconception if this fundamental law of science is not only widespread but also diverse (Ozmen & Ayas, 2003). Boujaoude & Barakat (2000) found that a significant proportion of students in secondary school could not solve conceptual problems in chemistry. The researchers also found that only 25% of secondary school students (with the majority of these from private schools) used the concepts of the conservation of matter as the basis for the various molecules present in different reactions. Identifying student misconceptions is critical for designing instructional interventions to help students to have a better understanding of science concepts.

Knowledge of student misconceptions (KSM)

A teacher's knowledge of the common student misconceptions that make it difficult to learn a concept such as conservation of matter is considered to be critical to effective teaching. While some researchers advocate that teachers should know common student misconceptions for the topics that they teach, others advocate that teachers should develop interviewing skills or tests to reveal student preconceptions in their classrooms. KSM is a part of Shulman's (1986) construct of pedagogical content knowledge, which he describes as the most useful forms of representation of ideas, powerful analogies, illustrations, examples, explanations, and demonstrations.

Shulman (1986) described the importance of teachers' knowledge of misconceptions in helping them identify the strategies that are beneficial in reorganizing the understanding of students. Such a view recognizes that learning science is as much about unlearning old ideas as it is about learning new ones. Learners struggle to change their misconceptions, ideas that make sense to them.

Grossman (1990) expanded the concepts of teacher SMK to include not just knowing the subject but also knowing the subject matter for teaching. Studies have proposed that teachers' CK should include the teachers' knowledge of students' misconceptions and typical errors. Teachers should examine concepts from the perspective of students, paying particular attention to the potential difficulties faced by students in learning concepts such as conservation of matter.

Relationship between CK and PCK

Content knowledge (CK) and PCK are two inextricably interwoven components of teacher knowledge, as described by Grossman (1990) that comprise accomplished teaching. Content knowledge is described as the knowledge of the subject matter that one is instructing on. Whereas pedagogical content knowledge is described as the knowledge of students' understandings, understandings of how to teach the curricula and the best instructional strategies for that concept. Shulman described PCK as how subject matter is organized, adapted, and represented for instruction (Shulman, 1986). Inevitably one must possess both of these to be the most effective at teaching and are the components of teacher knowledge as described by Grossman (1990).

Shulman (1986) also pointed out that although CK and PCK represent distinct categories of content knowledge, they share a common element: they are both highly dependent on the content to be taught. Studies support the fact that that PCK is specific to particular subject content and that the knowledge of this content is important and necessary for teachers' strong and deep PCK. In several policy documents, it is also supported that strong knowledge of the subject taught is a core component of teacher competence and consequently of their PCK.

Studies have shown that there is a significant interrelationship between CK and PCK of science teachers. Similarly, researchers have found that CK has a major influence on PCK.

Research into the relationship between CK and PCK in the teaching of chemistry topics has been conducted by various researchers. For example, De Jong (2005) found that most of the chemistry teaching master students started to think deeper about students' difficulties in understanding concepts such as particulate nature of matter after applying a special education related to PCK.

Within a chemistry classroom, this comprises the understanding of the chemical principles that are occurring at the submicroscopic level and the manifestation of these at the macroscopic level. Measuring content knowledge can be achieved in a multitude of ways in order to gain insight into the strengths and weaknesses of teachers in terms of content. However, understanding the chemistry is not the only component that a teacher must possess when facilitating student learning.

Agathangelou & Charalambous (2021) suggested that CK and PCK are two distinct but often strongly correlated constructs. The authors stated that CK could be considered pre-requisite of PCK. For instance, when the CK and PCK items were placed on the same item response theory scale in most of the CK–PCK pairs, the PCK items were more difficult than their aligned CK items; additionally, in most of the quasi-implication paths of the statistical implicative analysis, answering the CK items was found to be pre-requisite of answering their aligned PCK items. Majority of the studies are in agreement that having a good CK increased teachers' PCK and it contributed to improved student gains.

Components of PCK

PCK is defined as the subject matter knowledge for teaching (Shulman, 1986). PCK can also be described as the practical knowledge used by teachers to guide their pedagogical practices. The PCK framework consists of five components as described by Magnuson (1999). The five components are orientations toward science teaching; knowledge of science curriculum;

knowledge about students' understandings of specific science topics; knowledge about assessment in science; and knowledge about instructional strategies for teaching science (Figure 1).

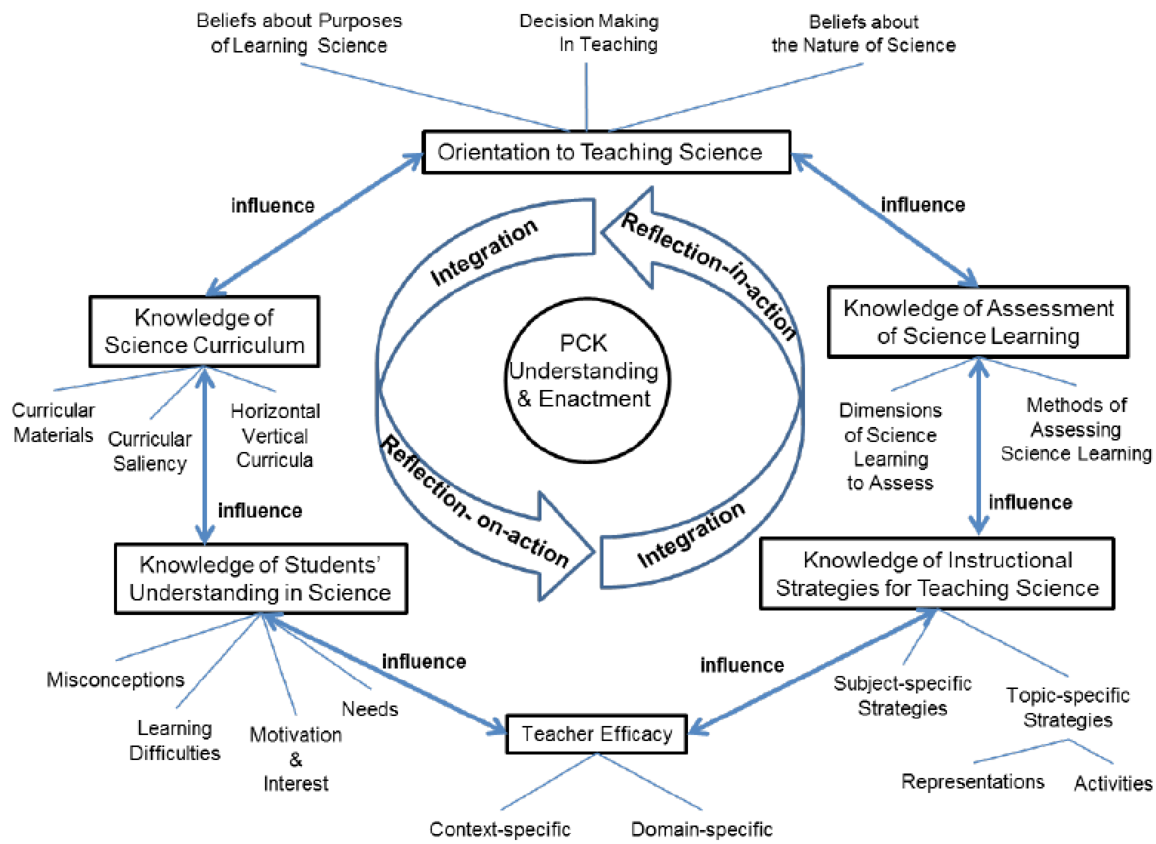


Figure 1: Illustration of the pedagogical content knowledge model for science (Astuti, 2017)

With regards to this study, the five components of PCK may be classified as; orientation in chemistry teaching; knowledge of chemical curriculum; knowledge of students' understanding of chemistry (and specifically conservation of matter); knowledge of assessment in chemistry; and knowledge of instructional strategies to teach conservation of matter.

The dimension of 'orientation on teaching science' refers to the teachers' knowledge and beliefs about teaching. The pedagogical practices of teachers are influenced by various factors including the social and policy context in which they teach, subject matter knowledge, their beliefs about teaching, and their PCK. The teachers' orientation towards teaching science is considered a cornerstone of the PCK construct because the knowledge and beliefs from this component provide a “conceptual map” through which all other tasks of teaching science are approached. Magnuson (1999) further describes seven different orientations towards teaching science. Among these are process, academic rigor, didactic, conceptual change, activity-driven, discovery, project-based science, inquiry and guided inquiry. They further include goals and characteristics of instruction that teachers with a specific orientation would possess. However, research indicates that teachers can hold multiple orientations including orientations that seem to have incompatible goals for teaching science (Smith & Neale, 1989).

The second dimension of PCK is the knowledge about science curriculum. The curricula knowledge refers to the teachers’ knowledge of current teaching techniques and current teaching materials (including books and software). This dimension includes teachers’ knowledge of the goals and objectives for students in the subject they are teaching and the ability of teachers to articulate the guidelines across topics addressed during the school year (Magnuson, 1999, p. 103). This component can be further subdivided into mandated goals and objectives and specific curricular programs and materials. Effective science teachers have knowledge of national and state-level documents that outline frameworks for the teaching and learning of science, which would be included in the subcategory of mandated goals and objectives (Magnuson, 1999).

The third aspect - knowledge about students’ understandings of specific science topics refers to the knowledge that teachers must have about their students in order to help them develop specific scientific knowledge” (Magnuson, 1999). Teachers are required to learn science concepts (relating to conservation of matter) which students find difficult to learn. It is suggested that if teachers know the misconceptions that students have in the topic of study, they will be in a position to plan effective instruction by interpreting students’ ideas and misconceptions (Bektas, 2017). When teachers do not have adequate content knowledge, they may not be aware of students' misconceptions. This component can be further broken down into two subcategories: knowledge of requirements for learning and knowledge of areas of student difficulty. The category of knowledge of requirements for learning means that teachers understand all of the skills and prerequisite knowledge students will need in order to learn the new concept. Teachers also have knowledge of various approaches that can be utilized in helping students of differing abilities and interests to learn this science concept. This category refers to teachers' knowledge of the topics that students find difficult to learn and the common alternative conceptions that they may have. This component of PCK allows teachers to more quickly predict and diagnose student challenges with learning the new content.

The fourth component of PCK - knowledge about assessment in science, requires teachers to possess the knowledge of dimensions of science learning as well as the knowledge of the methods used to assess students' learning within the selected topic (Bektas, 2017). Teachers should at all times assess what the concepts understood by students, where they need help, and what they should do next. Assessment can be used for various purposes in enhancing the teaching and learning of science. For instance, diagnostic assessment can help teachers determine what students know as they teach the science concepts while formative assessment can be used to guide daily classroom activities. Knowledge of assessment in science can be separated into two categories: "knowledge of dimensions of science learning that are important to assess and knowledge of the methods by which that learning can be assessed" (Magnuson, 1999, p 108). This component describes the teachers' knowledge of the different dimensions within a particular topic that should be assessed and the best way to assess these understandings. Assessments are also important because they help teachers understand the dimensions that are most difficult to assess. This is informed by the level of students' understanding of the science concepts presented to them by the teachers. Assessment provides the connection between teaching and learning, and it lets teachers know the result of their instructional activity. Teachers can use feedback from assessment to redesign pedagogical practices. Knowledge about assessment in science is critical because it helps to inform teaching and improve learning, while facilitating the monitoring of students' progress toward the achievement of the desired learning outcomes.

The final component of PCK is the teachers' knowledge of instructional strategies. Teachers are required to have the knowledge of the subject-specific and topic-specific strategies. Subject-specific strategies include general approaches for enacting science instruction including the learning cycle (Karplus & Their, 1967; Lawson, Abraham, & Renner, 1989). Topic-specific strategies on the other hand refer to the teachers' knowledge of the approaches to be used to help students understand the specific science concepts – in this case, the concepts relating to conservation of matter (Magnuson, 1999). The subject-specific and topic-specific strategies can be in the form of representations used to help students develop a better understanding of the topic. This implies that teachers can employ the use of pictures, drawings, examples, models, videos, and analogies – referred to as teaching strategies to assist students understand specific science concepts (Bektas, 2017). For instance, when teaching about conservation of matter, teachers should have proper teaching aids and prepare different experiments that can be used to enhance the understanding of the topic (Park, & Neuhaus, 2013). Without proper instructional strategies to demonstrate the key aspects of the topic being taught, students can have misconceptions in the topic. Effective teaching strategies are therefore important for eliminating misconceptions from students in chemistry topics.

Importance of PCK to science teachers

To begin with, science teachers with well-developed PCK are effective teachers because they have an understanding of the importance of students understanding science concepts. As such, teachers with PCK can use different appropriate and effective teaching methods and instruction strategies to improve students' understanding of science concepts (Chapoo, 2014). Teachers with a high level of PCK have a coherent framework or perspective from which to present the necessary information on the topic of study to the students. It allows teachers to make specific pedagogical decisions by being able to assess students' prior knowledge, ability levels, and learning strategies.

PCK also makes it easy for teachers to articulate the relationships between pedagogical ideas and the subject matter concepts. In this regard, low levels of PCK have been found to be linked to the use of simple recall questions. Science teachers with low PCK may have difficulty transforming and representing the concepts and ideas about science topics in ways that make sense to their students. Teachers with high PCK on the other hand have a better understanding and view of the content field on which they base their teaching decisions.

PCK is important for enhancing the quality of teaching-learning experience in the classroom. According to Rollnick & Mahvunga (2012), PCK is necessary for improving teacher education and assisting inexperienced teachers in making progress toward achieving competence in their pedagogical practice. Chai (2013) further observed that PCK helps to influence teachers' knowledge in understanding science and specifically the topic to teach and to solve the challenges associated with science teaching-learning.

Melo (2020) indicated that PCK is a necessity and a key characteristic in teacher training plans because it allows teachers to; identify and implement the factors that enhance the stability of teaching models; recognize how to determine the knowledge that they can use over the course of their pedagogical practice; validate the theoretical concepts that they teach; and enhance the development of good relationship with students. The authors further noted that PCK is critical for novice science teachers because it helps them adjust their teaching and it offers them the opportunities to conduct self-regulated reflective practices so as to improve their teaching of science topics.

In summary, at the core of effective content teaching is the teachers' PCK. PCK illustrates how the subject matter of a particular discipline is transformed for communication with learners. It includes recognition of what makes specific topics difficult to learn, the conceptions students bring to the learning of these concepts, and teaching strategies tailored to this specific teaching situation. To teach all students effectively, teachers indeed need to understand subject matter deeply and flexibly so they can help students map their own ideas, relate one idea to another, and re-direct their thinking to create powerful learning. Kathirveloon (2014) stated that in addition to allowing teachers to skillfully demonstrate their knowledge, teaching should include the ability of teachers to guide students to understand the content knowledge of science topics. This illustrates the importance of PCK in pedagogical practice. From the discussion above, it is also evident that PCK plays an important role in reducing teachers' misconceptions. Given the importance of PCK in shaping instructional practices, various studies have been performed to document teachers' PCK and the development of teachers' PCK, all of which are important for improving teaching.

Measuring PCK

Given the significant evidence illustrating the link between PCK, effective teaching, and student achievement, various studies have been conducted to measure PCK to allow the development of tools and approaches aimed at enhancing teacher evaluation (Morrison & Luttenegger, 2015; Schmelzing, 2012). It is important to measure teacher's PCK to evaluate the implementation of teacher training program (Maryati, 2019). Measurement of PCK can be explored at two levels: the planned PCK and enacted PCK. The outcome helps to provide a better and clearer understanding of how teachers design and implement PCK in their classrooms. The Planed PCK is a combination of teachers' content knowledge and pedagogical knowledge of learning strategies needed, so that certain science topics can be comprehensively understood by students. The enacted PCK is a type of PCK that can be observed during the learning processes (Maryati, 2019; Park & Suh, 2011).

The key approaches used to measure PCK include; multi-method approach, card-sorting, concept-mapping, convergent and inferential techniques, observation and interviews, and CoReS and PaPeRs.

Multi-method approach

This research will employ the use of a multi-method approach in evaluating the science teachers' PCK of conservation of matter and its significance in enhancing student learning of the science concepts. Multi-method approach uses a variety of techniques for collecting data on PCK including concept maps, interviews, and video-prompted recall. The data collected from multiple sources is then triangulated. Finally, researchers make inference about teachers' PCK based on the obtained results.

This study will employ the use of a concept inventory focused on conservation of matter. The concept inventory will be administered to teachers to test their CK and PCK. Concept inventories are assessments that are derived from scientific research to identify misconceptions of students (Hestenes, 1992). Concept inventories are traditionally utilized to gain insight into what prior understanding students are bringing to the classroom. They are then administered again after the unit of instruction is complete to understand what learning has occurred. Salder (2013) argue that a teacher's ability to identify the most common wrong answer on multiple-choice items is a measure of pedagogical content knowledge. Therefore, utilizing existing concept inventories can help determine a teacher's PCK related to a specific topic in a more time-efficient manner. In addition, concept inventories can simultaneously collect data on a teacher's content knowledge by looking for the correct responses to the questions within the inventory. Hashweh (1987) designed various tasks to evaluate teachers' PCK, with a key focus on teachers' content knowledge, conceptions of learning, instructional planning, and view of instruction. Three tasks were used to assess teachers' content knowledge. In the first task, teachers were required to provide a summary of a specific topic. Thereafter, they were prompted to relate the topic to: other ideas in the discipline; other areas of knowledge; and the students' experiences. The second task involved concept mapping where teachers were required to draw a map by connecting 20 terms in their teaching area and explain the relationships. The third task involved sorting exam questions into groups depending on the common ideas or concepts needed to answer the questions. To study the teachers' conceptions of learning, Hashweh (1987) conducted a clinical interview focused on the teachers' understanding of teaching for conceptual change. The author further examined the teachers' instructional planning by asking them to plan a lesson using a chapter from a science text that he provided. Finally, he asked the teachers to respond to a series of critical episodes to understand their view of instruction. The data obtained from the three tasks showed critical features of PCK. For instance, when planning a lesson based on a topic, the teachers discussed possible levels of treatment of the topic. The feedback from the teachers included analyses of both simple and complex versions of the topics covered in class.

Their decisions regarding the level of topic to teach were based on their students' understanding. The multi-method approach used by Hashwesh (1987) provided a rich view of PCK.

Hewson & Hewson (1989) developed an interview protocol known as the 'interview-about instance' which was helpful in identifying the conceptions of teachers of teaching science. The interview protocol was a structured interview that comprised short, written scenarios designed to represent instances and non-instances of science teaching. In this case, the science teachers were required to provide responses indicating whether or not science teaching was occurring. The interview focused on knowledge regarding the nature and purpose of the subject matter, teaching strategies, and pedagogical approaches. A multi-step process was used for the analysis of the teachers' responses. First, the authors defined and used six coding categories including: the nature of science learning, learner characteristics, rationale for instruction, preferred instructional techniques, and conceptions of teaching science. After coding, summary statements were prepared for each of the six categories, with direct quotes from transcripts being used in some cases. Using this approach helped the authors to identify changes and consistencies in the teachers' conceptions of teaching science. The interview protocol was found to be a powerful intervention technique that made teachers think critically about the aspects involved in science teaching without biasing their responses or altering their original conceptions.

Luft (2009) conducted a concurrent research study on the beliefs, PCK, and practices of induction science teachers in four different induction programs. The data from this mixed methods study were both qualitative and quantitative in nature. Interviews were conducted using the Teacher Belief Interview (TBI: Luft & Roehrig, 2007). This protocol is a semi structured seven-question interview that includes coding maps that help capture the epistemological beliefs. The interview protocol was developed and drawn from the work of Loughran (2001). The interviews were used for data collection, with teachers being asked to discuss the planning and enactment of a best lesson in science. The interview transcripts were transcribed and coded. The results of the coded interviews (based on the overall score of the categories to which teachers were assigned) indicated whether the teachers' PCK was limited, basic, or proficient. The third form of data collected were from classroom practices that were captured through observation and interviews about classroom practice. The classroom observations were conducted using the Collaborative for Excellence in Teacher Preparation Core Evaluation Classroom Observation Protocol (CETP-COP) that was developed by Lawrenz (2002). Inter-rater consistency was established before visiting classrooms. The mixed-methods approach employed by Luft (2009) allowed for the collection of multiple data points to understand the impact of each teacher's PCK in classroom instruction.

Another study that employed the use of the multi-method approach in measuring PCK was conducted by Smith & Neale (1991). The purpose of the study was to measure teachers' PCK in the context of an in-service program designed to support conceptual change not only in teachers' substantive content knowledge, but also in their ideas about teaching science. The teachers developed and presented activities that helped students identify, query, and take the necessary steps to resolve inconsistencies in their thinking about scientific concepts. To document changes, the authors interviewed the teachers, videotaped their instruction before and during the workshop, and asked them to write journals. The data obtained from the three sources were analyzed. The audiotapes of the interviews and the videotapes of classroom instruction were transcribed and then coded. The videotaped transcripts were examined for features of conceptual change teaching such as teacher role, student role, content, lesson segments, materials, and other relevant activities. The audiotaped interview transcripts were analyzed to determine teachers' orientations to science teaching and learning. The coding categories were used to map changes in the teachers' ability to translate content into classroom teaching – a critical aspect of PCK.

In summary, the studies above illustrated the importance of multiple sources of data. If used in isolation, each of the techniques would have introduced methodological questions concerning confirmability and validity. When a variety of data sources are used to establish a profile of a teacher's knowledge it helps to address methodological issues. The mixed-method approach offers great promise in measuring PCK as it helps teachers think about and examine their PCK. By offering multiple specific situations, this approach enables teachers to explore their assumptions about teaching and their knowledge of teaching specific topics in science. However, there are various issues associated with this study. For instance, the use of various techniques for measuring PCK is cumbersome and difficult to replicate. Data collection and analysis using the mixed-method approach are time consuming and energy intensive. For example, each interview requires approximately 30 to 40 minutes to administer. The process required for analyzing data collected via audiotapes is labor intensive since it requires to be transcribed and subjected to multi-step coding and summarizing. The need to employ such a labor- and time-intensive technique should be clear and convincing. These studies highlight the need to make difficult decisions regarding the data sources needed to effectively measure PCK.

Card-sorting

The card-sorting approach was originally designed as a research tool for identifying the goals and purposes for teaching science to a particular group of students. Hewson & Hewson's (1989) interview task to identify teachers' conceptions of teaching science led to the development of the card sort technique. With card sorts, the contents communicated by teachers during sorting offer insight into their science orientation and PCK. In Friedrichsen & Dana's (2003) study, it was observed that how teachers' consideration of the card scenarios was useful in helping them clarify what they believed about teaching and learning science.

Friedrichsen & Dana (2003) provided a clear elaboration of how the card-sorting approach works in assessing teachers' PCK. The card sorting technique unique to this study, modeled after Hewson & Hewson's (1989) original card sorting interview task, included the researchers designing a set of 20 cards with each describing an instructional strategy, planning technique, laboratory activity, or assessment strategy commonly used in high school biology teaching. The researchers indicated that they made pairs of prospective teachers who were then given a set of scenario cards. Teachers took turns sorting the scenario cards and playing the role of interviewer. During the interviews, emphasis was placed on listening carefully to the ideas expressed by the partner. One teacher acted as the interviewer while the partner sorted the cards. The interviewer asked the sorter to read the set of scenario cards and sort the cards into stacks classified to demonstrate teachers' pedagogical practice such as: (a) 'This scenario best represents how I would teach' (b) 'this scenario does not represent how I would teach' and (c) 'unsure.' The prospective teacher is then encouraged to think aloud during the initial card-sorting process. While the prospective teacher is sorting the cards, the interviewer notes the scenarios that elicit strong positive or negative reactions. Friedrichsen & Dana (2003) reported that in the cards-sorts method, there are usually scenarios that evoke visible reactions and comments. The number of card used is recorded and will form the basis of measuring the teachers' PCK.

When using the card-sorts approach, it has been found that experienced teachers respond differently to the card sort than novice teachers with a low level of PCK. Novice teachers tend not to ask additional questions about the scenarios, while experienced teachers infer contextual clues as they consider each scenario. Friedrichsen & Dana (2003) described card-sorting as effective method of measuring PCK, but time intensive. They suggested that continued research is required to further develop and improve the technique of measuring PCK, especially in terms of protocol development

Hewson & Hewson (1989) used a card-sorting method to determine pre-service teachers' conceptions of teaching science. Their research design employed in the study included developing a set of task cards, which describe specific orientations towards teaching science. Each task was designed to allow the respondents to consider a component of teaching science and to consequently provide a diversity of views without biasing their responses (Hewson & Hewson, 1989, p 197). These task cards allowed researchers to elicit the ideas of the educators during interviews and provided talking points during said interviews.

Concept mapping

Concept maps are graphical representations used for organizing knowledge and depicting relationships among concepts. Concept maps are an effective method for exploring both the quality and structure of teachers' SMK and PCK (Novak & Cañas, 2008). They comprise of nodes, enclosed words, and phrases representing key ideas connected by labeled lines that explain how the two ideas are related.

These nodes and links are organized hierarchically, with the most inclusive node at the top. One grouping of ideas is represented by hierarchies, a series of nodes whose top-most node is linked directly to the primary node, indicating a main category of ideas. Links across hierarchies, crosslinks, show connections between different categories of ideas. Another grouping of ideas occurs when one node has multiple subordinate nodes, known as chunks. These are ideas that are closely related to each other. Although concept maps may not be literal depictions of knowledge stored in the memory, they can reflect internal cognitive structures and the quality of connections between key ideas (Nixon, 2017).

Morine-Dershimer (1989) used concept maps to examine changes in the knowledge structures of preservice teachers. At the beginning and end of a methods course. The author asked the students to draw two concept maps; one about the concept that they taught in their peer teaching lesson during the course, and the second illustrating the concept of teacher planning. The students supplied their own key terms and were free to use any graphic design that they chose. The maps were analyzed for area and density. Morine-Dershimer (1989) found a significant increase in the number of main categories included in the maps and a slight increase in the number of subordinate levels. Based on these findings, the author believed that it reflected an increase in conceptual understanding of the lesson topics and of the notion of teacher planning. As a result, she concluded that concept maps contribute to enhancing the understanding of how novice teachers develop their knowledge base for teaching. The maps can also provide novice teachers with feedback about changes in their understanding.

Sadler (2013) acknowledged the importance of concept maps by indicating that the method allows researchers to gather quantitative information about a teacher's CK and PCK. In addition, concept maps allow researchers to collect large-scale data on teachers' PCK and its relationship to student learning gains. Sadler (2013) concluded that through the analyses of obtained via concept maps teachers could identify the common student misconception thus leading to improved learning by students.

While concepts maps are considered to be an effective instructional tool for measuring PCK, it has various limitations. One of the key limitations is linked to the way in which concept maps are analyzed. Analyses of concept maps often focus on surface features, such as the number of nodes or links (Stoddart, 2000). Such analyses are limited in their inferences about the quality of PCK. The use of concept maps has also raised much criticism due to the fact that studies using concept maps typically report low inter-rater reliabilities or do not include reliability statistics (Nixon, 2017).

Convergent and inferential techniques

Convergent and inferential techniques include the use of methods such as Likert-type self-report scales, multiple-choice items, and short answer formats. The common feature among these methods is that they use predetermined verbal descriptions of desired teacher knowledge as the criteria for comparing verbal answers of science teachers.

Multiple-choice test items are used for measuring content-specific pedagogical knowledge (C-P). They distinguish content-specific pedagogical knowledge from CK and general pedagogical knowledge (Kromrey & Renfow, 1991). The class of C-P items as described by Kromrey & Renfow, (1991) includes those items for which the examinee's determination of the correct response depends upon knowledge of the treatment of content in educational situations. They exclude items that only address content and items that address general pedagogical principles in the absence of content-specific interpretations. C-P items reflect the process of teaching the content, not the non-instructional practice of the discipline.

The reference study for this research employed the use of inferential modeling to assess teacher knowledge and investigate its relationship with student learning. Students were grouped in the different teachers' classrooms and for each student, the researchers had more than one score to predict.

Observation and interviews

The use of interview questions such as closed-ended questions are easily scored and they provide responses that are elaborate and thus enhance the understanding of teachers' level of PCK (Koirala, 2008; Morrison & Lutteneger, 2015). Observations of instruction provide great insight into a teacher's ability to perform PCK but require skilled or trained observers (Shanahan & Tochelli, 2014). Post-observation discussions can provide insight into a teacher's pedagogical reasoning which is particularly helpful after an observation of instruction. Those discussions require skilled facilitators, however, in order for conversations to be productive (Shanahan & Tochelli, 2014).

PCK has traditionally been studied through observations and interviews such as in Lantz and Kass's (1987) study which focused on three chemistry teachers. The researchers visited each teacher five times over the course of four months. Guiding questions focused on the ALCHEM curriculum materials were developed and utilized to serve as a common reference point for these interviews with the teachers. These questions allowed the researchers to elicit information from the teachers about the ALCHEM materials and "how they adapted, modified, and supplemented specific aspects of these materials for use in their own classrooms" (Lantz, 1987, p 118). Notes and transcripts of each site visit and interview were studied and then utilized to develop additional interview questions. These questions were aimed at probing various aspects of the teachers' observations and confirming interpretations of previous interview statements. These verifications of the researchers' interpretation provided an ongoing validity check with the teacher (Lantz, 1987, p 119). Reliability of the interviews and observations were not addressed within the study. These interviews and open-ended questions were coded into categories adapted from Schwab's four curriculum common places (Lantz, 1987). However, Baxter & Lederman

(1999) concluded that observations provide limited insight into teachers' PCK due to the internalistic nature of the construct within which some teachers may not even be aware that they possess or have the ability to clearly articulate.

CoRes & PaP-eRs.

The measurement of teacher's PCK can also be achieved using the CoRe (Content Representation) and PaP-eRs (Pedagogical and Professional-experience Repertoires) instruments. CoRe and PaP-eRs capture teachers' PCK with use of engaging portrayals - individual profiles based on data from interviews and observations (Loughran, 2001; Rohaan, 2009). It is an alternative way to evaluate PCK in action without a fixed format. CoRe can provide an overview of how teachers perceive the subject content being taught. CoRe allows an individual teacher or groups of teachers to fill in a template which elicits their ideas about main ideas, student misconceptions, ways of testing for understanding, known points of confusion, effective sequencing, and important approaches to framing of the ideas of a particular topic (Loughran, 2004). CoRe was developed by asking teachers to think about what they perceive as 'big ideas' relating to teaching certain topics based on their teaching experience (Mim, 2017). Loughran (2004) described CoRe as both a research tool for accessing science teachers' understanding of the content as well as a way of representing this knowledge. CoRe is usually written in tabular form. The horizontal direction contains 'big ideas' or important concepts in teaching certain topics. The vertical direction contains the teacher's considerations and views regarding teaching the topic along with instructions listed so that specific information about great ideas of how they taught content can be obtained.

PaP-eRs PaP-eR is based on a CoRe and is a way of capturing specific teaching episodes that address particular aspects of teaching this concept within a particular context and helps to capture PCK in action. PaP-eRs are deliberately designed to expose what the teacher thinks about certain aspects of PCK on a learning material and mostly based on learning process in the classroom (Loughran., 2001). PaP-eRs are intended to represent teachers' reasoning, such as the thoughts and actions of teachers in teaching. The presence of CoRe and PaP-eRs not only helps to measure the level of teachers' PCK but also describes this knowledge to others (Purwianingsih & Mardiyah, 2018).

The assessment of teachers' PCK on a topic illustrated in CoRe and PaP-eRs can help teachers think through new things about how to plan and organize their learning and use a more appropriate and meaningful approach to teaching the topic. This suggests that CoRe and PaP-eRs can be used and understood because these two formats can not only make teachers think about their teaching practices but also how they can influence how their teaching becomes more productive (Loughran, 2012).

Williams & Lockley (2012) observed that CoRes can help novice science teachers understand what PCK might involve and to develop their own representations of teaching in particular topic areas. The findings by Williams & Lockley (2012) support the outcomes of the study conducted by Loughran (2008) in which novice teachers were invited to create their examples of CoRes after examining and reflecting on those created by experienced teachers. The findings from Loughran's (2008) study showed that the focus on PCK using CoRes to frame their thinking about the links between science content and pedagogy helped the novice teachers to develop a better of how to teach science and how to teach to enhance student understanding.

Due to the thoroughness of CoRe and PaP-eRs, all five components of the teachers' pedagogical content knowledge can be assessed. However, the time intensiveness of this method means that very little data can be collected over a long period of time. Few science teachers can be studied at a given time due to the intensiveness of these research tools. However, many other science education researchers still use these methods in their studies of science teachers PCK.

Challenges in measuring PCK

Researchers have identified various challenges to assessing PCK. The first challenge is that PCK cannot be observed directly. By definition, PCK is partly an internal construct (a teacher's understanding of content-specific examples that best represent the specific topic of study), and knowledge of common student difficulties with the specific topic. When attempting to assess a teachers' knowledge of best examples, it is challenging to depend mainly on observational data because teachers can use only a small proportion of their wide range of examples during a particular teaching episode. Therefore, researchers may not have the opportunity to see and examine the examples not used by teachers during their pedagogical practice. Also, an observation would not indicate why a teacher opted to use some examples while avoiding others. According to Kagan (1990), observations provide a limited view of PCK, meaning that teachers have to be asked to articulate their knowledge.

Baxter & Lederman (1999) reported that teachers do not always express their thoughts and beliefs regarding PCK. In some cases, teachers may abstain from expressing unpopular beliefs and ideas concerning PCK. As a result, researchers may not get the right information during the process of measuring PCK.

Another challenge associated with the methodologies used to measure PCK is that they are time-consuming because they require a lot of time to develop, administer, and analyze. The methodologies used to measure PCK are also complicated and difficult to replicate. Most assessments of PCK are qualitative in nature, relying on cognitive techniques, such as interviews that generate lengthy transcripts to be analyzed, and concept mapping that requires the interpretation of involved coding systems. For example, the paper and pencil instruments that have been developed require significant effort to complete and often considerable time and energy to analyze. The literature needs more studies that focus on quicker methods of obtaining data for the assessment of CK and PCK. This study will fill this gap in the literature by providing a study where the measure of CK and PCK are conducted in a quantitative manner allowing for quicker analysis and results acquisition.

Conservation of matter

The law of the conservation of matter states that matter cannot be created nor destroyed in that the mass remains constant regardless of the various changes in the system. Atoms rearrange during a chemical reaction with the sum of the beginning reactants having the same mass as the sum of the ending products of the reaction. Pomper (1962) tells us that Antoine Lavoisier was the person who is accredited with the discovery of the law of conservation of matter. In his research, Pomper (1962) explains to us that Lavoiser was carrying out a series of experiments supporting the law of conservation of matter. The preservation of matter is the basic foundation of modern chemistry. Cachapus, (2000), gave a clear description of the law as indispensable when trying to understand chemistry in both subsequent studies and beyond one studying the various chemical reactions.

Although Georgia did not adopt the Next Generation Science Standards, the Georgia Standards of Excellence incorporate three-dimensional learning aspects, science and engineering practices, and crosscutting concepts. This mirrors the set-up of the Next Generation Science Standards (NGSS). One of the crosscutting concepts across all disciplines of science are the Laws of Conservation of matter and Energy. Therefore, this concept is extremely important in all branches of science whether that be explicitly or implicitly. In addition, science content, courses, and disciplines all are interconnected, build, and bridge between each other. Under this premise, all teachers of science 6-12 should understand this concept so that they do not pass any misconceptions along to their students.

The table below summarizes as a crosswalk the NGSS that incorporate the crosscutting concept of conservation of matter with all of the Georgia Standards of Excellence (GSE) that address the same concepts. NGSS codes middle school (MS), high school (HS), physical science (PS), life science (LS), and earth and space science (ESS) respectively. GSE codes eight grade physical science (S8P), seventh grade life science (S7L), sixth grade earth science (S6E), high school physical science (SPS), high school biology (SB), high school chemistry (SC), high school physics (SP), high school astronomy (SAST), high school earth science (SES), and high school environmental science (SEV).

Table 1: *NGSS and GSE Standard Comparisons*

NGSS		GSE	
MS-PS1-5	Develop and use a model to describe how the total number of atoms does not change in a chemical reaction and this mass is conserved	S8P1f	Construct an explanation based on evidence to describe conservation of matter in a chemical reaction including the resulting differences between products and reactants.
MS-LS2-3	Develop a model to describe the cycling of matter and flow of energy among living and non-living parts of an ecosystem.	S7L4	Develop a model to describe the cycling of matter and the flow of energy among abiotic components of an ecosystem.
MS-ESS2-4	Develop a model to describe the cycling of water through Earth's systems driven by energy from the sun and the force of gravity.	S6E3b	Plan and carry out an investigation to illustrate the role of the sun's energy in atmospheric conditions that lead to the cycling of water.
HS-PS1-7	Use mathematical representations to support the claim that atoms, and therefore mass, are conserved during a chemical reaction.	SPS3a	Plan and carry out investigations to generate evidence supporting the claim that mass is conserved during a chemical reaction.
		SPS3b	Develop and use a model of a chemical equation to illustrate how the total number of atoms is conserved during a chemical reaction.
		SC3a	Use mathematics and computational thinking to balance chemical reactions and construct an explanation for the outcome of a simple chemical reaction based on the outermost electrons
HS-PS1-8	Develop models to illustrate the changes in the composition of the nucleus of the atom and the energy released during the processes of fission, fusion, and radioactive decay.	SPS4a	Develop a model that illustrates how the nucleus changes as a result of fission and fusion.
		SPS4b	Use mathematics and computational thinking to explain the process of half-life as it relates to radioactive decay.
		SP6c	Develop and use mathematical models and representations to calculate the amount of substance present after a given amount of time based on its half-life and relate this to the law of conservation of matter and energy.

HS-LS1-6	Construct and revise an explanation based on evidence for how carbon, hydrogen, and oxygen from sugar molecules may combine with other elements to form amino acids and/or other large carbon-based molecules.	SB5b	Develop and use models to analyse the cycling of matter and flow of energy within ecosystems through the process of photosynthesis and respiration. -Arranging components of a food web according to energy flow. -Comparing the quantity of energy in the steps of an energy pyramid. -Explaining the need for cycling of major biochemical elements (C, O, N, P, and H).
HS-LS2-4	Use mathematical representations to support claims for the cycling of matter and flow of energy among organisms in an ecosystem.		
HS-LS2-3	Construct and revise an explanation based on evidence for the cycling of matter and flow of energy in aerobic and anaerobic conditions.	SB1e	Ask questions to investigate and provide explanations about the roles of photosynthesis and respiration in the cycling of matter and flow of energy within the cell.
HS-ESS1-2	Construct and explanation of the Big Bang theory based on astronomical evidence of light spectra, motion of distant galaxies, and composition of matter in the universe.	SAST3b	Develop and use models to explain the chemical composition and characteristics of the Sun and other solar system objects.
HS-ESS1-3	Communicate scientific ideas about the way stars, over their life cycle, produce elements.	SC1c	Construct an explanation based on scientific evidence of the production of elements heavier than hydrogen by nuclear fusion.
HS-ESS2-3	Develop a model based on evidence of Earth's interior to describe the cycling of matter by thermal convection.	SES1c	Develop a model of the physical composition of Earth's layers using multiple types of evidence.
HS-ESS2-6	Develop a quantitative model to describe the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere.	SEV1c	Analyze and interpret data to construct an argument of the necessity of biogeochemical cycles to support a sustainable ecosystem.

The studies focused on CK and PCK have not contributed to our knowledge base in regards to the Law of Conservation of Matter. This study provides the opportunity to add to the research-based literature by focusing on this important science concept. Based on the previously cited literature, the PCK and CK of 6-12 science teachers in relation to Conservation of Matter has not been extensively studied. This study used concept inventories to investigate the PCK and CK of 6-12 science teachers in the state of Georgia in regards to the concept of the Law of Conservation of Matter. Uniquely this study will focus on the Law of Conservation of matter.

Chapter 3: Methodology

Chapter Three begins with the problem and purpose statements and an iteration of the research questions. This is followed by the research methodology, design, and value of this mixed method study. Next is the research setting, data collection and instrumentation, and data analysis. The chapter concludes with the limitations and delimitations of the study.

The study of chemical reactions and conservation of mass is problematic for many students and is a central theme for 14-15-year-old pupils (Ozmen & Ayas, 2003). Since this concept is central and problematic for students, teachers should be aware of student difficulties in this area. Pedagogical content knowledge (PCK) and content knowledge (CK) are developed and intimately correlated in effective science teachers (Grossman, 1990). One of the tenets of PCK is the ability of teachers to predict student difficulties and misconceptions within the curriculum and concepts being taught. This ability allows teachers to plan curricula to address these misconceptions and to help students overcome them during the course of instruction.

The purpose of the study is to investigate chemistry teachers' CK and PCK as it relates to conservation of mass concepts through a conservation of mass concept inventory and semi-structured teacher interviews. Through this, the relationship of varying levels of CK and PCK and teacher demographics will be investigated. If teachers hold misconceptions, then it is likely that they will pass these on to their students (Yip, 1998). Interviews will also be conducted with a selected subset of the teachers after the testing of CK and PCK.

Research questions

The researcher seeks to answer the following research questions through this study.

1. Is there a relationship between content knowledge, pedagogical content knowledge, and self-identified teacher demographics in relation to the concept of conservation of matter?
2. Do teachers use their knowledge of common student misconceptions related to conservation of matter to address student needs for this concept of the curriculum?

Research Methodology and Design

Drawing on the recommendations of Abell (2008) to incorporate more mixed methods designs in the study of PCK, a mixed methods study to investigate the PCK of science educators in Georgia is proposed. The study seeks to answer the preceding research questions through the use of the research methods outlined below.

The totality of these research questions seeks to understand the correlation between teacher CK and PCK regarding what teachers know about students' understanding. This is measured with a test of CK and PCK, administered quantitatively with teachers, in the form of a concept inventory to measure both. The concept inventory will be used to investigate the relationship between teacher CK and PCK in accordance with part of the research study conducted by Sadler, (2013). Being able to identify common student misconceptions is positively related to students' science outcomes and is a measure of teacher PCK (Sadler, 2013). Qualitative data was collected during the concept inventory survey in order to determine why teachers chose the most common student misconception that they did. In addition, a qualitative semi-structured interview was conducted with a subset of teachers from the quantitative study to ascertain how the knowledge of student misconceptions and PCK are used in the classroom setting.

Value of Selected Methodology

The proposed research design offers several advantages. The study utilizes quantitative measures through utilization of the concept inventory, which allowed the researcher to obtain information in a shorter span of time. This study measures CK and PCK of teachers through administration of the concept inventory – teachers are required to answer the questions correctly to determine their CK and to also be required to identify the answer that indicates students' most common misconceptions on the same concept inventory in which to ascertain their PCK. More traditional methods for measuring CK and PCK of teachers require much more time intensive and labor-intensive methods which this study was able to avoid. In addition, this study allowed the researcher to obtain data from a wider and more diverse range of science teachers therefore providing a more comprehensive view of the state of CK and PCK within this population of teachers. Other methods of investigating PCK have not been able to incorporate such a large sample of teachers. This is limiting in that the few teachers that are studied may or may not be representative of the larger population of science teachers within this geographic area. The qualitative explanations for why teachers think the incorrect answers are chosen by the student strengthen the study by providing insight into contributing and attributing factors that may affect PCK. Additionally, the qualitative study adds strength to the design by providing an in-depth understanding of the research questions through open-ended questioning.

Instrumentation

A concept inventory focused on conservation of matter was administered to the instructors to test CK and PCK, respectively. A concept inventory tests for concept knowledge

(CK) of teachers and also tests teacher PCK by measuring the teacher's ability to identify common student misperceptions. This instrument is shown in Appendix A. All 22 items in the concept inventory were published by AAAS Project 2061. All items were developed with data based on students' common misconceptions. Each of the items in the assessment were given to a population of students in the United States. The questions come from two separate AAAS projects, the original Project 2061, and The Toward High School Biology project (*AAAS Science Assessment ~ Topics*, 2021). The Toward High School Biology (THSB) test questions were developed to determine middle school student's understanding of ideas about matter changes in alignment with the Next Generation Science Standards. All questions coded SB were given to 532 students in an NGSS adopted school district during the original Project 2061 Assessment development. All questions coded SC were given to populations of both middle school and high school students during the Toward High School Biology project. The most common student misconceptions were determined based on this data set. Each question has a breakdown of the percentage of students who answered each question along with the correct answer. The most common wrong answer of the student was considered the most common or prevalent student misconception. It was administered to measure CK with teachers choosing the correct answer and then readministered to teachers with them choosing the most common student misconception to measure PCK. The instructors were asked to identify the correct answer to each question as well as identify the most common student misconception for each question. These scores provide a comparison of CK and PCK for the quantitative analysis. To establish validity of the instrument, five 6-12 science teachers were asked to evaluate the instrument and its appropriateness for use with 6-12 students and educators.

Table 2: *Aspects of conversation of matter measured and source of questions*

Item Number	Concepts Assessed
SB001002	The mass of a silver coin is greater after it tarnishes because the number of silver atoms stayed the same and some sulfur atoms from the air linked to the silver atoms to form silver sulfide molecules.
SB002002	During a reaction where a reactant enters the system and no products leave, the mass of the system increases because the system now contains more atoms.
SB004003	After a chemical reaction occurs, some of the atoms are connected to different atoms than they were in the starting molecules. (This item uses circles to represent atoms.)
SB005001	If the number of atoms in the sealed jar stayed the same, the mass of the jar and everything inside it will stay the same because the mass of the atoms inside the jar stayed the same.
SB45002	Bubbles of gas forming as a seashell is placed in vinegar is an example of a chemical reaction.
SB051001	The mass of a glow stick will not change while the chemical reaction is occurring because the number of each type of atom inside the glow stick does not change. Some of the atoms separated from one another and then connected in different ways to form different molecules.
SB057001	When nitric acid and copper react, the atoms detach from one another and then link together in different ways to make the molecules of the red gas and green liquid.
SB058001	If the characteristic properties of the ending substances are different than the characteristic properties of the starting substances, a chemical reaction occurred. (This item used a table to show the properties of the substances.)
SB065001	Mass is conserved when a plant dies in a sealed jar.
SB066001	Two liquids undergo a chemical reaction in an open jar and bubbles form. The mass of the liquids is less after the reaction because a gas was produced, and that gas left the system.
SC035004	During a chemical reaction, atoms stay the same but rearrange to form new molecules.
SC043005	When baking soda and lemon juice react in a sealed plastic bad, the weight will not change because the number of each kind of atom does not change.
SC045004	Two liquids undergo a chemical reaction in an open jar and bubbles form. The mass of the liquids is less after the reaction because some atoms went into the air.
SC056004	The weight of a jar containing water and sugar stays the same after some of the sugar dissolves.
SC059004	When a chemical reaction occurs in a sealed container, the mass of the materials in the container stays the same.
SC066005	When two white powders react to form a yellow powder, the yellow powder is made up of the same kinds of atoms as the white powders, but the atoms are combined into different molecules.
SC075004	When mold grows on a piece of bread in a sealed container, the bad and its contents weigh the same before and after the mold start growing.
SC077005	If a chemical reaction occurs between two liquids in a sealed jar, the mass will not change if a gas is formed, and it will not change if a solid is formed.

SC078003	Mass is conserved when a stick of butter is cut into pieces.
SC084004	As a thermometer is heated and the level of liquid in the thermometer rises, the mass of the liquid stays the same.
SC089005	The number of each type of atom stays the same during the combustion of propane. (This item uses circles to represent atoms.)
SC090003	The number of each kind of atom stays the same during the reaction between copper and oxygen. (This item uses circles to represent atoms.)
SC092004	When a liquid changes to a gas in a sealed container and the number of atoms stays the same, the mass of the jar and everything in it also stays the same.
SC094004	Mass is conserved when a plant dies in a sealed jar.
SC102002	The number of each kind of atom stays the same during a chemical reaction (This item uses circles to represent atoms.)

The reliability of the concept inventory must also be considered. Cronbach's alpha was utilized to establish the reliability of the data gathered from the concept inventory. The Cronbach value for the assessment was 0.826 which is within the acceptable range. This value measures the internal consistency of a set of survey items and is used to help determine whether a collection of items consistently measure the same characteristic. The validity of the concept inventory was ascertained by having five middle school and high school teachers evaluate its validity to assess what a science teacher should know about the conservation of mass. Additional validity was ascertained by asking participants if any questions were unclear in the survey or if there is anything they would like to address about it.

Participant Recruitment

To recruit participants for this study, the researcher utilized a variety of social networks. The survey was posted on GSTA (Georgia Science Teachers Association) and NGSS (Next Generation Science Standards) Facebook pages. The researcher also contacted GSTA district and state coordinators as well as NSTA (National Science Teachers Association) district and state coordinators for help in disseminating the survey to science teachers within the state. The researcher also used her own professional network to disseminate the information. Therefore, the researcher utilized both random and snowball sampling.

Survey Sample

Demographic information that was obtained with the concept inventory include age, years as a science teacher, level of science course (general, honors, accelerated, AP, IB), gender, and years as a science teacher in 6-12, science course taught, and teacher preparation route. The latter includes the options of teacher of middle school earth science, middle school life science, middle school physical science, secondary physical science, secondary biology, secondary life science, secondary chemistry, secondary physics and AP/IB biology, life science, physics and chemistry.

During this study the researcher utilized a population of science teachers whose teaching positions included middle school earth science, middle school life science, middle school physical science, secondary physical science, secondary biology, secondary life science, secondary chemistry, secondary physics and AP/IB biology, life science, physics and chemistry. All science disciplines are included because conservation of matter is a crosscutting concept that exists in and affects every aspect and discipline of science. These sample sizes range from eight to one-hundred thirty-eight teachers each. This is illustrated in Table 3 and indicates that a total of 498 teachers began and completed the quantitative survey of 690 total teachers who began the survey. Teachers were able to select more than one subject due to often teaching more than one prep. These teachers are all located within Georgia.

Table 3

Number and Type of Quantitative Survey Participants

Teachers of:	Number of teachers	Percent of Participants
Middle school physical science	112	22.5
Middle school life science	133	26.7
Middle school earth science	138	27.7
Secondary physical science	97	19.5
Secondary life science	55	11.0
Secondary physics	32	6.4
Secondary chemistry	51	10.2
AP Chemistry	28	5.6
AP Physics	25	5.0
AP Biology	24	4.8
AP Environmental Science	22	4.4
IB Biology	15	3.0
IB Chemistry	13	2.6
IB Physics	8	1.6

The sample of teachers who were surveyed had a varying degree of experience with the majority of teachers having between 1- and 10-years experience in the classroom, specifically 74.3% of participants. Table 4 below shows the number of teachers that have each representative number of years of teaching experience.

Table 4

Quantitative Survey Participants Years of Teaching Experience

Years of Teaching Experience	N	Percent of Participants
Less than 1 year	13	2.6
1-5 years	198	39.8
6-10 years	172	34.5
11-15 years	74	14.9
16-20 years	29	5.8
21-30 years	10	2.0
30+ years	2	0.4

The quantitative survey participants had a variety of teacher preparation routes. The varying experiences can be seen through Table 5 shown below. It can be seen through the table that

56.4% of teacher participants completed a bachelor's degree as their teacher preparation program, while 22.5% of teaching participants completed a Masters in Teaching as their teacher preparation program.

Table 5

Quantitative Survey Participants Teacher Preparation Routes

Preparation Program	N	Percent of Participants
Bachelor's in Science Education	180	36.1
MAT in Science Education	112	22.5
Teach for America	60	12.0
Georgia TAPP Program	36	7.2
Other Alternate Certification	6	1.2
Bachelor's in Education (non science)	101	20.3

The teacher participants had a variety of highest levels of degrees attained as shown in Table 6 below. The distribution of highest degrees attained shows 35.5% have bachelor's degrees, 36.3% have Master's degrees, 21.2% have an Education Specialist degree, and 5.4% have a doctoral degree.

Table 6

Quantitative Teacher Participants Highest Degree Attained

Highest Degree Attained	N	Percent of Participants
Bachelor's	177	35.5
Master's	181	36.3
Education Specialist	106	21.2
Doctorate	27	5.4

There was a reasonable distribution of male to female teacher respondents. The gender of the participants is shown in Table 7 below.

Table 7

Gender of Quantitative Survey Participants

Gender	N	Percent of Participants
Male	189	38.0
Female	285	57.2
Non-binary/third gender	12	2.4
Prefer not to say	10	2.0

The teacher participants of the quantitative survey also indicated whether they currently teach an honors or advanced class. For the purposes of this study teaching an honors level course means teaching the advanced students in a given course. For middle school teachers this could be teaching advanced sixth, seventh, or eight grade science or teaching high school physical science to advanced eight graders in the middle school. Approximately half of the participants taught a non-honors level class according to the data presented in Table 8 below.

Table 8

Quantitative Survey Participants Honors Level Teaching Responses

	N	Percent of Participants
Honors	220	44.2
Non-Honors	262	52.6
Prefer Not to Say	16	3.2

Data Collection

Consent was obtained for the survey by presenting participants with the consent statements before the beginning of the survey where participants had to acknowledge consent to begin. The instrument was delivered via Qualtrics online platform. No names were collected but emails were collected for follow-up interviews. Email addresses were collected and utilized to ensure there were no duplicate survey takers. Follow-up interviews were conducted online virtually via the Zoom platform following an open-ended semi-structured interview guide, as shown in Appendix B. Consent for these interviews were emailed to the participant prior to the interview. All data collected was stored on a password protected computer. Additionally, names were not collected. IRB was acquired before collection of data and is included in Appendix C. The first fifty participants to complete the survey received a $10 Amazon gift card. Any teachers who participated in the follow-up interview received a $20 Amazon gift card.

Interview Participant Selection

There were 498 total survey participants that completed the quantitative survey. These participants were invited to a follow-up interview lasting 10 to 15 minutes. From this population, 16 participants consented and participated in a follow-up interview. As described earlier in this chapter, all participants identities remain confidential, and pseudonyms were given to avoid identification of the participants.

Purposeful sampling was used to select participants for their interviews based on their answers during the quantitative survey portion. Participants were chosen to maximize the variety of answers and to highlight how teachers use knowledge of common student misconceptions to drive their instruction. The demographics of each interview participant is shown below in Table 9. The researcher made many efforts to diversify the interview participants but was limited by participation interest and willingness.

Table 9

Interview Participant Information

Pseudonym	Gender	Subjects Taught	Years Teaching	Teacher Preparation Route	Highest Degree Attained	CK	PCK
Ashley	Female	Secondary Physical Science, Chemistry	1-5	MAT	Bachelors	95	50
Mary	Female	AP Chemistry, Chemistry	25-30	Other	Masters	100	59
Dan	Male	Secondary Physical Science	6-10	Bachelor’s in Science Education	Masters	13	22
Jim	Male	Secondary Physical Science	6-10	Bachelor’s in Science Education	Masters	36	9
Brett	Male	Middle School Earth Science	11-15	MAT	Masters	31	28
Paul	Male	Chemistry	<1	Bachelor’s in Science Education	Bachelors	68	18
David	Male	IB Biology	1-5	Bachelor’s in Science Education	Bachelors	27	13
Mike	Male	AP Physics	<1	Bachelor’s in Science Education	Bachelors	18	9
Sally	Female	AP Chemistry, AP Physics	6-10	MAT	Masters	100	73
Greg	Male	Middle School Life Science	1-5	Bachelor’s in Science Education	Bachelors	64	23
Michelle	Female	AP Biology, Anatomy	6-10	Bachelor’s in Science Education	Doctorate	90	45
Lily	Female	AP Chemistry, Chemistry	16-20	Georgia TAPP	Specialists	90	40
Josh	Male	AP Biology, Biology	25-30	MAT	Masters	91	45
Megan	Female	AP Environmental Science, Secondary	11-15	Bachelor’s in Science Education	Specialists	91	41

Tracey	Female	Physical Science Middle School Life Science	25-30	Bachelor's in Science Education	Masters	91	45
Katie	Female	Secondary Life Science, Chemistry	1-5	Bachelor's in Science Education	Bachelors	45	32

The first research question is quantitative in nature. It seeks to analyze the content knowledge that teachers within these disciplines surveyed possess in the area of conservation of mass and the correlation between the teachers' CK and their PCK. As noted by Sadler (2013), quantitative research on testing CK and PCK in science teachers is lacking. Additionally, this study explored a new avenue of research in seeking to test the correlation between science teachers' CK and PCK. PCK is tested by a teacher's ability to select student's most common misperceptions on the concept inventory. It is hypothesized that teachers with higher PCK will have higher CK scores and that teachers with higher CK will have higher PCK scores. The results of identifying these misperceptions will be compared against the data obtained from the AAAS Project 2061 initiative, as explicated under the data analysis section. The questions in the new concept inventory have already been administered to a representative population of students prior to the questions being published by the AAAS Project 2061 initiative. All the answer choices are based on student misconception data. The most common student misconception is the wrong answer choice that the most students choose. If 10% choose A, 20% choose B, 20% choose C, and 50% choose D and B is the correct answer then, the most common student misconception is D. That is the wrong answer choice that the most students choose. It is this answer to which teachers will need to identify correctly in order to score on the PCK test.

Data Analysis

Table 10 indicates the data that was analyzed. This is structured according to research question. Sadler et. al.'s study looked at Pedagogical Content Knowledge and Content Knowledge in comparison to student pre and post test scores. The researcher wished to collect self-reported demographic data in order to discern if there is a relationship amongst demographic data and PCK and CK.

Table 10: Research and Analysis Questions and Required Data for Research Question 1

Data	**Question**	**Statistical Test**
• CK score • PCK score	Is there a relationship between CK and PCK?	correlation coefficient
• PCK score • Categorical age of teacher • Categorical level of course taught • Categorical years of experience teaching • Highest Degree Attained • Sex • Categorical level of course taught • Categorical years of experience teaching • CK score	Is there a relationship between PCK and self-reported demographics?	Step-Wise Multiple Liner Regression

Table 11: *Research Question 2 Supporting Questions and Data*

Research Question	Supporting Questions	Data Source
How do teachers use their knowledge of common conceptual student misconceptions related to conservation of mass to address student needs within this concept of the curriculum?	How do misconceptions affect learning in their classroom?	• Explanation Data • Interviews
	How does the teacher plan on addressing common student misconceptions?	• Interviews
	How does the teacher modify or help with these challenges or difficulties moving forward?	• Interviews

First the above data for question 1 was scored, dummy coded, and deidentified. In other words, the teacher participant score sheets received a coded identifier in place of their name to retain confidentiality. Each pair of CK and PCK tests were linked per teacher with these coded identifiers. Descriptive statistics was run on the data and normality was determined to see if parametric or nonparametric tests should be utilized.

In order to analyze the data collected, several different statistical methods were employed. Regarding the analyses for RQ 1, first descriptive statistics were performed on the quantitative data (from the concept inventory) in order to determine the mean, median, mode, standard deviation, and normality of the data. Reliability coefficients were calculated to measure teachers' overall consistency on the concept inventory using Cronbach's alpha. The data was then analyzed using Kolmogorov-Smirnov in order to determine the normality of the data. The data was then analyzed accordingly through parametric statistical techniques. In order to answer the research questions specific statistical tests were utilized as listed in the table above. To determine the correlation between PCK and CK, a correlation coefficient was used. Although the normality of the data was in question, additional tests were run to determine that the normality did not have a negative effect on the results of the analysis. The independent and dependent variables on RQ1 are CK/demographics and PCK, respectively, and were measured in order to determine if they are positively correlated. RQ2 is qualitative and therefore does not have variables.

As participants went through the concept inventory and answer what they think is the most incorrectly chosen answer by students, teachers were also be asked for an explanation of why they chose the most common student misconception that they did. This qualitative data was then open coded and grouped according to the focus the teacher placed within the explanation and coded for similarities and differences.

Data Collection for Interview

In addition to administration of the concept inventory, a small sample of approximately fifteen teachers participated in a qualitative interview to elicit further information and explanations regarding the correct answers for questions and most common student misconceptions. This took place after administration of the concept inventory. The teachers were interviewed to answer RQ2: How do teachers use their knowledge of common student misconceptions related to conservation of mass to address student needs for this concept of the curriculum? This follow-up interview guide instrument is attached as Appendix B. Teachers were chosen based on the answers they gave in their explanations. The researcher chose participants for interviews that specifically reference different components of PCK when discussing misconceptions. The participants surveyed were also chosen so that a broad range of PCK levels and scores are represented in the sample to discern any differences between the two groups. In this way, the researcher was able to ask teachers to elaborate on the explanations and relate this to the teachers' scores in CK and PCK. A small sample of teachers was used. The number was dependent on the answers given in the surveys by teachers and how they help the researcher answer the research question, known as purposeful sampling.

The interviews were transcribed and open coded to gain insight into the correlations between PCK, CK, and teacher demographics as well as offer further data and explanations for the quantitative relationships obtained. These codes are contained in Appendix D in the codebook. The interviews were also analyzed using predefined codes that are based on the different components of PCK that the participant references. The identification of each correct answer allowed the researcher to investigate and quantify the teachers' CK whereas the identification of the most common student misconception or incorrect answer allowed the researcher to quantitatively determine the knowledge of students' misconceptions which allowed the researcher to extrapolate knowledge about the teachers PCK within this domain. Inter-rater reliability was established by having another researcher code a section of qualitative responses and interviews. The expert coded and the researcher discussed the codes until 100% agreement was reached. At the conclusion of the data analysis, a copy of the findings were sent to all study participants as an additional check for trustworthiness.

Chapter 4: Results and Findings

The purpose of this chapter is to present the results and findings of the data collected in this study. This chapter is organized by research question in order to present the findings and results of both the quantitative survey and the qualitative interviews. The researcher seeks to answer the following research questions through this study.

1. Is there a relationship between content knowledge, pedagogical content knowledge, and self-identified teacher demographics in relation to the concept of conservation of matter?
2. How do teachers use their knowledge of common student misconceptions related to conservation of matter to address student needs for this concept of the curriculum?

Research Question 1

Teachers responded to a 22-question survey related to Conservation of Mass. Answering the question correct results in a CK score. Whilst being able to identify the most common student misconceptions results in a PCK score. The descriptive statistics of the CK and PCK data from the survey is shown below in Table 12. There were 498 complete surveys. All partially complete surveys were removed from the data set. Surveys were also checked to ensure that no two surveys contained the same email identifier. The mean for CK in percentage was 32.33 with a standard deviation of 20.93. PCK had a lower maximum, mean, and standard deviation. PCK had a mean of 26.84 and a standard deviation of 11.69 also utilizing the percentage correct.

Table 12

Descriptive Statistics of Quantitative Survey

Score	Frequency	Mean	Standard Deviation	Minimum	Maximum
CK	498	32.33	20.93	0	100
PCK	498	26.84	11.69	0	68

The distribution of PCK vs CK is shown in Figure 2 below. As can be seen in the figure, the distribution of scores is wide. Those with higher CK scores tend to have slightly higher average PCK scores. A Pearson product-moment correlation was run to determine the relationship between CK and PCK. There was no correlation between CK and PCK (r = .032, n = 438, p= .502) according to this statistical test. This indicates that there is no statistical correlation between a score received for CK and a score received for PCK in the data sample.

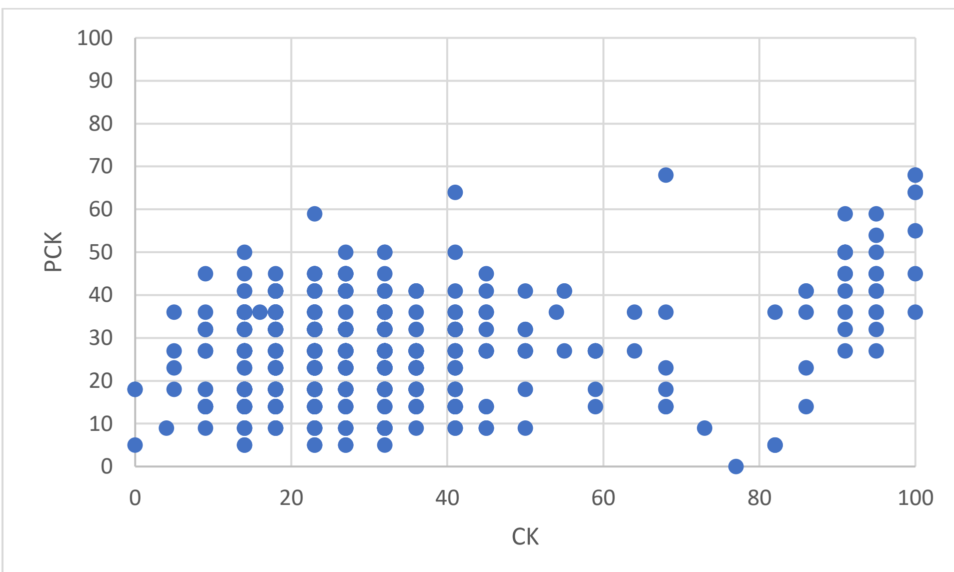


Figure 2: PCK Scores vs CK Scores on Quantitative Survey Assessment

The normality of the sample was in question as one of the driving assumptions of step-wise multiple linear regression. Outliers were included within three standard deviations of the mean (N=462). In order to determine the influence of the outliers, Cook's Distance was calculated. Cook's Distance measures how much the model coefficient estimates would change if an observation were to be removed. The Cook's Distance values for the sample are shown in Table 13 below. Based on the fact that all of the values fall below 1, we can safely assume that no outliers are substantially influencing the outcome of the model.

Table 13

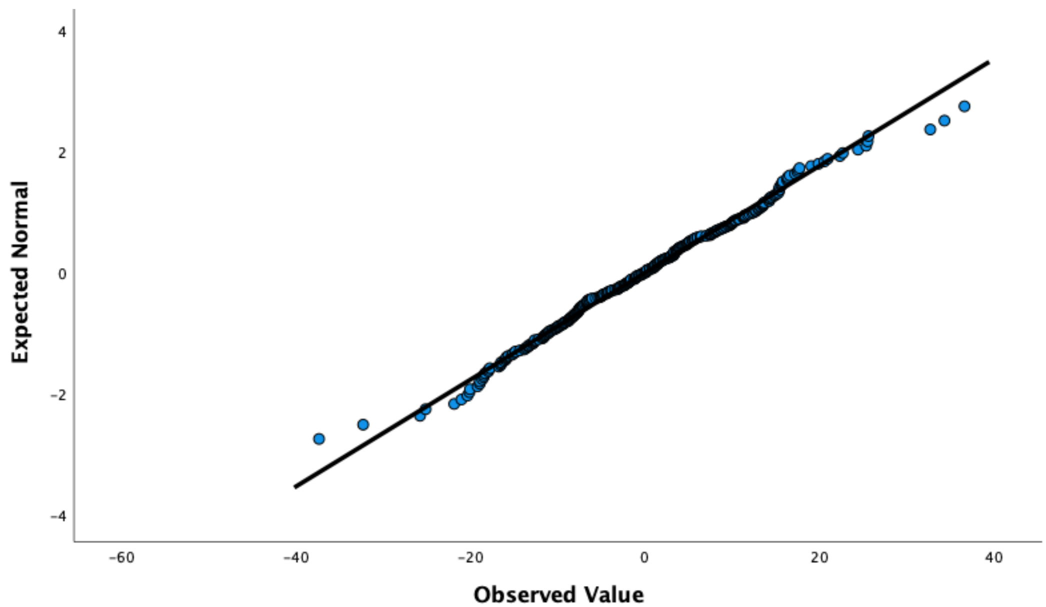
Cook's Distance Minimum and Maximum Values

	Cook's Distance	
N	**Minimum**	**Maximum**
462	0.000	0.053

The normality of the residuals was also investigated in order to further strengthen the results obtained from the step-wise multiple linear regression. The Q-Q plot of the residuals is shown below in Figure 3. As can be seen in Figure 3, the normality of the residuals is normal because the output is linear, strengthening the assumptions of this predicted model.

Figure 3

Q-Q Plot of Normality of Residuals



Step-wise multiple regression analysis was used to test if gender, years teaching, teacher preparation route, subjects taught, highest degree attained, teaching honors level classes, and Content Knowledge significantly predicted teachers' PCK scores on the assessment. Group 1 of the step-wise linear regression variables were the demographic variables. These variables are ones in which an individual has no controls over it, similar to individual characteristics. Group 2 of the step-wise linear regression included the highest degree the teacher had attained, the teacher education preparation route and class preps which are all related to the teachers' credentials. The last group in the step-wise multiple linear regression was CK which is a direct measure of the teacher's skill level and ability/knowledge. The results of the multiple linear regression indicated that CK scores and teaching Honors level classes predicted teachers' performance on the PCK assessment as shown in Table 14. The regression is statistically significant with about 7.8% of the variance in PCK explained by the variables ($_{adj}R^2$=.078) of teaching an honors-level class (β=-.131, p<.01) and CK score (β=.247, p<.001). The other variables did not statistically predict PCK scores in this model. Teaching an honors-level class was a negative predictor of PCK. The f value of the predicted model is 6.447 with a p value of less than .001.

Table 14

Hierarchical Regression Model Predicting Teacher PCK Score (N=462)

Predictors	Standardized Beta Coefficients		
	Step 1	Step 2	Step 3
Years of Experience	-.038	-.008	-.030
Gender	-.021	-.027	-.035
Highest Degree		.046	.038
Teacher Prep		.009	.043
Honors		-.135**	-.131**
CK			.247***
R^2	.002	.019	.078*
F-value for Model	.413	1.767	6.447***
Change in R^2		.017	.059

Note. Significance of the p-value is noted *<.05, **<.01, ***<.001.

In an effort to understand why teaching honors level courses was a negative predictor in the regression model for PCK, a distractor analysis was conducted on the PCK data. The teacher participants were separated into four categories based on their level of teaching (high school or middle school) and whether they taught honors or not. Therefore, the groups were middle school non-honors, middle school honors, high school non-honors, and high school honors. There were 122 participants that taught non-honors middle school, 80 that taught honors middle school, 82 that taught non-honors high school, and 163 that taught honors high school courses. This data can be seen in Table 15 below.

Table 15

Sample Sizes of Four Participant Groups for Distractor Analysis

	Middle School	High School
Non-Honors	122	82
Honors	80	163

The CK and PCK means were determined for each of the four participant groups and are shown in Table 16. The results indicated that high school honors level teachers have the lowest PCK of the four groups and middle school honors teachers have the highest PCK.

Table 16

Means for Four Participant Groups for Distractor Analysis

	Middle School		High School	
	CK	PCK	CK	PCK
Non-Honors	27.6	26.6	29.4	26.7
Honors	32.1	27.6	29.9	24.2

In order to determine if there was a statistical difference between the means of each group for CK and PCK, a two-way ANOVA was conducted. The results of the ANOVA for CK are shown in Table 17. The dependent variables for the ANOVA were CK or PCK respectively while the independent variables were level of teaching (middle/high) and honors level teaching. The ANOVA result indicated the difference between the groups is significant ($F=6.13$, $df= 1$, $p<.05$) is a significant difference in the effect of teaching between middle/high (Middle/High: $p=.014$) but not for whether they taught honors or not (Honors: $p=.851$).

Table 17

Results for 2 Way ANOVA for CK Means for Distractor Analysis

Predictor	Sum of Squares	*df*	Mean Square	F	p
(Intercept)	476808.17	1	476808.17	1109.10	<.001
Middle/High	2637.08	1	2637.08	6.13	.014
Honors	15.21	1	15.21	0.035	.851
Error	205681.05	478	430.30		

The results of the two-way ANOVA for PCK of the participants once separated by level and honors level teaching are reported in Table 18. The PCK data interaction is significant with a $p<0.05$. So, there is a significant difference in the effect of teaching whether or not they teach honors and level at which they teach ($F=4.52$, $df=1$, $p<.05$). There is a significant main effect for teaching honors or not (Honors: $p=.034$), but no significant main effect for level at which they teach (Middle/High: $p=.457$).

Table 18

Results for 2 Way ANOVA for PCK Means for Distractor Analysis

Predictor	Sum of Squares	*df*	Mean Square	F	p
(Intercept)	316092.58	1	316092.58	2329.51	<.001
Middle/High	75.13	1	75.13	.554	.457
Honors	613.08	1	613.08	4.52	.034
Error	64860.02	478	135.69		

During the distractor analysis, the answer choice chosen by the participants in each group was converted to a percentage of participants in the group that choose each answer choice. This allowed the researcher to see what the most common answer chosen for each group was as well as what distractors for the correct answer were chosen by each group. This allows the researcher to further analyze the data in an attempt to see which distractor was being chosen most commonly within each group and therefore help the researcher to understand the PCK within each subgroup. When analyzing the distractor analysis, the group that had the most teacher participants pick the actual most common student wrong answer based on the national data was determined for each level (high school vs middle school) between honors and non-honors teaching. This information is summarized in Table 19 below. Based on the results it can be seen that high school non-honors teachers were far more likely than high school honors teachers to choose the most common student wrong answer. This helps to explain the finding that teaching an honors level class has a negative effect on the PCK of the participant because a portion of the teacher participants are choosing distractors instead of the actual most common student wrong answer.

Table 19 shows the breakdown of the frequency of each group to have the highest percentage of participants choose the most common student wrong answer across all four groups for each of the 22 questions. Based on the data, it can be seen that high school non-honors teachers were more likely than any other group to choose the most common student wrong answer (frequency of 10 out of 22 questions). The group with the lowest frequency of choosing the most common student wrong answer was high school honors teachers (frequency of 2 out of 22 questions).

Table 19

Summary of Frequency of Highest Percentage to Choose Most Common Student Wrong Answer

	Middle School	High School
Non-Honors	6	10
Honors	4	2

After compiling the frequency data from the distractor analysis, the researcher went through and looked question by question at the most prominent answer choices for the teacher participants in the honors high school group. It was found that 17% (N=29) of high school honors teachers were choosing the actual correct scientific answer for the most common student misconception. Therefore, these teachers may be misinterpreting the question as written or truly think that is what their students would put because they believe that their students do not have misconceptions. So, the most common student answer would indeed be the answer most chosen by their students. This finding helps explain the negative effect that teaching honors has on the multiple linear regression analysis. Some of the honors level high school teachers are choosing the actual correct student answer for the most common student wrong answer and that is part of the cause of them having the lowest PCK of the four subgroups.

Research Question 2

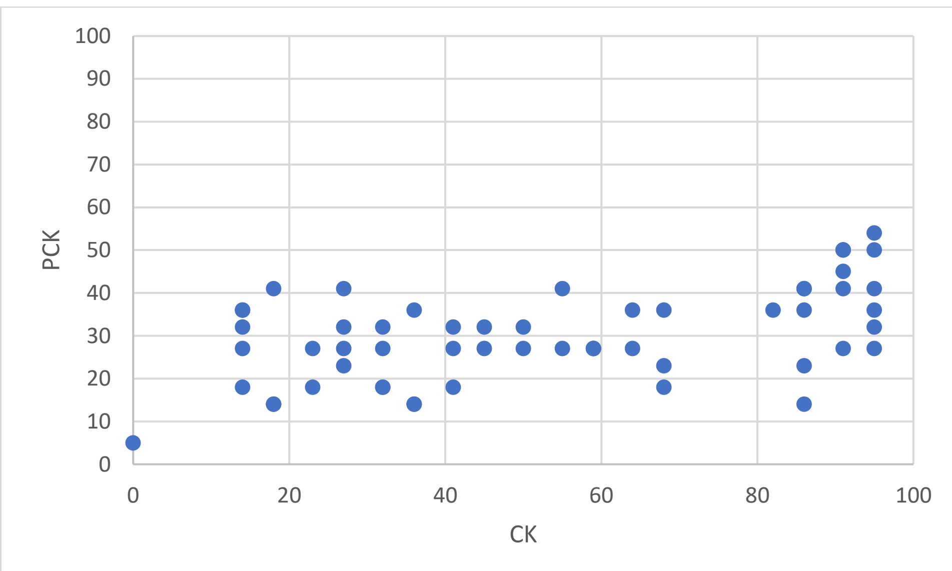
In order to answer the second research question, "How do teachers use their knowledge of common student misconceptions related to conservation of matter to address student needs for this concept of the curriculum?", several other questions were addressed. The interview questions developed to answer this question include:

1. What do you identify as the reasons for common student misconceptions?
2. How do misconceptions related to conservation of matter affect learning in your classroom?
3. Has your knowledge of student misconceptions affected how you teach? How has knowledge of theses misconceptions affected how you teach?
4. How have you altered your curriculum due to your knowledge of these misconceptions?

Reasons for common misconceptions. Participants responded to why they thought the answer they chose for the most common student wrong answer on the PCK was the most common misconception held by students. This data was coded for each individual question from the survey as well as codes that emerged from the given responses. These codes can be accessed in the code book contained in Appendix D. The responses were coded into one of four groups based on how they responded to the prompt. Of the responses 498 survey conducted 1604 codable qualitative responses were collected. If every teacher who took the survey provided responses for every item there would have been 10,956 qualitative responses. The distribution of CK and PCK scores for the qualitative responses collected are shown below in Figure 4. This distribution is consistent with the larger sample of data collected.

Figure 4:

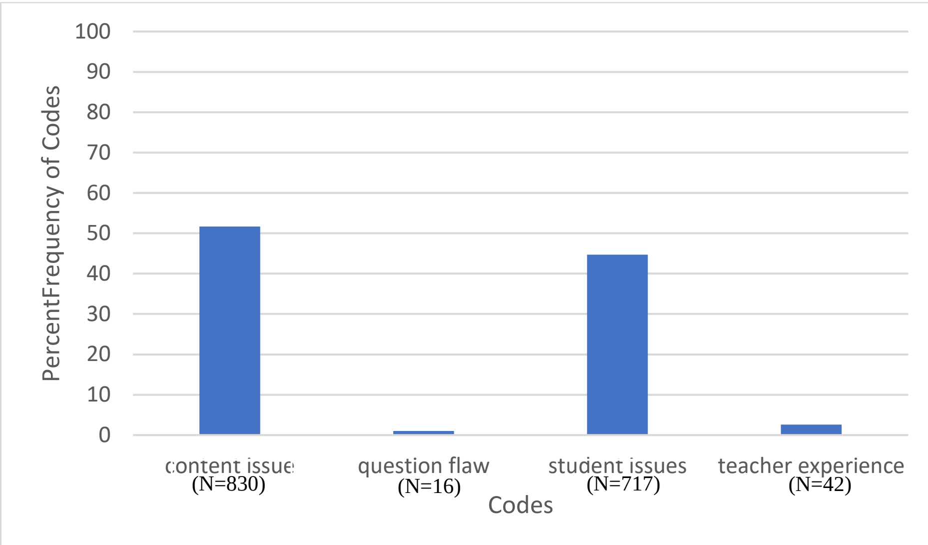
PCK vs CK for Qualitative Responses Collected



Four categories emerged from the written responses as follows, 51.7% (N=830) were related to student issues with understanding content, 1% (N=16) discussed flaws within the question or answer choices themselves, 44.7% (N=717) were barriers the students have in learning the content, and 2.6% (N=42) discussed teacher experience as a reasoning for knowing which answer was the most common student wrong answer. The qualitative survey responses were open coded into four categories as shown in Figure 5. Responses related to student issues with understanding the content where content specific to the wording of each question. For example, a participant writes in her reasoning that “most students fail to differentiate endothermic and exothermic reactions”. While another participant writes “a lot of them tend to believe that chemical reactions increases mass in some kind of ways and thereby form silver sulfide molecules.” These responses attempt to reason through the confusion in the main concepts that have caused the misconception. Alternately some responses discussed student barriers to the content that are beyond the control of the teacher in the classroom. These responses were coded as students’ issues and some examples include “students can’t express themselves clearly” and “students don’t know what to listen to.” These responses indicate a barrier to learning that the educator cannot directly influence with their pedagogical content knowledge. Other participants stated that the reason they could identify the misconception most likely chosen by students was due to their own experience in the classroom. These responses included statements like “most students I have taught say this” and “I have been teaching for a long time.” These statements indicate the teacher has knowledge of the misconception due to some previous experience with seeing the misconception come up in their classroom. Lastly a small percent of responses referred to issues with the question itself that were the main cause of the student misconception. Responses such as these included comments such as “because this is a misleading question” and “there is no logic before and after the sentence pattern.”

Figure 5

Percentage of Codes on Qualitative Survey Responses.



Note: The number above each bar indicates the number of participants who were coded at the specific level.

The researcher then looked to see if there were any patterns in how teachers responded based on the questions themselves. The first survey question involved the increase in mass of silver coins that tarnish to form silver sulfide molecules. The question asks for an explanation of why the mass of the silver coins increased. Of the responses, 39.2% (N=830) were content focused, 3.9% (N=16) were issues with the question itself, 41.2% (N=717) were student issue focused, and 15.7% (N=42) were teacher experience. Content focused responses ranged from "students do not understand that atoms rarely turn into other atoms, that it only happens in nuclear reactions, [and] students also don't think of air as containing much other than oxygen", to "there is confusion on where atoms are located and also difficulty understanding open systems". Those that found the issue was within the question itself made comments such as "because this is a misleading question" and "because they couldn't understand the question." The responses that were coded as issues and barriers with students included "students can't express themselves clearly", "they don't read the questions to understand most times," "because it is easy for students to have fixed thinking and make wrong answers," and "because it's easy to mislead them." The highest number of total responses as well as highest number of responses coded as teacher experience were recorded for this first question. This being the first question in the survey the most teachers participated in answering this question. Having the highest number of teacher experience codes can also be attributed to this first question receiving the highest response. The responses coded teacher experience gave reasons such as "I have been teaching for a long time," because I have seen many students choose this answer," and "most students I have taught tend to give it as an answer."

Table 20

Summary of Codes for Qualitative Survey Data with Percent Coding Frequency per Question

Question	N	Content Issue	Question Issue	Student Issue	Teacher Experience
1	104	39.2	3.9	41.2	15.7
2	94	45.7	2.1	48.9	3.2
3	80	53.8	2.5	42.5	1.3
4	83	50.6	2.4	45.7	1.2
5	82	57.3	2.4	39	1.2
6	70	55.7	1.4	41.4	1.4
7	70	55.7	0	41.4	2.9
8	72	51.4	0	45.8	2.8
9	72	55.6	0	43.1	1.4
10	77	48.1	0	50.1	1.3
11	75	50.7	0	48	1.3
12	73	57.5	0	41.1	1.4
13	72	51.4	0	45.8	2.8
14	71	52.1	0	46.5	1.4
15	58	65.5	0	31.1	3.4
16	68	55.9	0	42.6	1.5
17	69	55.1	0	43.5	1.4
18	68	50.0	0	47.2	1.4
19	66	45.5	0	53	1.5
20	59	47.5	0	50.8	1.7
21	63	50.8	0	47.6	1.6
22	60	50	0	48.3	1.7

The total number of responses for each question decreased throughout the survey from 104 responses on the first question to 60 responses on the last question. This indicates that the participants could have suffered from survey fatigue. The question with the fewest responses was question 15. There was a drop off of ten responses between question 14 and 15. Interestingly question 15 is an application of Conservation of Mass to a biological system. This is congruent with interview data which indicated that teachers have a harder time applying Conservation of Mass to non-conventional systems such as looking at matter cycling. There were a lower number of responses coded as student issues for question 15. As the data in Table 15 shows, approximately half of responses for each question were coded as student issue and approximately half were coded as focusing on content issues. There were one or two teachers that used teacher experience as reasoning for knowing the most common student misconception throughout the whole survey. Question 1 also had the highest responses of question issues reported. However, after analyzing the data, the number of teachers answering decreased significantly in that category for the remainder of the survey.

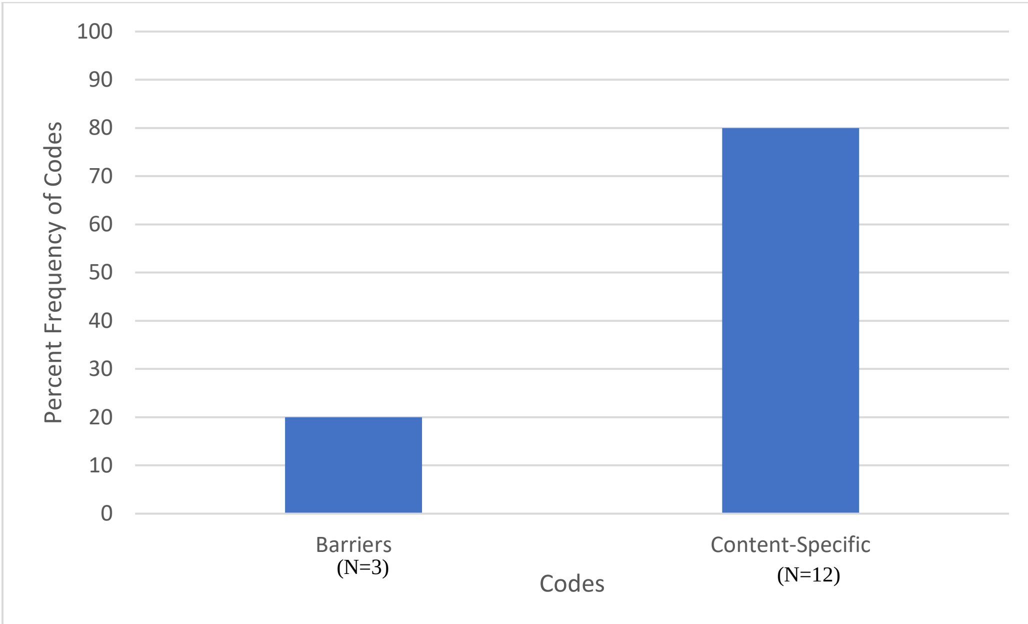
A significant finding to come out of the qualitative survey data is that teachers hold misconceptions surrounding Conservation of Mass. Two prominent teacher misconceptions were found. The first teacher misconception deals with the idea of splitting atoms. The responses coded as being content focused that were also coded as misconceptions include: “The students did not remember that atoms are broken down and chemically reacted.”, “fail to understand the dissociation of atoms.”, and “The atoms basically broke down to release the molecule.” All of these responses are congruent with a misconception that atoms break apart during a chemical reaction. This is also a common misconception amongst students.

The second category of misconceptions dealt with matter cycling in biological systems. There were two specific questions that involved biological systems. The first question involves a living plant being placed in a sealed jar. The plant subsequently dies, and the participants are asked what happens to the mass of the jar. Several teachers incorrectly commented that the students would assume that the mass stays the same when in fact it will decreases because the leaves are drying out and the plant is withering. The teacher is making the statement that the student would have the incorrect understanding that the mass would stay the same. The teacher goes to further explain that the mass would actually decrease because the leaves were drying out and withering as the plant dies. These answers indicate that the teachers do not see this as a continuous system of matter cycling within the jar. The second biological question addresses a slice of bread in a sealed bag that has mold grow on it. The mold increases in mass and the participants are asked to predict the mass after the mold has grown. Once again several teachers had misconceptions related to this matter cycling question. One participant indicates that because the mold increased in weight the total contents of the bag had to increase in weight failing to account for the fact that this is in fact a closed system where mass would remain constant. This shows that the teacher does not have a firm understanding of matter cycling in closed systems.

Misconceptions effect on learning. Select teachers participated in a follow-up qualitative interview. There were 16 teachers who participated. In response to the question "How do misconceptions related to conservation of matter affect learning in your classroom?", responses collected were classified as discussing barriers to learning or discussing content specific instances where misconceptions were especially troublesome. These categories emerged from the data. 20% (N=3) of respondents indicated that there were barriers that contributed to misconceptions and learning difficulties in their classroom as indicated in Figure 5. Katie a high school physical science teacher with average CK and PCK comments that the “cultural, social backgrounds of some students” get in the way and students therefore are not as receptive to learning specific concepts. This illustrates that Katie recognizes the barriers to learning content in her classroom but has not gotten to the point of addressing these barriers yet. Jim comments that “negative attitudes” contribute to students having difficulty learning and “difficulty believing the book.” These negative attitudes and social, culture backgrounds are therefore acknowledged by these educators as barriers to teaching and learning in their classroom. The other 80% of responses were coded as focused on content. These answers indicate that the educator, while recognizing that barriers do happen to student learning, does not let it become an excuse for misunderstanding. These educators focus on how the students have misconceptions inherent in their understanding of the content and see the misconceptions themselves as the barriers that must be overcome to help increase student understanding. This approach allows teachers to leverage Pedagogical Content Knowledge in order to control the aspects of misconceptions that are within the teachers control. In order to apply PCK, a prerequisite is to acknowledge barriers to learning but work towards solutions to student misunderstandings that are within the teachers’ immediate control within the classroom.

Figure 6

Distribution of Qualitative Interview Responses to Effect of Misconceptions on Learning.

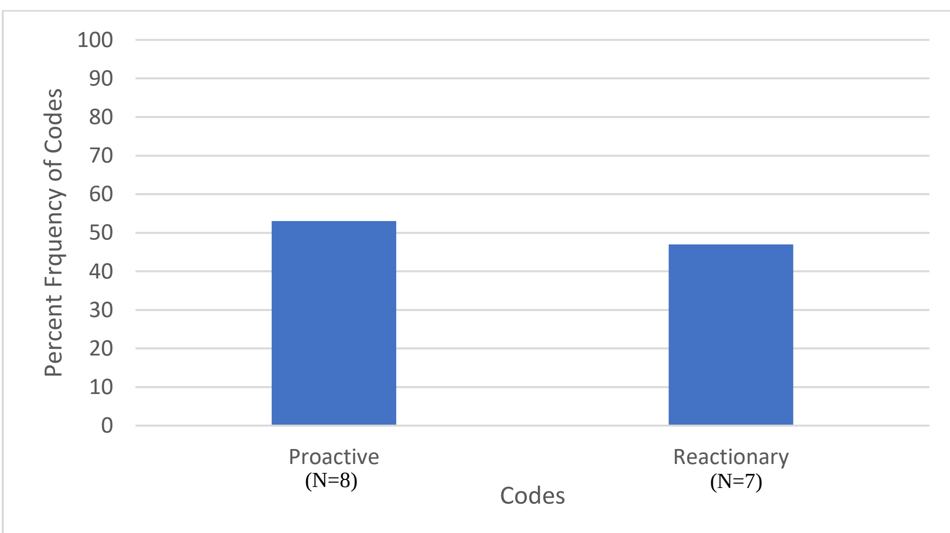


Note: The number above each bar indicates the number of participants who were coded for that code.

Misconceptions affect teaching. In response to the question, "How has your knowledge of these misconceptions affected how you teach?", 53% (N=8) of responses mentioned proactive methods or preassessments to gain knowledge of these student misconceptions whereas 47% (N=6) of responses mentioned reactive methods of addressing student misconceptions as shown in Figure 7 below. Proactive methods were classified as ones in which the response referenced preassessment for identification of student misconceptions or predicting student misconceptions prior to the lesson based on research-based or historical data. Michelle, an AP Biology and Anatomy teacher comments "I always do a pre-assessment," demonstrating that she collects data about student misconceptions from students prior to instruction. Ashley, a secondary physical science and chemistry teacher describes getting in front of the student's misconception prior to instruction in her interview: "If I can head off the student's misconceptions and can work hard to figure out what they are before my lesson and … head that off" then she can prevent misconceptions from multiplying. 75% (N=6) of the respondents who discussed being proactive or pre-assessing student misconception had an above average PCK score on the quantitative survey. In order for teachers to address misconceptions, they must first acknowledge they exist and be aware of them. This question demonstrates that teachers apply one of two methods to become aware of misconceptions so that they can then adjust their teaching and curriculum accordingly. Teachers either pre-identify the misconception or wait for the misconceptions to come up during class or assessments.

Figure 7

Distribution of Qualitative Interview Coded Responses to the interview question, "How has knowledge of student misconceptions affected how you teach."



Megan, an AP Environmental Science and secondary physical science teacher describes the evolution from thinking about misconceptions in terms of reacting to them to preparing for them ahead of time. She describes herself in the following as someone who used to just address misconceptions but now, she wants to know where the student misconceptions come from and why the students have these misconceptions in the first place.

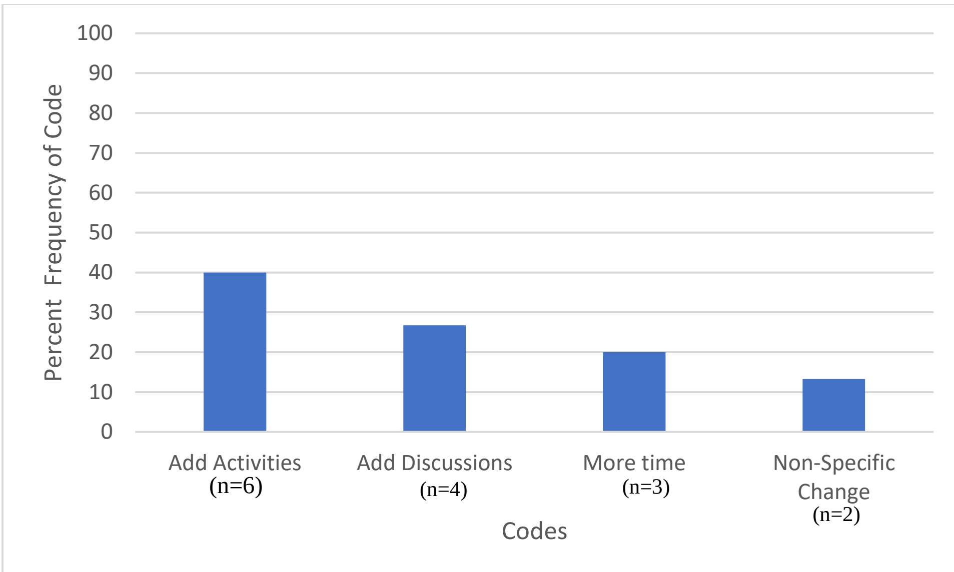
> *It's kind of evolved over time because initially they would say okay what are student misconceptions and then how do you address them. And I would literally say okay you might think this, but this is the way it should be. So, I would literally be more reactive than proactive but as time has gone on I found that I kind of have to figure out why do those misconceptions happen in the first place.*

100% (N=8) of respondents that referred to reactive methods in terms of addressing misconceptions had a high PCK score on the quantitative survey. Tracey, a middle school life science teacher comments "When you see students make multiple students make the same mistake um you kind of get an idea of what the way they're thinking and so you change how you present it you know." In this manner the teacher notices the same misconception from multiple students and then changes the presentation to address this misconception after noticing it. This illustrates a reactionary response to misconceptions that come up during a lesson.

Altering curriculum due to misconceptions. In response to the question, "How have you altered your curriculum due to your knowledge of these misconceptions?", respondents were separated into two major categories based on misconceptions having influenced a change in their delivery of curriculum or them implementing no changes due to misconceptions. 13.3% (N=2) of respondents did not change their curriculum due to misconceptions while 86.7% (N=14)did change their curriculum in some manner due to misconceptions. The responses that alter curriculum in some way due to misconceptions were further sub-divided into four subcategories: changing or adding activities, addition of discussion and analysis questioning, more time devoted to difficult concepts, a non-specific change. As shown in Figure 7, 40% (N=6) of respondents referenced adding or changing activities in the classroom when altering curriculum due to misconceptions. Lily, a veteran AP Chemistry and chemistry teacher discussed the need to restructure the curriculum guide provided by her district. She believes in teaching chemistry from “small to big” indicating she arranges her curriculum so that students learn about submicroscopic properties of matter before moving on to reactions and stoichiometry. Whereas Sally, an AP Chemistry and AP Physics teacher with an MAT describes the need to add more “experiences” with particulate level diagrams to her AP Chemistry class in order to help students connect Conservation of Matter to the submicroscopic level of representation. Paul, a first-year chemistry teacher mentions utilizing analogies and experiments to engage his students and address misconceptions in his classroom while Megan, an AP Environmental Science and secondary physical science teacher describes teaching on the fly online by incorporating an interactive activity due to misconceptions that needed to be addressed. The addition of discussions and analysis questions were referenced by 26.7% (N=4) of the respondents. Jim, a high school physical science teacher states that he adds follow-up questions to aid in assessing further need for intervention when misconceptions arise. Mary, a veteran AP Chemistry and chemistry teacher discusses the use of analysis questions as follow-up to address misconceptions and also notes that she has a class discussion surrounding the misconception before moving on in the curriculum. While only 20% (N=3) of respondents cited adding more time to their coverage of content related to misconceptions. Jim, a high school physical science teacher describes adding instructional time for more explanations surrounding topics that have misconceptions. Michelle, an AP Biology and anatomy describes adding additional instructional time to address prior knowledge needed that often lack due to misconceptions. 13.3% (N=2) of respondents cited making changes to their classes due to misconceptions but were not specific on what those changes were. Josh, a veteran AP Biology and biology teacher discusses trying to implement changes over the past several years but was not specific as to what changes he made to his classroom.

Figure 8

Distribution of Coded Teacher Interviews for the interview question, "How they Alter Curriculum due to Misconceptions."



Survey effect. The final interview question, "Did the survey change how you think about student misconceptions and how will this affect your teaching moving forward?", respondents categorized the survey experiences as having either no effect or a positive effect on them professionally. 20% of respondents indicated the survey had no effect on them professionally and did not change their thinking. 80% of respondents indicated that the survey had influenced their thinking of awareness, reflection, and treatment of misconceptions moving forward. This demonstrates that the teachers found it professionally beneficial to go through a concept inventory, try to pick out the most common student wrong answer, and think about why the student would have chosen that answer.

The qualitative interviews were coded holistically, and two main themes emerged. These themes included learning by doing and professionally beneficial. Learning by doing refers to a hands-on approach to learning, meaning students must interact with their environment in order to adapt and learn. 40% of participants mentioned learning by doing as something they do or would like to do related to misconceptions. Katie, a veteran middle school life science teacher discussed the need to do experiments in order to give the students hands-on experiments to address student misconceptions in her class. Lily, a veteran AP Chemistry and chemistry teacher refers to giving the students visuals and things to look at as a way to address misconceptions in class. Tracey, an early career biology and chemistry teacher talks about the need to give students activities to allow the student to engage with the content. These responses indicate that these educators believe that allowing students to interact with and engage directly with science through activities and experimentation in order to best address student misconceptions in science.

The second theme was professionally beneficial. Of the interview responses, 73% had passages that were coded as professionally beneficial. Professionally beneficial refers to statements that the participants made about the survey exercise having a positive benefit professionally for them. Lily, a veteran AP Chemistry and chemistry teacher talks about how completing the survey brought misconceptions to “the forefront of her mind” and reminded her that students do have these ideas. Sally, an AP Chemistry and AP Physics teacher with an MAT says the questions got her thinking more deeply about what the students might be thinking and stated she would like to have a set of questions of this caliber for more topics that she teaches. Jim said he was reminded that students have different thinking capacities and for the “first time got into the mind of a student.” Mary, a veteran AP Chemistry and chemistry teacher states that completing the survey was a “real benefit to me …. because you know we kind of neglect those ideas of misconceptions.” These responses indicate that the activity of completing a concept inventory looking for not only the correct answer but the most common student misconception and thinking about the reasoning for that misconception is powerful professionally to teachers.

Chapter 5: Discussion

The subject matter of this research was to study the use of CK and PCK by middle school and secondary science teachers when teaching the law of conservation of mass. The research revolved around two research questions. The first question aimed at establishing a relationship between content knowledge, pedagogical knowledge, and demographics of the self-identified middle school or high school science teacher. The second question was to study the teachers' utilization of their knowledge of common learners' misconceptions about conservation of the matter. This research hypothesized that teachers who possess higher PCK will automatically record higher CK scores, and this happens the vice versa. Such teachers are also believed to have gained knowledge about the students to a larger extent making them experienced in "knowledge of content and students" (Ball, 2008).

Relationship between CK and PCK

By using a Pearson product-moment correlation, the analysis of the collected data showed no relationship (lack of correlation) between CK and PCK. Earlier studies revealed that teachers' PCK may be related to their content knowledge but yet the two are distinguishable (Krauss, 2008). Carpenter (1988) found modest associations between CK subscales and learner-specific PCK. Similar to existing literature, this study proves the lack of correlation between CK and PCK. However, recent studies such as Sadler (2013) found that high-performing students gain more if their teachers have both CK and PCK, which is knowledge of the science content and related pedagogies for teaching it, and awareness of the learners' misconceptions compared to those having SMK only. However, for low-performing students, such associations were not observed (Hill & Chin, 2018). Quantitative research by Campbell (2014) showed that the mathematical content knowledge of teachers is significantly related to pedagogical knowledge and performance or achievement of the students. These results indicates the existence of mixed findings on the relationship between CK and PCK based on the existing literature and the findings of this study.

Relationship between PCK and Teacher's Demographics

Step-wise multiple regression results established that PCK scores are statistically dependent on CK scores and the teaching honors-level classes. There are no previous studies found linking PCK to teaching advanced/honors courses. Pedagogical content knowledge (PCK), a form of Subject Matter Knowledge (SMK) possessed by teachers' helps the students learn (Sadler, 2013). Teachers with high levels of PCK and CK are believed to possess robust knowledge of the learners' preconceptions, conceptions, misconceptions, interests, and reactions to specific instructional approaches (Hill & Chin, 2018). Having PCK in general means that the teacher can undertake professional noticing which includes their expertise to reveal students' needs and interests, their understandings and lack of, and how they effectively respond to adjustments in instructions (Sherin, Jacobs, & Philip, 2011).

Teachers' Use of their Knowledge of Common Student Misconceptions

Teachers' experience gained from the period of educating and interacting with students and reading literature related to students thinking about a concept or topic (Andrews, Auerbach, & Grant, 2019) helps to identify learners' misconceptions. This research backs this argument by revealing that educators reflected on their previous experiences when asked about the student's misconceptions. A teacher with many years of experience has substantial inventories of concepts that enable them to identify common misunderstandings across the learners (Salder, 2013). Therefore, content knowledge can be seen as highly contextualized to the teacher and the subject and greatly manifested during teaching. However, little evidence from this study connects the misconceptions of the teachers to the structure of the content being taught or questions being asked. This means that teachers are less likely to establish misconceptions about the content being taught based on a misleading question or narration and even a lack of logic in the structured narration. Only a few respondents indicated the teachers admitted that the questions were misleading and they could not understand them.

Teachers also have misconceptions about students' understanding of the questions asked regarding the Law of Conservation of Mass. Some of the misconceptions held by teachers are shared amongst students proving the early argument by Park and Oliver (2008) that teachers who possess misconceptions can pass them to their learners. For example, this study has revealed that teachers have a misconception about the breaking apart of atoms during a chemical reaction and a closed system jar with a plant retaining its mass after the plant dies. In such a situation, the teacher greatly dominates the class discussion and teaching session and also endeavors in questions with low cognitive load (Rollick & Mavhunga, 2002). These examples show that in some cases, teachers lack adequate knowledge of the content they teach and tend to pass the inaccurate knowledge to the students. As a result, they establish misconceptions to simplify the understanding and pass such delusions to students during learning.

Effect of Misconceptions on Classroom Learning

The literature on student preconceptions has gaps in showing the impact of teacher's awareness on learner's misconceptions on the student's knowledge acquisition (Sadler, 2013). This research fills this gap by showing that misconceptions about taught content are connected to students' social and cultural backgrounds and are believed to hinder effective learning. A small percentage of teachers believe that students have negative attitudes to the subject, theme, or topic in context, and such attitude together with their backgrounds makes learning difficult. Despite the above perception, this study has established that a large percentage (80%) of the educators focused on the content of the misconception rather than the student deficit. These teachers worked on ensuring that students' misconceptions do not affect their learning. They recognize the existence of misconceptions as barriers and work on teaching strategies to reduce misunderstandings caused by them. They achieve this by leveraging the Pedagogical Content Knowledge (PCK) as a prerequisite to solving the problem of misunderstanding.

The work of Grossman (1990) indicated that CK and PCK are the main knowledge source for teachers and their ability to instill knowledge in learners depend on how the teachers have mastered the content. However, teachers only apply PCK when misconceptions are within their area of control. Grossman (1990) argued that PCK offers educators the ability to anticipate difficulties and misunderstandings of the learners and the knowledge to assess and address them. This research shows that capability and know-how only apply in the sections or regions lying within the teacher's control; implying that it is difficult for a teacher to identify and address learners' misconceptions beyond the educator's understanding. There is a need to establish studies that aim at investigating how PCK can be applied to areas beyond the control of the teacher in the classroom.

How Teachers Address Student Misconceptions

According to Shulman (1986), learners bring accumulated misconceptions to class based on their backgrounds and educators need to enact strategies that successfully reorganize the awareness of the students regarding the lessons and concepts to be taught. In this study, teachers from Georgia employed both proactive or pre-assessment methods (53%) and reactive methods (47%) to address learners' misconceptions. Earlier researchers argued that teachers need interviewing skills or administer tests to identify students' preconceptions (Sadler, 2013). In this research, proactive methods identified include earlier prediction of the learner’s misconceptions and using referenced pre-assessment of the initial responses to identify the misconception. These strategies assist teachers to identify the misconceptions before giving students instructions and this prevents their intensification. From this study, such preliminary misconception identification and/or prediction increases the PCK score because teachers acknowledge and also become aware of the misconceptions that hinder their ability to help students acquire knowledge. Such an entire process fits the process of learning science that entails unlearning incorrect ideas and learning new appropriate ones (Sadler, 2013).

Teachers show great effort to identify the origin of the student’s misconception. This helps them to be more reactive when addressing and eliminating or minimizing them. One of the reactive ways established in this research is watching the number of students making similar mistakes regarding the concept being taught. Andrews, Auerbach, and Grant (2019) referred to this technique as "knowledge of monitoring and responding" where the teacher observes the thinking of the learner to understand weak areas, evaluate the effectiveness of instructions, and provide real-time response. As a teacher, this gives a perception of what the students think and it becomes easier to adjust the way the information is presented. A reactionary response to students' misconceptions provides workable solutions to prevent the misunderstanding from affecting the acquisition of the correct knowledge. Such an approach enables the instructor to establish opportunities for learners where they can use logic while creating their own reasoning (Andrews, Auerbach, & Grant, 2019). An example includes a case where the teacher can resist offering answers to students with an aim of asking them follow-up questions after the lesson.

Teachers' knowledge about students is critical to good teaching as well as helping educators evaluate the misconstruction and understanding of learners, adjusting the instructions and creating guidelines to address shared misconceptions, and creating appropriate learning groups (Hill & Chin, 2018). This research has established that a large percentage (86.7%) of teachers do alter the curriculum based on what they understand about students' misconceptions. The alteration done by teachers from this study includes adding or changing learning activities, providing extra discussion and analysis questions, allocating hard concepts more time, and other changes that are not specific. Examples of curriculum alterations provided by teachers in the interview include teaching submicroscopic properties of matter first and then introducing stoichiometry and using particulate diagrams. These adjustments offer students appropriate basic knowledge as well as expand their experience on the topic being discussed in the class and thus improving their learning (Hill & Chin, 2018).

Apart from adjustments to instructions, another approach to misconception identification revealed in this research is asking preliminary questions and undertaking class discussions to reveal and address the underlying misunderstandings before digging deep into teaching. According to Hill and Chin (2018), when teachers who have additional knowledge on the level of content mastery among learners will remediate the learners' misunderstanding through asking suitable questions and utilizing their critical thinking. After identifying the assumptions from students using learners’ content mastery, educators can use the knowledge to plan to reteach the not-well mastered content and create learning activities and tasks which intend to rectify the misconceptions. Therefore, adjustments based on the identified misunderstandings aim at improving the performance of the student in terms of mastering scientific content. The majority (80%) of the respondents noted that adjusting the curriculum transformed the awareness, treatment, thinking, and reflection of the learners. This implies that identifying misconceptions before teaching and adjusting the curriculum to address these misunderstandings have a positive impact on the learning outcomes.

However, 20% of the respondents in this study noted that curriculum adjustment had no professional impact on the learners as their thinking remained constant. It can be argued then that such a percentage uses data-focused programs to identify students' misconceptions which according to Hill and Chin (2018) fail. Literature offers various reasons for such failure including having a very narrow focus on students’ understanding and different planning of the lessons after identifying the misunderstanding (Jacobs, Lamb, Philipp, & Schappelle, 2011).

Most of these adjustments to identify and address learners' misconceptions require more instructional time. Although 20% tend to use this strategy, there is no clear indication of how it fits with the developed lesson plan. In their work, Goertz, Olah, and Riggan (2009) established that there was a high probability of teachers regrouping the learners and re-teaching the concepts but there were lower chances of adjusting the instructions or remedying the misunderstanding of the learners. This study further revealed that there are teachers who do modifications to the curriculum to minimize and eliminate the negative effects of misconceptions on the learning ability. However, they do not know what specific changes they impose on the curriculum design.

On learning, this research demonstrates that 40% of teachers utilize strategies where students learn by doing and where the hands-on-approach mechanism is deployed. The mechanism facilitates the way in which the learners interact with the environment and others to adapt as well as learn. This relates to Vygotsky's social constructivism where learning happens through social activities and interactions that entails sharing experiences, assumptions, ideas, and knowledge. According to the findings from Georgia teachers, this learning entails experimental learning to address misconceptions and using visuals and other content presentations. This takes the form of constructivism where through experiments and visual interactions, students apply their unique experiences and skills to understand the learning concepts.

Visual presentation and experimental interactions enable learners to directly interact with scientific concepts and reactions. It takes the approach of generative work where learners work in groups or on their own to create ideas and generate output beyond what is presented in the instructions (Andrews, Auerbach, & Grant, 2019). The approach employs constructive and instructive learning where students can address their misunderstandings while constructing knowledge from their unique experiences and the teacher's PCK. Therefore, the participant teachers believe in progressive education where teachers leverage social interactions to enable students to share, acquire, and retain knowledge. As a form of generative learning, the actions of teachers enhance deep understanding and significant transfer of understanding across various contexts (Chi and Wylie, 2014).

Conclusion

Effective learning of science concepts depends on the content knowledge, especially related to the subject the teachers possess. Teachers with high experience have been proven to possess substantial knowledge of the content as well as students' common misconceptions. Lack of knowledge about the content and also the students' misunderstanding may lead to erroneous teaching and students retaining similar misconceptions about scientific concepts. Therefore, the knowledge about the students' misinformation helps the teacher to anticipate their misunderstandings and adjust teaching and instruction procedures to suit the student's interests and needs. The experience gained from teaching the subject shows that SMK is important in facilitating the student's performance even though the content knowledge lacks correlation with pedagogical content knowledge.

After identifying students' misunderstandings, teachers have various strategies to use to create awareness and minimize the impact of misconceptions on learning. From the results, one of the principal techniques includes experimental activities and visual presentation approaches to aid learning based on misconceptions identified before the lesson. With these techniques, tutors can actively engage learners either individually or in groups in asking challenging questions, offering advanced instructions, or encouraging social learning. These activities enable learners to use reasoning and create new understanding based on interaction with others, with the teacher, and with the new materials that contradict their misconceptions by offering accurate and appropriate knowledge. This study has also shown that instructors can also modify the curriculum based on their subject matter and existing knowledge about students' misconceptions. Such modifications are done to enable students to be aware of the misconceptions and establish effective remedies.

Limitations

The study, as with any research design, also has some potential disadvantages. This study was conducted during COVID-19 and therefore research with students was limited due to learning loss as a result of the pandemic. This meant that the researcher had to utilize a national student data set in order to determine the most common student misconception. This is a limitation because PCK is the teacher knowing their own students which may not be representative of this national population. The mixed methods design did not allow the researcher to gain an in-depth understanding of specific teachers' PCK regarding law of conservation of mass in science. This means that the researcher has a broader view that may not be able to discern the intricacies between the relationships of CK, PCK, and type of science teacher. Therefore, this study does not necessarily contribute to the literature in terms of understanding the interrelationships amongst these constructs. However, the design will have the ability to provide a snapshot of the current state of PCK regarding the topic within the state. The study also offers a one-time view of the PCK and CK of these teachers. Therefore, the proposed research study does not have the ability to discern the change or growth of CK and PCK over time.

Suggestion for Future Studies

Despite the above findings, various limitations of this study call for further investigations. First, there are still mixed findings on the relationship between content knowledge and pedagogical content knowledge even though subject matter knowledge has been established to be significant in enhancing students' achievement. Future studies need to undertake an in-depth investigation of the relationship to provide conclusive results. Secondly, the research has identified various modifications or adjustments teachers make to the curriculum and lesson plans to remedy students' misconceptions. However, it does not discuss how such adjustments fit the official allocated time for a specific lesson in the overall school's program. Lesson modifications to address students' misconceptions in most cases require additional time. Therefore, there is a need to investigate how teachers who modify their lessons fit with the designed teaching program. One major limitation to this study was the use of a national sample of student data in order to ascertain the most common student wrong answer data. This study could be undertaken such that the students of the teacher participants were given the concept inventory. In this way the actual most common student wrong answer for their specific students could be determined and the researcher could ask the participants about their specific student results. Furthermore, the study could be repeated but separating out middle and high school teachers that teach honors and non-honors courses could be looked at. Additionally, the idea of the content of the degree that the teacher participant holds could be investigated to see if it affects the PCK of the teacher.

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Appendix A

Qualtrics Survey

Consent

CONSENT FORM

Title of Research Study: *Investigating the Content Knowledge and Pedagogical Content Knowledge of Science Teachers in Relation to Conservation of Matter*

Researcher's Contact Information: Lyric Portwood, 404-947-0447, lportwood@paulding.k12.ga.us

You are being asked to take part in a research study. The information in this form will help you decide if you want to be in the study. Please ask the researcher(s) if there is anything that is not clear or if you need more information.

Description of Project
The purpose of the study is to investigate the correlation between content knowledge, pedagogical content knowledge, and self-reported demographics in middle and secondary science teachers in Georgia in relation to the Law of Conservation of Matter. The study seeks to answer this question as well as to determine how these teachers use their knowledge of common student misconceptions related to conservation of matter to address student needs for this concept in the curriculum.

Explanation of Procedures
If you agree to participate in this study:
You will be asked to complete an online survey regarding conservation of matter twice. The first time the participant will be asked to identify the correct answer and the second time through you will be asked to identify the most common student wrong answer. In addition, the participant will be asked to provide an explanation for why the participant think this is the most common student wrong answer. A subset of participants will then be asked to complete a follow-up interview in which a semi-structured interview will allow the researcher to answer how teachers use their knowledge of student misconceptions to plan curriculum.

Participation is voluntary. You can refuse to take part or stop at any time without penalty. Wihtdrawling from the study will not affect any benefits that the participant is otherwise entitled to.
Risks or Discomforts
Participation in this study may result in some feeling uncomfortable while answering questions that the participant may not be familiar with.

Benefits
There are no direct benefits to the participant for participation in this study, however the science education community will benefit from data and conclusions drawn from this study's findings. The study will help inform the community about the correlation between content knowledge, pedagogical content knowledge, and self-reported demographics for science teachers in Georgia in relation to conservation of matter and how these teachers use knowledge of student misconceptions in their teaching of the concept.

Compensation

The first 50 participants to complete the surveys will receive a $10 Amazon gift card. All participants who complete a follow-up interview will receive a $20 Amazon gift card.

Confidentiality
We will take steps to protect your privacy, but there is a small risk that your information could be accidentally disclosed to people not connected to the research. To reduce this risk we will not collect names or IP addresses. *Data will be stored on a secure password-protected computer that will also be kept under lock and key.* The confidentiality of participants will be maintained by using a descriptor for each participant to prevent identifying information. We will only keep information that could identify you *by your email address. The information will not be used or distributed for future research*

Research at Kennesaw State University that involves human participants is carried out under the oversight of an Institutional Review Board. Questions or problems regarding these activities should be addressed to the Institutional Review Board, Kennesaw State University, irb@kennesaw.edu.
If you agree to participate in this research study, please sign below:

I Consent

I DO NOT Consent

Self-Reported Demographics

What is your preferred email for contact for future communication related to this study?

Please select the subjects you teach. (Select all that apply)

Middle School Earth Science

Middle School Life Science

Middle School Physical Science

High School Physical Science

High School Life Science

High School Chemistry

High School Physics

AP Biology

AP Environmental Science

AP Chemistry

AP Physics

IB Biology

IB Chemistry

IB Physics

Do you teach advanced and honors level classes?

No

Yes

How many years have you been teaching 6-12 science?

Less than 1 year.

1-5 years

6-10 years

11-15 years

16-20 years

20-30 years

30 + years

Select you teacher preparation certification route below.

Bachelor's in Science Education

MAT in Science Education (Masters degree with initial certification)

Teach for America

Georgia TAPP Program

Other alternate certification route

Bachelor's in Education in field other than science

What is your highest level of education to date?

Bachelor's degree

Master's degree

Education Specialist degree

Doctorate degree

What is your gender?

Male

Female

Non-binary / third gender

Prefer not to say

Choose the BEST answer for each question

The surface of silver coins tends to darken (tarnish) when left exposed to air for along time. A scientist wants to find out if the mass of silver coin will be more, less, or the same after the coin tarnishes. She starts with a shiny silver coin that is made up of only silver atoms. She measures the mass of the coin.

Then she puts the coin on a shelf and leaves it there for a long time. When she looks at the coin again it has tarnished. The scientist determines that the tarnish is silver sulfide. Silver sulfide is a molecule that is made up of silver atoms and sulfur atoms. The scientist measures the mass of the tarnished coin. She finds that the mass of the coin is more than it was before it tarnished.

Why is the mass of the silver coin greater after it tarnishes?
Pick the **BEST** answer to the question.

Because some silver atoms changed into sulfur atoms, and sulfur atoms are heavier than silver atoms.

Because the silver sulfide molecules that make up the tarnish were released from inside the coin, so the number of atoms and molecules increased.

Because mass always increases when a chemical reaction takes place, and the formation of silver sulfide molecules involves a chemical reaction.

Because the number of silver atoms stayed the same and some sulfur atoms from the air linked to the sulfur atoms to form silver sulfide molecules, so the number of atoms and molecules increased.

What do you think is the most common student wrong answer from the above question?

Because some silver atoms changed into sulfur atoms, and sulfur atoms are heavier than silver atoms.

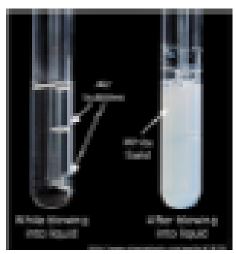
Because the silver sulfide molecules that make up the tarnish were released from inside the coin, so the number of atoms and molecules increased.

Because mass always increases when a chemical reaction takes place, and the formation of silver sulfide molecules involves a chemical reaction.

Because the number of silver atoms stayed the same and some sulfur atoms from the air linked to the sulfur atoms to form silver sulfide molecules, so the number of atoms and molecules increased.

Why do you think this is the most common student wrong answer?

A scientist is investigating changes in mass that may occur during chemical reactions. First, she pours.a colorless liquid into a test tube and measures the mass of the liquid. Then she puts a straw in her mouth and blows air into the liquid through the straw. A chemical reaction occurs and a white solid forms in the liquid, qhich makes the liquid look cloudy. No gas is produced. The scientist measures the mass of the cloudy liquid and compares it to the mass of the liquid before she blew air into it.



Will the mass of the cloudy liquid be more than or the same as the mass of the liquid before the scientist blow air into it? Why?
Pick the **BEST** answer to the question.

The mass of the cloudy liquid will be more than the mass of the liquid before the scientist blew into it because new atoms are created in the test tube when the scientist blows into the liquid.

The mass of the cloudy liquid will be more than the mass of the liquid before the scientist blew into it because molecules from the scientist's breath reacted with molecules in the liquid to form a solid substance that stayed in the test tube, so the number of atoms in the test tube increased.

The mass of the cloudy liquid will be the same as the mass of the liquid before the scientist blew into it because the molecules from the scientist's breath passed through the liquid and left the test tube, so the number of atoms in the test tube does not change.

The mass of the cloudy liquid will be the same as the mass of the liquid before the scientist blew into it because the scientist's breath does not have mass and does not add atoms to the test tube.

What do you think is the most common student wrong answer from the above question?

The mass of the cloudy liquid will be more than the mass of the liquid before the scientist blew into it because new atoms are created in the test tube when the scientist blows into the liquid.

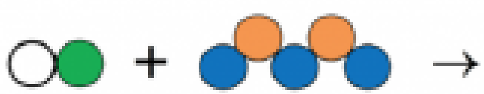
The mass of the cloudy liquid will be more than the mass of the liquid before the scientist blew into it because molecules from the scientist's breath reacted with molecules in the liquid to form a solid substance that stayed in the test tube, so the number of atoms in the test tube increased

The mass of the cloudy liquid will be the same as the mass of the liquid before the scientist blew into it because the molecules from the scientist's breath passed through the liquid and left the test tube, so the number of atoms in the test tube does not change.

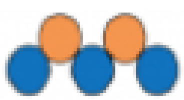
The mass of the cloudy liquid will be the same as the mass of the liquid before the scientist blew into it because the scientist's breath does not have mass and does not add atoms to the test tube.

Why do you think this is the most common student wrong answer?

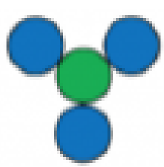
The diagram below shows models of the molecules that make up two different substances. In the diagram, atoms are represented by circles, and the molecules are represented by two or more circles connected to each other. The different colored circles represent different types of atoms.



Which of the following could represent one of the molecules that result from the chemical reaction between these two substances? Why?
Pick the **BEST** answer to the question.

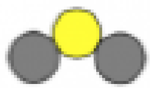


Because nothing happed to the structure of the molecules during a chemical reaction.



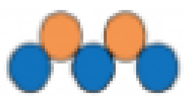
Because some of the atoms are now connected to different atoms than they were in the starting molecules.

Because the molecules that result from a chemical reaction have to include every type of atom from the starting molecules.

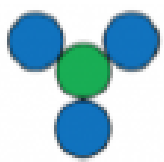


Because new types of atoms are formed during chemical reactions.

What do you think is the most common student wrong answer from the above question?

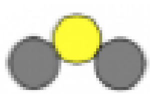


Because nothing happed to the structure of the molecules during a chemical reaction.



Because some of the atoms are now connected to different atoms than they were in the starting molecules.

Because the molecules that result from a chemical reaction have to include every type of atom from the starting molecules.



Because new types of atoms are formed during chemical reactions.

Why do you think this is the most common student wrong answer?

A student placed a liquid in a jar and sealed it. Then she heated the liquid and it turned into a gas. If the number of atoms in the sealed jar stated the same, what happened to the mass

of the jar and everything inside it after she heated it?
Pick the **BEST** answer to the question.

The mass increased because the mass of the atoms inside the jar increased.

The mass decreased because the mass of the atoms inside the jar decreased.

The mass stayed the same because the mass of the atoms inside the jar stayed the same.

Whether the mass increased, decreased, or stayed the same depends on whether a chemical reaction occurred.

What do you think is the most common student wrong answer from the above question?

The mass increased because the mass of the atoms inside the jar increased.

The mass decreased because the mass of the atoms inside the jar decreased.

The mass stayed the same because the mass of the atoms inside the jar stayed the same.

Whether the mass increased, decreased, or stayed the same depends on whether a chemical reaction occurred.

Why do you think this is the most common student wrong answer?

Which of the following is an example of a chemical reaction?
Pick the **BEST** answer to the question.

Salt crystals being crushed into a powder

A powder dissolving in hot water to make hot chocolate

The water from sweat evaporating off of your skin and into the air

Proteins from food being broken down into amino acids in your digestive system

What do you think is the most common student wrong answer from the above question?

Salt crystals being crushed into a powder

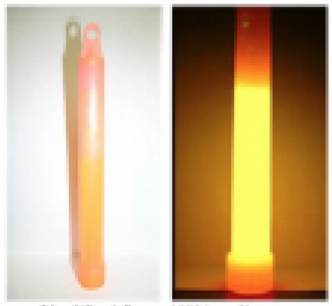
A powder dissolving in hot water to make hot chocolate

The water from sweat evaporating off of your skin and into the air

Proteins from food being broken down into amino acids in your digestive system

Why do you think this is the most common student wrong answer?

A person is going for a walk in the evening. To make sure that she can be seen walking when it gets dark, she wears a glow stick around her neck. The flow stick can be used as a light source when she bends the stick. Although the stick is sealed, bending the stick allows the chemicals to come in contact and react with each other. During the chemical reaction, light is given off by the glow stick.



Modified from Wikipedia.org

When the reaction stops, light is no longer given off. What happens to the mass of the stick after the chemical reaction occurs? Explain.
Pick the **BEST** answer to the question.

The mass will decrease because there are fewer atoms inside of the glow stick after the reaction. Some of the atoms were turned into energy that is given off in the form of light.

The mass will increase because there are more atoms inside of the glow stick after the reaction. Some energy from the light was tuned into atoms.

The mass will stay the same because the number of each type of atom inside the glow stick did not change. Some of the atoms separated from one another and then connected in different ways to form different molecules.

The mass will stay the same because the total number of atoms inside of the glow stick did not change. Some of the atoms changed into different atoms that form different molecules.

What do you think is the most common student wrong answer from the above question?

The mass will decrease because there are fewer atoms inside of the glow stick after the reaction. Some of the atoms were turned into energy that is given off in the form of light.

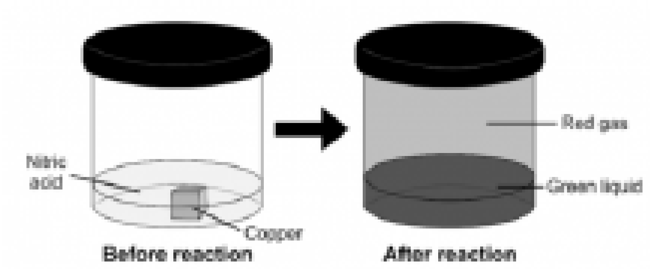
The mass will increase because there are more atoms inside of the glow stick after the reaction. Some energy from the light was tuned into atoms.

The mass will stay the same because the number of each type of atom inside the glow stick did not change. Some of the atoms separated from one another and then connected in different ways to form different molecules.

The mass will stay the same because the total number of atoms inside of the glow stick did not change. Some of the atoms changed into different atoms that form different molecules.

Why do you think this is the most common student wrong answer?

As part of an experiment in science class, a student placed a piece of copper, which is a reddish-orange solid, and some nitric acid, which is a colorless liquid, into a container and sealed it. A chemical reaction occurred, and the student saw a green liquid and a red gas form in the container.



What happened to the atoms that made up the copper and nitric acid?
Pick the **BEST** answer to the question.

The atoms broke down to release the molecules of the red gas and green liquid.

The atoms detached from one another and then linked together in different ways to make the molecules of the red gas and green liquid.

The atoms turned into different atoms and then connected to form the molecules of the red gas and green liquid.

Nothing happened to the atoms. The red gas and green liquid are made up of the same molecules as the nitric acid and copper, but the molecules are different colors.

What do you think is the most common student wrong answer from the above question?

The atoms broke down to release the molecules of the red gas and green liquid.

The atoms detached from one another and then linked together in different ways to make the molecules of the red gas and green liquid.

The atoms turned into different atoms and then connected to form the molecules of the red gas and green liquid.

Nothing happened to the atoms. The red gas and green liquid are made up of the same molecules as the nitric acid and copper, but the molecules are different colors.

Why do you think this is the most common student wrong answer?

A scientist performs two experiments. Before conducting the experiments, she determines the characteristic properties of each of the starting substances. In the first experiment, she heats a liquid (Liquid 1), and a gas (Gas 1) forms. In the second experiment, she passes an electric current through a different liquid (Liquid 2), and two gases (Gas 1 and Gas 2) form. After the experiments, the scientist determines the properties of each of the ending substances. The table below summarizes her findings for each experiment.

Experiment 1		Color	Melting Point (°C)	Boiling Point (°C)
Before heating	Liquid 1	Colorless	-114	78
After heating	Gas 1	Colorless	-114	78
Experiment 2		**Color**	**Melting Point (°C)**	**Boiling Point (°C)**
Before electric current	Liquid 2	Colorless	0	100
After electric current	Gas 2	Colorless	-219	-183
	Gas 3	Colorless	-259	-253

Did a chemical reaction occur during either of these experiments? Explain.
Pick the **BEST** answer to the question.

A chemical reaction occurred during both of these experiments because matter changed during each experiment and all changes to matter involve chemical reactions.

A chemical reaction occurred during both of these experiments because the scientist will not be able to turn gases back into liquids in either experiment and chemical reactions are irreversible changes.

A chemical reaction occurred only during Experiment 1 because heat was used during Experiment 1 and chemical reactions require heat in order to occur. Experiment 2 did not involve heating, so a chemical reaction did not occur.

A chemical reaction occurred only during Experiment 2 because Gases 2 and 3 have different properties than Liquid 2 and new substances with different properties always form during chemical reactions. In Experiment 1, Gas 1 has the same properties as Liquid 1, so a chemical reaction did not occur.

A chemical reaction did not occur during either experiment because a chemical reaction requires at least two starting substances and there is only one starting substance in each experiment.

A chemical reaction did not occur during either experiment because the starting substances and ending substances of each experiment are all colorless substances and a color change must occur in order for it to be a chemical reaction.

What do you think is the most common student wrong answer from the above question?

A chemical reaction occurred during both of these experiments because matter changed during each experiment and all changes to matter involve chemical reactions.

A chemical reaction occurred during both of these experiments because the scientist will not be able to turn gases back into liquids in either experiment and chemical reactions are irreversible changes.

A chemical reaction occurred only during Experiment 1 because heat was used during Experiment 1 and chemical reactions require heat in order to occur. Experiment 2 did not involve heating, so a chemical reaction did not occur.

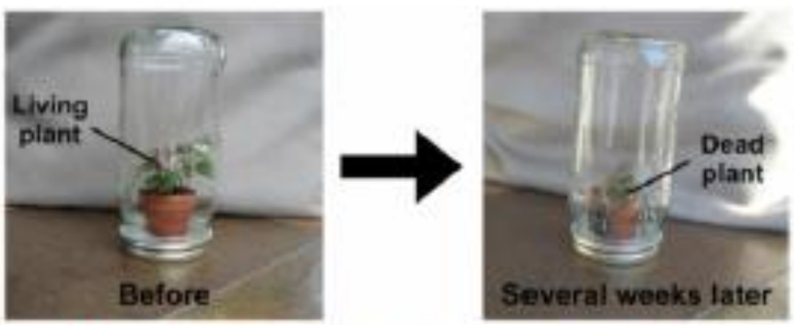
A chemical reaction occurred only during Experiment 2 because Gases 2 and 3 have different properties than Liquid 2 and new substances with different properties always form during chemical reactions. In Experiment 1, Gas 1 has the same properties as Liquid 1, so a chemical reaction did not occur.

A chemical reaction did not occur during either experiment because a chemical reaction requires at least two starting substances and there is only one starting substance in each experiment.

A chemical reaction did not occur during either experiment because the starting substances and ending substances of each experiment are all colorless substances and a color change must occur in order for it to be a chemical reaction.

Why do you think this is the most common student wrong answer?

A student places a living plant in a jar and seals it so nothing can get in or out. He determines the total mass of the jar and everything inside it. Several weeks later, the plant is dead.



What will happen to the total mass of the jar and everything inside it after the plant dies? Pick the **BEST** answer to the question.

The mass will decrease because even though there is the same amount of matter in the jar, the matter has less mass because the plant and soil dried out.

The mass will decrease because matter is destroyed when living things die, so there is less matter in the jar.

The mass will increase because the plant released gases into the jar when it died, so there is more matter in the jar.

The mass will stay the same because the jar is sealed, so there is the same amount of matter in the jar.

What do you think is the most common student wrong answer from the above question?

The mass will decrease because even though there is the same amount of matter in the jar, the matter has less mass because the plant and soil dried out.

The mass will decrease because matter is destroyed when living things die, so there is less matter in the jar.

The mass will increase because the plant released gases into the jar when it died, so there is more matter in the jar.

The mass will stay the same because the jar is sealed, so there is the same amount of matter in the jar.

Why do you think this is the most common student wrong answer?

A student has two different liquids in open jars. She measures the mass of the liquids. Then she pours the liquid from one jar into the other jar, and she observes bubbles. After the bubbling stops, she measures the mass of the liquids again and finds that the mass of the liquids is now less than the mass of the liquids before they were mixed together.

How can her observation be explained?

Pick the **BEST** answer to the question.

A chemical reaction occurred and the mass always decreases during a chemical reaction.

A gas was produced during the chemical reaction and gases have less mass than liquids.

A gas was produced during the chemical reaction and gases can leave an open container like the jars.

Matter was destroyed during the chemical reaction and mass is a measure of the amount of matter.

What do you think is the most common student wrong answer from the above question?

A chemical reaction occurred and the mass always decreases during a chemical reaction.

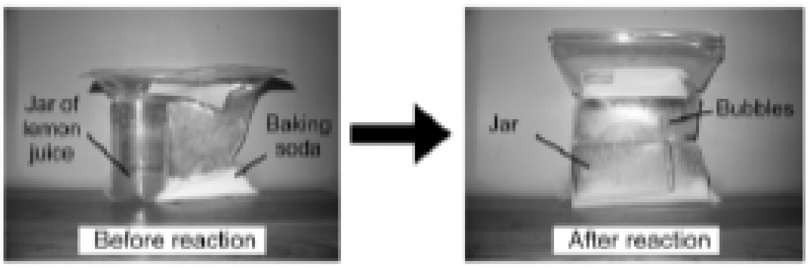
A gas was produced during the chemical reaction and gases have less mass than liquids.

A gas was produced during the chemical reaction and gases can leave an open container like the jars.

Matter was destroyed during the chemical reaction and mass is a measure of the amount of matter.

Why do you think this is the most common student wrong answer?

A student places some baking soda and a jar of lemon juice in a plastic bag and seals the bag. She weighs the bag and everything in it. She shakes the bag so that the lemon juice spills out of the jar and mixes with the baking soda inside the bag. The student observes that bubbles form, and the bag expands.



If the student weighs the bag and everything in it after the bubbling stops and compares the final weight to the starting weight, what will she find out?
Pick the **BEST** answer to the question.

The final weight will be greater than the starting weight because new atoms are produced during the experiment.

The final weight will be less than the starting weight because some of the atoms are destroyed during the experiment.

The final weight will be the same as the starting weight because the number of each kind of atom does not change during the experiment.

The final weight will be the same as the starting weight because some atoms are destroyed, but new ones are created during the experiment.

What do you think is the most common student wrong answer from the above question?

The final weight will be greater than the starting weight because new atoms are produced during the experiment.

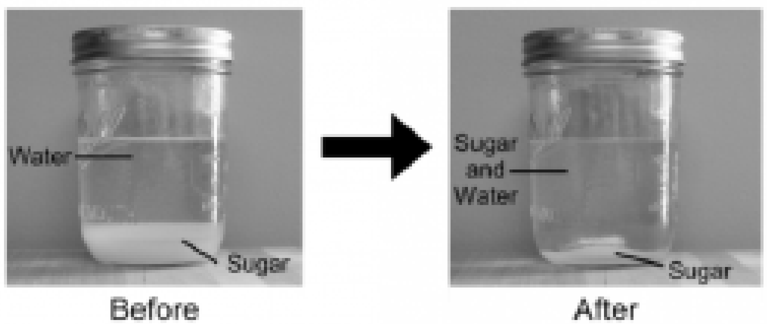
The final weight will be less than the starting weight because some of the atoms are destroyed during the experiment.

The final weight will be the same as the starting weight because the number of each kind of atom does not change during the experiment.

The final weight will be the same as the starting weight because some atoms are destroyed, but new ones are created during the experiment.

Why do you think this is the most common student wrong answer?

A student adds water and sugar to a jar and seals the jar so that nothing can get in or out. The student then weighs the jar containing the water and sugar. After some sugar dissolves, the student weighs the jar and its contents again.



What will happen to the weight of the jar containing the water and sugar after some sugar dissolves?
Pick the **BEST** answer to the question.

The weight will stay the same.

The weight will increase.

The weight will decrease.

The weight will depend on how much sugar dissolves.

What do you think is the most common student wrong answer from the above question?

The weight will stay the same.

The weight will increase.

The weight will decrease.

The weight will depend on how much sugar dissolves.

Why do you think this is the most common student wrong answer?

A chemical reaction is taking place in a sealed container. What will happen to the mass of the materials in this sealed container?
Pick the **BEST** answer to the question.

The mass will increase.

The mass will decrease.

The mass will stay the same.

It will depend on which chemical reaction occurs.

What do you think is the most common student wrong answer from the above question?

The mass will increase.

The mass will decrease.

The mass will stay the same.

It will depend on which chemical reaction occurs.

Why do you think this is the most common student wrong answer?

Two white powders were mixed together. A chemical reaction occurred, and a yellow powder was formed. What is the relationship between the yellow powder and the white powders?
Pick the **BEST** answer to the question.

The yellow powder is made up of the same kinds of atoms as the white powders, but the atoms are combined into different molecules.

The yellow powder is made up of the same kinds of molecules as the white powders, but the molecules are a different color.

The yellow powder was released from inside the atoms of the white powders.

There is no relationship between the yellow powder and white powders.

What do you think is the most common student wrong answer from the above question?

The yellow powder is made up of the same kinds of atoms as the white powders, but the atoms are combined into different molecules.

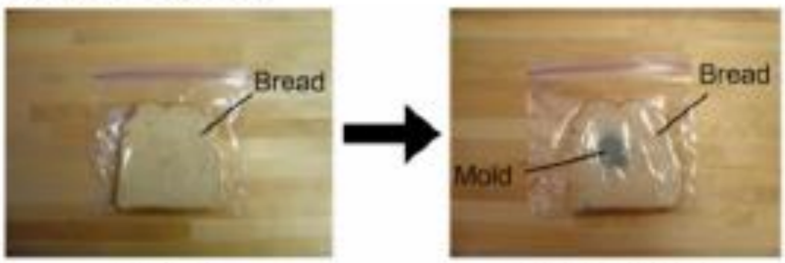
The yellow powder is made up of the same kinds of molecules as the white powders, but the molecules are a different color.

The yellow powder was released from inside the atoms of the white powders.

There is no relationship between the yellow powder and white powders.

Why do you think this is the most common student wrong answer?

A student placed a piece of bread in a plastic bag. He sealed the bag so that nothing could get in or get out. After two weeks, he noticed mold growing on the bread. (Note that the mold's weight increases as it grows.)



Before After two weeks

The student weighed the bag and its contents before and after the mold started growing. After two weeks, did the bag and its contents weigh the same, more, or less than it did before the mold started growing?
Pick the **BEST** answer to the question.

The bag and its contents weighed the same.

The bag and its contents weighed more.

The bag and its contents weighed less.

More information is needed to tell if the weight of the bag and its contents changed.

What do you think is the most common student wrong answer from the above question?

The bag and its contents weighed the same.

The bag and its contents weighed more.

The bag and its contents weighed less.

More information is needed to tell if the weight of the bag and its contents changed.

Why do you think this is the most common student wrong answer?

A reaction occurs between two liquid substances in a sealed jar. What will happen to the mass of the sealed jar and its contents after the reaction occurs?
Pick the **BEST** answer to the question.

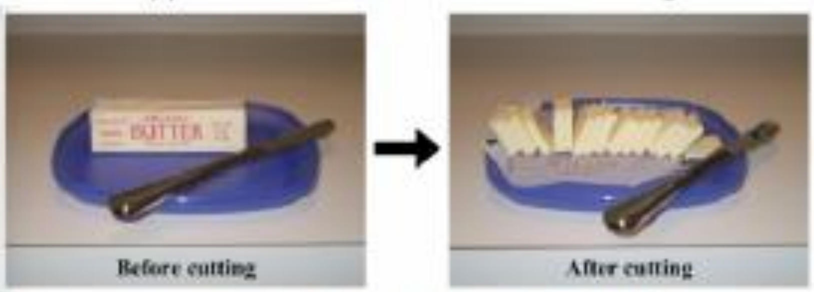
The mass will change if a gas is formed, and it will change if a solid is formed.
The mass will change if a gas is formed, but it will not change if a solid is formed.
The mass will change if a solid is formed, but it will not change if a gas is formed.
The mass will not change if a gas is formed, and it will not change if a solid is formed.

What do you think is the most common student wrong answer from the above question?

The mass will change if a gas is formed, and it will change if a solid is formed.
The mass will change if a gas is formed, but it will not change if a solid is formed.
The mass will change if a solid is formed, but it will not change if a gas is formed.
The mass will not change if a gas is formed, and it will not change if a solid is formed.

Why do you think this is the most common student wrong answer?

A student uses a knife to cut a stick of butter on a dish into smaller pieces. The student weighs the dish, knife, wrapper, and butter before and after cutting his butter into pieces.



Will the dish, knife, wrapper, and butter weigh more, less, or the same when the butter is in small pieces and why?
Pick the **BEST** answer to the question.

They will weigh more because there are more pieces of butter.

They will weigh less because the butter is in smaller pieces.

They will weigh less because some of the butter disappears when it is cut.

They will weigh the same because the amount of butter has not changed.

What do you think is the most common student wrong answer from the above question?

They will weigh more because there are more pieces of butter.

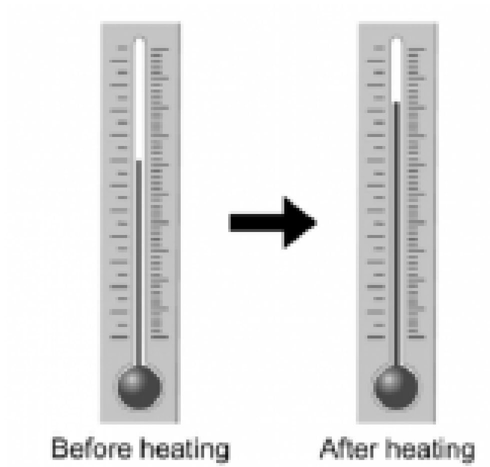
They will weigh less because the butter is in smaller pieces.

They will weigh less because some of the butter disappears when it is cut.

They will weigh the same because the amount of butter has not changed.

Why do you think this is the most common student wrong answer?

A thermometer is heated. The volume of the liquid inside of the thermometer increases, and the level of the liquid rises.



What happens to the mass of the liquid in the thermometer as the level of the liquid rises? Pick the **BEST** answer to the question.

The mass increases.

The mass decreases.

The mass stays the same.

It depends on the type of liquid.

What do you think is the most common student wrong answer from the above question?

The mass increases.

The mass decreases.

The mass stays the same.

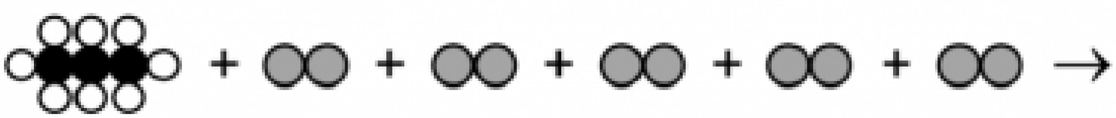
It depends on the type of liquid.

Why do you think this is the most common student wrong answer?

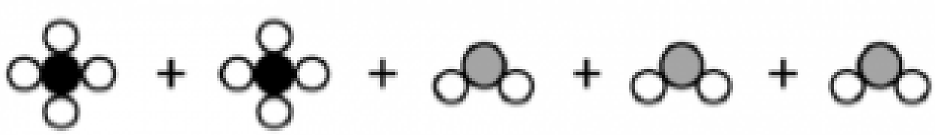
In the diagrams below, atoms are represented by circles, and molecules are represented by circles that are connected to each other. The different colored circles represent different kinds of atoms.

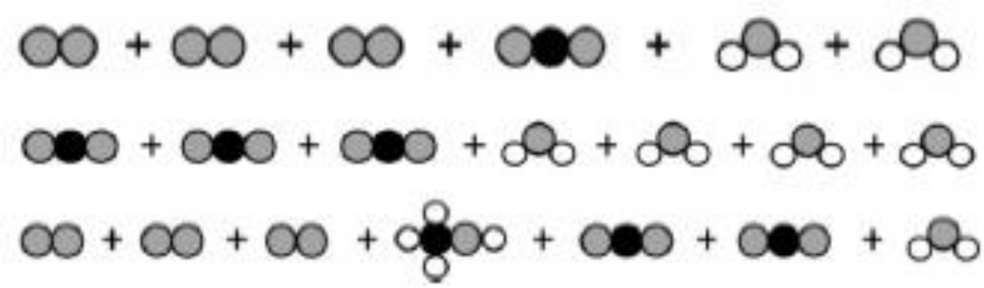
A propane molecule is made up of 3 carbon atoms and 8 hydrogen atoms. An oxygen molecule is made up of 2 oxygen atoms.

The diagram shows one propane molecule and five oxygen molecules.

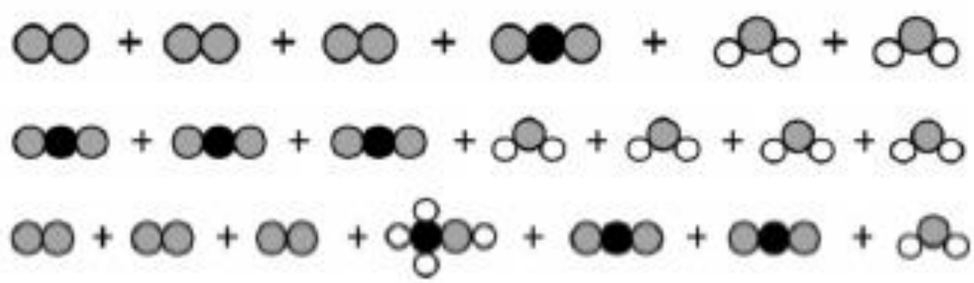


Which of the following diagrams could represent the molecules formed when propane and oxygen molecules react?
Pick the **BEST** answer to the question.



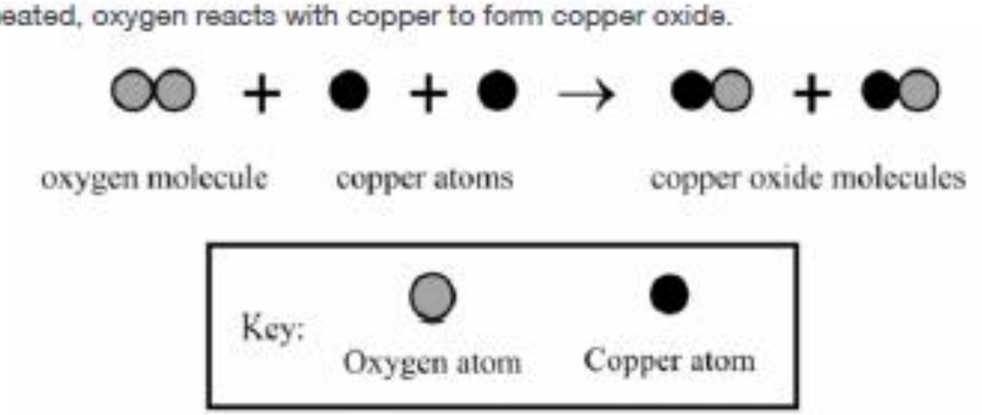


What do you think is the most common student wrong answer from the above question?



Why do you think this is the most common student wrong answer?

When heated, oxygen reacts with copper to form copper oxide.



If this reaction occurs in a sealed container, will the mass of the container and everything in it increase, decrease, or stay the same and why?
Pick the **BEST** answer to the question.

The mass will stay the same because the number of each kind of atom stays the same.

The mass will decrease because two substances combine to form one substance.

The mass will increase because a new kind of molecule is formed.

More information is needed to tell if the mass will change.

What do you think is the most common student wrong answer from the above question?

The mass will stay the same because the number of each kind of atom stays the same.

The mass will decrease because two substances combine to form one substance.

The mass will increase because a new kind of molecule is formed.

More information is needed to tell if the mass will change.

Why do you think this is the most common student wrong answer?

A student placed a liquid in a jar and sealed it. Then she heated the liquid and it turned into a gas. If the number of atoms in the sealed jar stayed the same, what happened to the mass of the jar and everything inside it after she heated it?
Pick the **BEST** answer to the question.

The mass increased.

The mass decreased.

The mass stayed the same.

It depends on whether a chemical reaction occurred.

What do you think is the most common student wrong answer from the above question?

The mass increased.

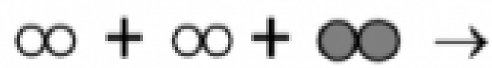
The mass decreased.

The mass stayed the same.

It depends on whether a chemical reaction occurred.

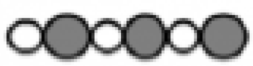
Why do you think this is the most common student wrong answer?

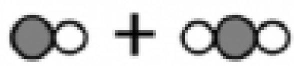
The diagram below shows molecules before they react in a chemical reaction. Atoms are represented by circles, and molecules are represented by circles that are connected to each other. The different colored circles represent different kinds of atoms.

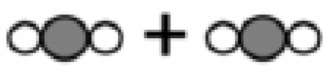


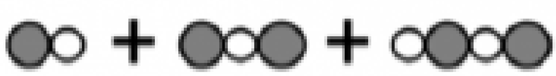
Which of the following diagrams could represent the molecules that result from the chemical reaction and why?

Pick the **BEST** answer to the question.


Because there were 6 atoms before the reaction and 6 atoms after the reaction.

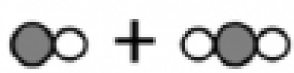

Because there were 2 kinds of molecules before the reaction and 2 kinds of molecules after the reaction.

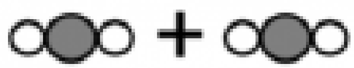

Because there were 4 white atoms and 2 gray atoms before the reaction and 4 white atoms and 2 gray atoms after the reaction.


Because there were 3 molecules before the reaction and 3 molecules after the reaction.

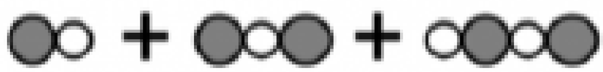
What do you think is the most common student wrong answer from the above question?


Because there were 6 atoms before the reaction and 6 atoms after the reaction.


Because there were 2 kinds of molecules before the reaction and 2 kinds of molecules after the reaction.



Because there were 4 white atoms and 2 gray atoms before the reaction and 4 white atoms and 2 gray atoms after the reaction.



Because there were 3 molecules before the reaction and 3 molecules after the reaction.

Why do you think this is the most common student wrong answer?

Powered by Qualtrics

Appendix B

Teacher Follow-Up Survey Interview Guide

If you remember, during the past several week, you took the Follow-Up Survey (show paper copy of survey) and I would now like to talk with you about a few of the items on it.

- Tell me about what you teach, where you teach, how long you've been teaching, and your educational background
- Of these questions, are there any that you like to elaborate on? Why?
- Are there any other items that stand out that you would like to discuss with me? Why?
- How do misconceptions related to conservation of matter affect learning in your classroom?
- Has your knowledge of student misconceptions affected how you teach? How has knowledge of theses misconceptions affected how you teach?
- How have you altered your curriculum due to your knowledge of these misconceptions?
- Can you give me a description of a typical lesson you have used to help address student misconceptions in relation of conservation of mass?
- After completing the survey, did the survey change how you think about student misconceptions? How will this affect your teaching moving forward?

Appendix C

IRB Application

IRB #: IRB-FY22-30
Title: Investigating Content Knowledge and Pedagogical Content Knowledge of Science Teachers in Relation to Conservation of Matter
Creation Date: 7-20-2021
End Date:
Status: Approved
Principal Investigator: Lyric Portwood
Review Board: KSU IRB
Sponsor:

Study History

Submission Type	Initial	Review Type	Exempt	Decision	Exempt

Key Study Contacts

Member	Kimberly Cortes	Role	Co-Principal Investigator	Contact klinenbe@kennesaw.edu
Member	Lyric Portwood	Role	Principal Investigator	Contact ldc8881@students.kennesaw.edu
Member	Lyric Portwood	Role	Primary Contact	Contact ldc8881@students.kennesaw.edu

Initial Submission

Identify type of Review

After checking appropriate option, navigate to the next page to begin. Complete all applicable questions. Incomplete submissions will be returned. Refer to help text throughout the submission for additional information and guidance. When complete, click submit, and then click Certify. (when there is a Faculty Sponsor, the Faculty Sponsor will also need to certify)

✓ Initial IRB Review Request Form

Request for Determination of Human Subjects Research
(if you are unsure if your project requires IRB review)

Request to Rely on External IRB

1.1 Getting Started

All projects that meet the definition of research with human subjects (45 CFR 46.102) must be reviewed and approved by the IRB, or receive an exempt determination, prior to beginning the research. Submissions are initially screened by IRB staff to determine completeness and appropriate type of review. Submissions may be returned to the study team for changes before the review type is assigned. The review type may be reassessed at any time during the review process.

**Submissions requiring full committee review must be received at least 30 days prior to the scheduled committee meeting to allow time for pre-review. The IRB meets as needed during the regular academic year. IRB meeting schedule is posted here.*
**Submissions requiring Exempt or Expedited review will be reviewed in the order received. For more information about the IRB submission Process, IRB Tracking, and Kennesaw IRB Tasks, please refer to the Kennesaw IRB Website.*

*required

Principal Investigator?s Assurance Statement

I certify that the information provided in this application is complete and accurate.

I understand that as principal investigator, I have ultimate responsibility for the conduct of the study, the ethical performance of the project, the protection of the rights, safety and welfare of the human subjects, and strict adherence to the study protocol and any conditions or modifications stipulated by the KSU IRB.

I will submit modifications of the protocol and/or the informed consent form and/or any other documents to the IRB for approval prior to applying those changes in the study as required.

I agree to abide by the policies and procedures of the KSU IRB regarding the protection of human subjects including, but not limited to:

- Ensuring that all personnel involved in the study have completed the human subjects training online course.
- Ensuring that the study will be conducted by qualified personnel only.

- Obtaining Informed consent from subjects or their legally appointed representatives or guardians, using the informed consent form stamped with approval by the IRB and providing a copy of the signed form to the subject.
- Reporting of adverse events or other unexpected problems and risks involving human subjects to the IRB promptly.
- Prompt compliance with decisions of the IRB that may include a decision to stop or terminate the research.
- If required, obtaining approval for continuing with the study after the end of the approval period by submitting a request for renewal before the study expires. I understand that if I fail to apply for renewal, the study will automatically expire and all activity must cease until IRB approval is granted.
- Closing my study when the research is complete: enrollment closed, data collection complete, analysis of private identifiable data complete, data de-identified.
- Maintaining accurate and complete research records including all informed consent documents and communication with the IRB, for at least 3 years from the date of study completion.

✓ Acknowledged

Is this a Class Project?

Yes

✓ No

1.2 Basic Information

*required

Funding

Is this study funded or intended to be submitted for funding?

Yes

✓ No

Study Personnel

What is your status at Kennesaw State University?

Faculty/Staff

✓ Student

*required

Principal Investigator

All responsible researchers, co-investigators, faculty advisors, and unaffiliated investigators are required to complete the CITI educational program.

Please visit the Compliance Website for more information and access to CITI training

https://research.kennesaw.edu/irb/

Name: Lyric Portwood
Organization: EDU-Secondary & Middle School
Address: 1000 Chastain Rd , Kennesaw, GA 30144-5591

Phone: 4705786000
Email: ldc8881@students.kennesaw.edu

*required
Primary Contact

Name: Lyric Portwood
Organization: EDU-Secondary & Middle School
Address: 1000 Chastain Rd , Kennesaw, GA 30144-5591
Phone: 4705786000
Email: ldc8881@students.kennesaw.edu

*required
Faculty Sponsor
All responsible researchers, co-investigators, faculty advisors, and unaffiliated investigators are required to complete the CITI educational program.
Please visit the Compliance Website for more information and access to CITI training https://research.kennesaw.edu/irb/

Name: Kimberly Cortes
Organization: SCM-Chemistry & Biochemistry
Address: 1000 Chastain Rd , Kennesaw, GA 30144-5591
Phone:
Email: klinenbe@kennesaw.edu

Other Study Personnel
All responsible researchers, co-investigators, faculty advisors, and unaffiliated investigators are required to complete the CITI educational program.
Please visit the Compliance Website for more information and access to CITI training https://research.kennesaw.edu/irb/.

External Collaborators
Are there any Non-KSU study personnel?

Yes

✓ No

Is there anyone on the study team with a financial conflict of interest related to this study?

Yes

✓ No

Tentative study start and end dates

Start Date
09/01/2021

End Date

06/02/2022

External Sites and Site Authorization

Identify any external sites where recruitment or research activities will take place *(Leave blank if n/a)*

For Multi-Site Research: Detail the responsibilities of each site with regard to protections of participants, such as reporting of findings or adverse events. For research conducted outside of KSU and its affiliates, describe any site-specific regulations or customs affecting the research and any local scientific and/or ethical review requirements.

International research: In addition to describing specific laws, regulations, and customs, also describe researcher safety; data/sample safety, storage, and transfer; relationship with the communities; other information as appropriate.

Qualtrics will be used to administer the survey to the study participants. Facebook, GSTA, and message boards will be used to recruit study participants via a link to the study in Qualtrics. The researcher will reach out to the local representatives of each GSTA district and ask for assistance in distributing the survey to participants via message boards and email chains. The follow-up interviews will be conducted via Zoom.

Attach letter(s) of authorization/permission provided by the external site

1.3 Research Design

Level of Review

✓ Exempt

Exempt human subjects research is a subset of minimal risk research involving human subjects that does not require approval by an IRB; however, it does require a review and a final determination by a member of the Human Research Protection Program . The IRB Office is responsible for reviewing and granting all determinations of Exempt human subjects research.

**Research involving prisoners cannot be Exempt*
**Limited IRB Review is conducted for Exempt Category 2 (iii), 3 (iii), and 4(iii);*
**KSU does not enter into IRB Authorization Agreements (IAAs) for Exempt research.*

Category 1 - Education research
Research, conducted in established or commonly accepted educational settings, that specifically involves normal educational practices that are not likely to adversely impact students' opportunity to learn required educational content or the assessment of educators who provide instruction. This includes most research on regular and special education instructional strategies, and research on the effectiveness of or the comparison among instructional techniques, curricula, or classroom management methods.

Category 2 - Surveys, Interviews, Educational Tests, and Observations of Public Behavior
Research that only includes interactions involving educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures, or observation of public behavior (including visual or auditory recording) if at least one of the following criteria is met:
(i) The information obtained is recorded by the investigator in such a manner that the identity of the human subjects cannot readily be ascertained, directly or through identifiers linked to the subjects;
(ii) Any disclosure of the human subjects' responses outside the research would not reasonably place the subjects at risk of criminal or civil liability or be damaging to the subjects' financial standing, employability, educational advancement, or reputation; or
(iii) The information obtained is recorded by the investigator in such a manner that the identity of the human subjects can readily be ascertained, directly or through identifiers linked to the subjects, and an IRB conducts a limited IRB review to make the determination required by 46.111(a)(7).

✓ **Applies to studies that collect data using one or more of the following research methods ONLY:*
Surveys ? Interviews (including cognitive interviews) ? Focus groups ? Educational tests (e.g., cognitive, diagnostic, aptitude, achievement) ? Observation of public behavior (i.e., behavior that occurs in a public place where there is no expectation of privacy and where no special permission is required to observe others such as a public venue)

**What's NOT allowed: Interventions, collection of bio-specimens, research with children*

**Limited IRB Review is required for Exempt 2(iii), when sensitive identifiable data are collected, to ensure that adequate protections are in place to protect subject privacy and the confidentiality of data. This means that the IRB must review and approve procedures for data management and security where sensitive information is collected with direct identifiers (e.g., name, address, email, phone number, social security number, student ID, patient ID) OR indirect identifiers, such as a code that can link back to a subject, or data elements that could be combined to readily re-identify a subject (e.g., dates, employment history, etc.).*

Category 3 - Benign behavioral interventions
Research involving benign behavioral interventions in conjunction with the collection of information from an adult subject through verbal or written responses (including data entry) or audiovisual recording if the subject prospectively agrees to the intervention and information collection and at least one of the following criteria is met:
(i) The information obtained is recorded by the investigator in such a manner that the identity of the human subjects cannot readily be ascertained, directly or through identifiers linked to the subjects;
(ii) Any disclosure of the human subjects' responses outside the research would not reasonably place the subjects at risk of criminal or civil liability or be damaging to the subjects' financial standing, employability, educational advancement, or reputation; or
(iii) The information obtained is recorded by the investigator in such a manner that the identity of the human subjects can readily be ascertained, directly or through identifiers linked to the subjects, and an IRB conducts a Limited IRB review to make the determination required by 46.111(a)(7).

**Examples: Benign behavioral interventions could include having participants play an online game, having them solve puzzles under various environmental conditions, or having them decide how to allocate a nominal amount of cash between themselves and others.*

**What's NOT allowed: research with children, deception (unless prior agreement from participants is obtained), physiological data collection methods that touch participants (e.g., EEG; wearable devices; blood pressure monitors)*

**Deception: If the research involves deceiving participants regarding the nature or* *purposes of the research, this Exemption is not applicable unless the participant consents to the deception. This should occur through a participant being informed through the consent process that there are portions of the study that they will be unaware of or not fully described. Debriefing participants about the nature of the deception is required, unless a waiver is specifically requested and granted.*

**Limited IRB Review is required for Exempt 3(iii) - when sensitive identifiable data are collected to ensure that adequate protections are in place to protect subject privacy and the confidentiality of data. This means that the IRB must review and approve procedures for data management and security where sensitive information is collected with direct identifiers (e.g., name, address, email, phone number, social security number, student ID, patient ID) OR indirect identifiers, such as a code that can link back to a subject, or data elements that could be combined to readily re-identify a subject (e.g., dates, employment history, etc.).*

Category 4 - Secondary Research (Identifiable Private Information/Biospecimens Secondary research uses of identifiable private information or identifiable biospecimens, if at least one of the following criteria is met:
(i) The identifiable private information or identifiable biospecimens are publicly available;
(ii) Information, which may include information about biospecimens, is recorded by the investigator in such a manner that the identity of the human subjects cannot readily be ascertained directly or through identifiers linked to the subjects, the investigator does not contact the subjects, and the investigator will not re-identify subjects;
(iii) The research involves only information collection and analysis involving the investigator?s use of identifiable health information when that use is regulated under HIPAA for the purposes of ??health care operations?? or ??research?? as those terms are defined at 45 CFR 164.501, or for ??public health activities and purposes?? as described under 45 CFR 164.512(b). **(iv) The research is conducted by, or on behalf of, a Federal department or agency using government-generated or government-collected information obtained for non-research activities, if the research generates identifiable private information that is or will be maintained on information technology that is subject to and in compliance with section 208(b) of the E-Government Act of 2002, 44 U.S.C. 3501 note, if all of the identifiable private information collected, used, or generated as part of the activity will be maintained in systems of records subject to the Privacy Act of 1974, 5 U.S.C. 552a, and, if applicable, the information used in the research was collected subject to the Paperwork Reduction Act of 1995, 44 U.S.C. 3501 et seq.

**What's NOT allowed: Collection and analysis of protected health information (PHI) and personally identifiable information (PII). If you intend to collect both PHI and PII, the research could not be reviewed under an Exempt category. This study would likely fall under an Expedited Category 5.*

**Since HIPAA does not apply to biospecimens, Exempt 4(iii) applies only to the secondary use of PHI (which can include information obtained from biospecimens).*

Category 5 - Public Benefit / Service Program Research
Research and demonstration projects that are conducted or supported by a Federal department or agency, or otherwise subject to the approval of department or agency heads (or the approval of the heads of bureaus or other subordinate agencies that have been delegated authority to conduct the research and demonstration projects), and that are designed to study, evaluate, improve, or otherwise examine public benefit or service programs, including procedures for obtaining benefits or services under those programs, possible changes in or alternatives to those programs or procedures, or possible changes in methods or levels of payment for benefits or services under those programs.

Each Federal department or agency conducting or supporting the research and demonstration projects must establish, on a publicly accessible Federal Web site or in such other manner as the department or agency head may determine, a list of the research and demonstration projects that the Federal department or agency conducts or supports under this provision. The research or demonstration project must be published on this list prior to commencing the research involving human subjects.

Category 6 - Taste / Food Quality Evaluation & Consumer Acceptance

Expedited

Full Committee

Provide background/scientific rationale for the project.

The study of chemical reactions and conservation of matter is problematic for many students and is a central theme for 14-16 year old students(Ozmen & Ayas, 2003). Since this concept is central and problematic for students, teachers should be aware of student difficulties in this area. Pedagogical content knowledge (PCK) and content knowledge (CK) are developed and intimately correlated in successful science teachers (Grossman, 1990). One of the tenets of PCK is the ability of teachers to predict student difficulties and misconceptions within the curriculum and concepts being taught. This ability allows teachers to plan curricula to address these misconceptions and to help students overcome them during the course of instruction.

The purpose of the study is to investigate chemistry teachers' CK and PCK as it relates to conservation of matter concepts through a conservation of mass concept inventory and semi-structured teacher interviews. Through this, the relationship of varying levels of CK and PCK and teacher demographics will be investigated. If teachers hold misconceptions, then it is likely that they will pass these on to their students (Yip, 1998). Surveys will also be conducted with a selected subset of the teachers after the testing of CK and PCK.

Describe the objectives/aims of the project.

1. Is there a relationship between content knowledge, pedagogical content knowledge, and self-identified teacher demographics in relation to the concept of conservation of matter?
2. How do teachers use their knowledge of common student misconceptions related to conservation of matter to address student needs for this concept of the curriculum?

Check all that apply

- ✓ Audio
- ✓ Video
- Medical Records/HIPAA
- Educational Records/FERPA
- Urine
- Saliva
- Blood
- Other

Research Procedures

Provide a thorough, sequential description of all research procedures, interventions, assessments, and subject activities. Include time commitments for each activity. Describe how information will be captured *(e.g. hard copy forms, audio and/or video recordings, note taking, computer task, etc.)*. Upload data collection forms, surveys, etc. *(please see Help text for more information regarding specific types of research projects)*

A concept inventory survey will be administered via Qualtrics to 6-12 Science Teachers in Georgia. There are 22 questions in the survey. For each question you will choose the correct/best option and then choose which option is the most commonly chose wrong answer being sure to explain your choice as to why students would most often choose that option. The survey should take approximately 20 minutes to complete. After administering the concept inventory, the researcher will choose a stratified subset of participants based on their scores and response for a follow-up interview. The follow-up interview will be conducted via zoom and will be video and audio recorded. Follow-up surveys will take approximately 30 minutes.

Attach data collection forms, surveys, etc here

Do NOT upload links to surveys or other study materials as links are not static. The IRB requires an actual document to be a permanent part of the file.

---

interview guide aug 26 21.pdf

updated survey sept 3 21.pdf

Data Analysis

Describe methods and assumptions such as loss to follow-up, as appropriate. Describe arrangements for data analysis. If a project incorporates qualitative rather than quantitative methods, describe qualitative analysis. Describe how the data will be examined and statistically analyzed to answer project objectives. Describe how missing or incomplete information will be handled in analysis.

First the above statistical data for question 1 will be scored, dummy coded, and deidentified. In other words, the teacher participant score sheets will receive a coded identifier in place of their email to retain confidentiality. Each pair of CK and PCK tests will be linked per teacher with these coded identifiers. Descriptive statistics will be run on the data and normality will be determined to see if parametric or nonparametric tests should be utilized.

In order to analyze the data collected, several different statistical methods will be employed. Regarding the analyses for RQ 1, first descriptive statistics will be performed on the quantitative data (from the concept inventory) in order to determine the mean, median, mode, standard deviation, and normality of the data. Reliability coefficients will be calculated to measure teachers' overall consistency on the concept inventory using Cronbach's alpha. The data will then be analyzed using Kolmogorov-Smirnov in order to determine the normality of the data to determine if parametric or nonparametric statistical tests should be utilized to analyze the data. The data will then be analyzed accordingly through either parametric or nonparametric statistical techniques. To determine the correlation between PCK and CK, a coefficient correlation will be used unless the data is not parametric. In this case, a rank correlation will be run. To determine the relationship between CK or PCK and the self-reported demographics a regression will be run if parametric and a rank correlation if nonparametric. The independent and dependent variables on RQ1 are CK/demographics and PCK, respectively, and are measured in order to determine if they are positively correlated. RQ2 is qualitative and therefore does not have variables.

For each question when the participant chooses the most likely wrong answer they will also be asked for an explanation of why they chose the most common student misconception that they did. This qualitative data will then be open coded and grouped according to the focus the teacher placed within the explanation and coded for similarities and differences. In addition to administration of the concept inventory, a small sample of approximately ten to twenty teachers will be chosen to participate in a qualitative interview to elicit further information and explanations regarding the correct answers for questions and most common student misconceptions. This will take place after administration of the concept inventory. The teachers will be interviewed to answer RQ2: How do teachers use their knowledge of common student misconceptions related to conservation of mass to address student needs for this concept of the curriculum? This follow-up interview guide instrument is attached as Appendix B. Teachers will be chosen based on the answers they gave in their explanations in the survey. The researcher will choose participants for interviews that specifically reference different components of PCK when discussing misconceptions. The participants surveyed will also be chosen so that a broad range of PCK levels and scores are represented in the sample to discern any differences between the two groups. In this way, the researcher will be able to ask teachers to elaborate on the explanations and relate this to the teachers' scores in CK and PCK. A small sample of teachers will be used. The number is dependent on the answers given in the surveys by teachers and how they help the researcher answer the research question, known as purposeful sampling.

The interviews will be transcribed and open coded to gain insight into the correlations between PCK, CK, and teacher demographics as well as offer further data and explanations for the quantitative relationships obtained. The interviews will also be analyzed using predefined codes that are based on the different components of PCK that the participant references. The identification of each correct answer will allow the researcher to investigate and quantify the teachers' CK whereas the identification of the most common student misconception or incorrect answer will allow the researcher to quantitatively determine the knowledge of students' misconceptions which will allow the researcher to extrapolate knowledge about the teachers PCK within this domain. At the conclusion of the data analysis, a copy of the findings will be sent to all study participants as an additional check for trustworthiness.

Any missing or incomplete data will be disregarded from the study sample.

1.4 Subject Selection

Describe the targeted subject population including age range, gender and other criteria, as relevant

The target populating is 6-12 grade science teachers in the state of Georgia. I am seeking participants of varying genders, nationalities, preparation programs, ages, and experiences.

Inclusion Criteria

Participants that teach sixth through twelfth grade science in the state of Georgia.

Exclusion Criteria

Any person not teaching sixth through twelfth grade science in the state of Georgia.

Provide the maximum number of subjects to be enrolled or maximum number of records to be accessed.

760

Vulnerable Populations

Check any or all vulnerable populations who will be targeted for research participation, if applicable

Subjects are considered vulnerable when they are not considered as autonomous agents and/or their voluntariness is compromised.
There are two important types of vulnerability:
(1) Decisional impairment, whereby potential subjects lack the capacity to make autonomous decisions in their own interest, perhaps as a result of undue influence/inducement
(2) Situational/positional vulnerability, whereby potential subjects may be subject to undue influence or coercion

Children

Students

Employees

Individuals with Cognitive Impairment

Prisoners

Pregnant Women

Fetuses

Neonates

Other

Explain the rationale for using these particular vulnerable populations *(Leave blank if n/a)*

Describe the additional protections in place for these groups *(Leave blank if n/a)*

1.5 Subject Recruitment and Consent

Compensation (*Leave blank if n/a)*

If compensation will be offered, describe here. *(this includes extra credit that may be offered for student participation)* Include the amount of compensation, method of payment, method of pro-ration if the subject withdraws from the research. If study personnel will be required to collect any information in order to provide the compensation (name, address, email address, SSN), include those details which should also be included in the consent form.
If you will use a drawing/raffle/lottery, please see related guidance
https://research.kennesaw.edu/irb/participant-ince...
The first fifty participants to successfully complete the survey will be compensated with a $10 Amazon gift card. Each teacher that participates in a follow-up interview will be given a $20 Amazon gift card. No pro-ration will be enforced for withdrawal from the study. The git cards will be sent via email to the email the participants provided in their survey. The reasoning for only the first 50 participants to receive the compensation is to encourage participants to complete the survey.

Recruitment

Describe the plan *(when, where, how)* to identify potential subjects, including database review, if applicable. Describe how the population will be identified, and how initial contact will be made. Provide information regarding access to the population that will allow recruitment of the necessary number of subjects.

Specify if any advertising/recruitment materials will be used, including verbal/electronic announcement of the research. Upload recruitment material(s) as supporting documents with your submission.
During September 2021, after obtaining IRB approval, the researcher will post a description of the research study on the NGSS Science Teacher Facebook pages, Georgia Science Teacher Association Facebook page, the Georgia Science Teacher and the Association discussion board. In addition the researcher will reach out to all of her professional contacts and will provide them with a description of the study as well. They will be encouraged to pass the survey along via word of mouth and email. Further, the researcher will contact district and state representatives of both state and national science teacher professional associations and ask for assistance in distributing the study. Please find the description that will be provided to the professional contacts, etc. below.
"Seeking 6-12 Georgia Science Teachers for participation in a voluntary research study about content knowledge and pedagogical content knowledge. The first fifty participants who complete the 20-30 minute study survey will receive a $10 Amazon gift card. Participants may additionally be asked to

participate in a 20-30 minute follow-up interview.
Interview participants will receive a $20 Amazon gift card."

The following statement will be used for contacting district and state representatives:
"I am seeking participants for my doctoral study on Pedagogical Content Knowledge and Content Knowledge in Relation to Conservation of Matter in 6-12 Georgia Science Teachers. I am seeking participants who currently teach in a 6-12th grade Science in a Georgia School. The study consists of a approximately 20 minute survey. Some participants will also be asked to participate in a 20 minute follow-up interview. The first 60 participants to complete the survey will receive a $10 Amazon gift card. All participants who are selected and complete a follow-up interview will receive a $20 Amazon gift card."

Attach all materials related to Subject Recruitment *(email templates, flyers, in-person script, social media posting)*

Screening (*Leave blank if n/a)*

Describe the screening process *(how researchers will confirm that potential subjects meet inclusion/exclusion criteria).* Explain what happens with screen failures and any data obtained from screen failures, *if applicable.*

Attach screener here, if applicable

Consent Waivers

Are you seeking a waiver *(no consent from subjects)* or alteration *(does not include all required elements, ie. deception)* of informed consent?

Are you seeking a waiver of the requirement to document informed consent *(no signature)*?

Yes

✓ No

Consent

Describe the process *(when, where, how)* for obtaining informed consent including considerations for privacy. If research involves minors, describe assent process and how parent permission will be obtained. Upload consent/assent/parental permission documents/scripts. If applicable, detail the process to ensure ongoing consent throughout the duration of the project and for ensuring that the subjects understand the research. Describe steps taken to minimize the possibility of coercion or undue influence, the method used for documenting consent, the use of comprehension quizzes, and, if applicable, who might be asked to provide permission or consent on behalf of the subject. If minors who are recruited will turn 18 during the research, provide a process for consenting them as an adult when they turn 18.

Informed consent will be obtained via Qualtrics prior to beginning the survey. Interview participants will be emailed a consent form and asked to sign and return via email to the researcher. The data will not be collected unless consent is obtained from the participant.

Attach consent, minor assent, parental permission here.
Do NOT upload links to consent forms or other study materials as links are not static. The IRB requires an actual document to be a permanent part of the file.
Consent Form survey Sept 22 21.docx Sample documents: Consent Templates

Consent Form sept 22 21 interview.docx

HIPAA Authorization (*Leave blank if n/a)*

If you are collecting Protected Health Information (PHI) from a covered entity, include a detailed list of all PHI, including identifiers, to be collected. Provide justification for use of the PHI. If you will you be obtaining HIPAA authorization for access to and/or collection of PHI, indicate whether you will be using a separate HIPAA Authorization form OR a consent document that includes a HIPAA Authorization section .

If you are requesting a waiver of HIPAA or a waiver of HIPAA for recruitment purposes only, indicate so and provide appropriate justification for the waiver.

Attach Authorization form here, if applicable.

Non-English Speaking Subjects (*Leave blank if n/a)*

If target population is non-English speaking, indicate what language(s) is/are the primary language(s) of prospective subjects and will be used by those obtaining informed consent. The informed consent discussion must be conducted in language in which the subject is proficient. If subjects are expected to be non-English speakers, describe the process to ensure that the verbal/written information provided to those subjects (including recruitment materials, surveys, etc.) will be in the appropriate language. All applicable consent forms and project materials should be translated. Include the Translation Certification form with translated documents.

Attach translated versions of all study materials, if applicable

Cognitively Impaired Adults/ Use of a Legally Authorized Representative (LAR) (*Leave blank if n/a)*

If the target population includes cognitively impaired adults, describe the process (how, who) to determine whether an individual is capable of consent. Describe how the subjects? decisional capacity will be assessed as the project proceeds in order to evaluate any deterioration or improvement in the ability to consent. Describe the process for obtaining assent from the research subjects and consent from the LAR, and how the authority to provide consent will be confirmed.

Withdrawals

Describe procedures that will be followed when subjects withdraw during data collection. Describe the process for subjects to withdraw from the project after participation is complete, if applicable. Describe conditions under which the researcher might withdraw a subject from the project. Describe what will happen to data obtained from withdrawn subjects.

For a participant to withdrawal from the study, the participant will contact the researcher via email or phone number provided on the consent form. The researcher will then delete and discard all data and contact information related to that participant. The researcher will only withdrawal participants from the study with incomplete data or survey responses or who do not fit the inclusion criteria.

1.6 Protection of Subjects

Risks to Subjects

State any possible psychological, physical, social, economic, or legal risk of harm to subjects including their likelihood and seriousness.

Examples:

- Is there potential for a loss of data confidentiality and how serious would loss of confidentiality be for the subject? Consider breach of confidentiality or invasion of privacy as a risk for all subjects.
- If there is a potential for subjects to become upset as a result of the research procedures, and thus require psychological or medical attention?
- Is there potential for emotional stress, boredom, or fatigue?
- Is there risk of physical harm from the intervention (such as from blood draws, brain stimulation or maximal exercise)?
- Could the research create potential social stigmatization or legal action by authorities if research data become known outside of the project team?
- Are there potential risks to the subject related to the political, social, or economic context in which they live?
- Are there economic burdens that may result from participating in the research?

There is a potential risk that there could be a loss of data confidentiality or invasion of privacy. This would mean that their email addresses might be compromised. There is also a possibility that the participant may feel uncomfortable if they do not the answer to some of the survey questions.

State the plan for preventing or minimizing risk of harm *(e.g. screening to assure appropriate selection of subjects, sound research design, appropriate project team training, prompt de-identification of data, safety monitoring and reporting)*. Include details regarding additional protections for vulnerable populations. Include provisions for psychological or medical attention, if required as a result of research procedures or the means for referral for such services.

All data collected will be promptly de-identified and password protected. In addition the data will be stored on a password protected computer that will be locked away. The survey includes screening questions to ensure the appropriate selection of subjects. The study has a research design that is well grounded and cogent. The researcher has received training in the methods employed in the study.

Benefits

Describe the potential direct benefits that individual subjects may experience from taking part in the research. Clearly indicate if there is no direct benefit to participating *(e.g. completing a survey)*.

Taking part in this research may benefit the participant by helping them become a more reflective practitioner as they think about how to answer the study questions.

Describe the benefits to society that will/may result from this research.

Society will benefit from the findings of this study. This study will allow the science education community to assess the current state of PCK in 6-12 science teachers in Georgia. Therefore based on the results interventions can be designed to improve teacher pedagogical content knowledge.

Privacy

Privacy refers to an individual and their right in controlling the extent, timing, and circumstances of access of others to themselves. Individuals have greater concerns about privacy whenever the requested information is considered to be of a sensitive nature. Describe procedures to protect subjects privacy including privacy considerations during recruitment, informed consent, and data collection *(such as access to private rooms, closed doors, etc.)*. Describe the setting in which the subject will be interacting with a researcher.

In order to ensure privacy, the survey will not collect IP addresses, names, phone numbers, or addresses. The only personal information that will be collected is an email address. This contact information will not be shared nor disclosed to anyone other than the researcher. The researchers will use this information to schedule follow-up interviews. The participant will receive an emailed copy of the consent form prior to an interview. The interview will be virtual and recorded but will not be shared with anyone other than the researcher. The emails of those that receive the gift cards will be shared with KSU businesses services for record keeping purposes.

Data Management

- Describe data management procedures *(for electronic, paper, recordings, etc.)* from the time it is collected until the data are permanently de-identified or destroyed, if applicable.
- Describe who will have access to the data and how data will be handled/maintained securely.
- Provide specific information regarding where identifiable data and consent forms will be stored.
- If portable devices are being used, how are data being protected?
- If data will be transferred to collaborators outside of KSU, describe procedures for data transfer.
- Describe plans for destroying all identifiers prior to project completion.
- Describe whether research data may or will be used for future research.
- Describe what will be done with any audio, video, or digital records after the project is completed.

Considerations for securely storing data include:

- Paper records are locked in a secure location.
- Electronic records are stored on password protected or encrypted computer as appropriate based on sensitivity of data.
- Identifiers are stored separately from project data.
- For identifiable data and/or specimens, a coding process should be used to store data and/or specimens without identifiers, the list linking subject name to their study ID or pseudonym should be stored separately from all other project records. Please note the document linking identifiers to the study ID or pseudonym must be destroyed prior to study conclusion.

The electronic records from this study will be stored on a password protected computer that will be locked away when not in use. Email addresses will be stored separately from survey and interview data. All recordings and study data will be permanently deleted following conclusion of the research. The identifiable information collected in this study will not be used for future research.

If greater than minimal risk, briefly describe the data and safety monitoring for the project and upload supporting documents.
Describe whether researchers have obtained or will apply for a federal Certificate of Confidentiality.

Subject Complaints

Describe procedures *(other than information provided in consent document)* for handling subject complaints or requests for information about the research. The procedures should offer a safe, confidential, and reliable channel for current, prospective, or past research subjects *(or their designated representative)* permitting them to discuss problems, concerns and questions, or obtain information.

Participants will have access to the researcher via phone and email. The researcher will respond to all inquiries from participants within 48 hours. All concerns and questions will be dealt with in a professional and timely manner.

Adverse Event Reporting

Describe the process for monitoring and reporting any unanticipated problems or adverse events to the IRB *(must be reported to the IRB Office within 7 calendar days)*. In addition to the KSU IRB, there may be additional entities that will require reporting *(e.g. other IRBs, sites, etc.)*

The study will be monitored at all times by the researcher. If an adverse or issue were to arise, the researcher would contact KSU IRB to report this within 48 hours. In addition the faculty advisor would also be contacted within the same time frame.

Appendix D

Codebook

Node	**Definition**	**Example**
How do misconceptions related to conservation of matter affect learning in your classroom?	How have you altered your curriculum due to your knowledge of these misconceptions?	"No", "As I've learned about misconceptions over the years, I have certainly like tried to add and tr to change the way I tackle a topic sometimes", "I take the county pacing guide and throw it out the window"
Effects of Survey Question	After completing the survey, did the survey change how you think about student misconceptions? How will this affect your teaching moving forward?	"I don't know that it changed how much I think about student misconceptions or what I think about them", "es I was able to think deeper and research about the conception and also how I can copy that and how I can try to make sure that is not affecting my students"
Elaborate on Questions Question	Of these survey questions, are there any that you like to elaborate on? Why?	"Well one thing I will say that I remember writing about is how often students confuse energy and matter", "I don't know that anything that necessarily stuck out in terms of questions", "I think everything was okay"
Knowledge of Student Misconceptions Question	Has your knowledge of student misconceptions affected how you teach? How has knowledge of theses misconceptions affected how you teach?	"Yeah I guess just trying to kind of predict what are some of the things that they might misunderstand about something and either provide experiences that will help to show them like example questions and talk through my mindset", "Um, yeah because even because I have four classes back to back, the same thing. So I'll present this particular thing and they'll ask me a question, like

		oh dang, I didn't even think about that"
Misconceptions Affect Learning Question	How do misconceptions related to conservation of matter affect learning in your classroom?	"I think misconception is really really wide…It's really tough dealing with that and we just have a headache because we have to go over everything once again", "definitely ty to make sure that I elaborate on the difference. I still feel like it goes over a lot of people's heads the nuance that's there sometimes"
Learning by doing	Refers to a hands-on approach to learning, meaning students must interact with their environment in or order to adapt and learn.	"have to do some practicals because they tend to think that theory there is not real", "actual hands on lab experience is what I am going to give them to supplement", "provide experiences that will help them like see in person"
Origin of misconceptions middle school	Refers to possibilities for student misconceptions being from a previous grade level, specifically middle school	"I know exactly what my middle school teachers are teaching", "There's a shaky background there….a lot of teachers here in our district in middle school"
Professionally beneficial	Refers to participating in the survey as having a positive effect on their teaching and/or planning for future instruction	"Yes it brought to the forefront of my mind that it really does happen", "Yes, I think having a bunch of different examples of places where they could just got me thinking more"
teaching on the fly	Refer to addressing misconceptions as they come up immediately in the moment during instruction.	"Well then I need to change something really quick on the fly", "So I do a constant readjustment throughout the day as things come up"
Change-Add Activities	Refer to changing, modifying, and adding activities to supplement difficult concepts in instruction.	"I put a little bit of math in each unit and add stuff to gas laws, kinetics, etc.", "We should be modifying on a daily basis the boxed curriculum and add to it"

Discussion-Analysis Questions	Refers to implementing additional discussions and analysis questions during complex content instruction.	"Yes, having some follow-up questions on in order for me to know their understanding and further it", "I'll still do the same lab but add in an analysis question that confronts that idea"
More Time	Refers to allocating more time during instruction for complex concepts.	"Sometimes I can have some getting more time with the students trying to explain", "Yes, I've had to add days to certain pieces of the curriculum"
No Action	Does not refer to making instructional changes due to misconceptions that arise.	"No I don't make changes", "No"
Non-Specific Change	Refers to the need/want to make instructional changes but is not specific on what those are.	"As I've learned about misconceptions over the years, I certainly have tried to add and ty to change the way that I tackle a topic", "Yes I've had to for some classes"
No Effect	Refer to the completion of the survey as having no effect on them professionally.	"I don't think so. I've had these ideas for a lot of years", "Not really…it's just being aware of them."
Positive Effect	Refers to the completion of the survey as having a positive effect on them professionally.	"Yeah. I can recall these questions and how the students make and why their reasoning", "Yes because I was about to get deeper and I was able to research about the conception"
Proactive-Preassess	Refers to using proactive methods such as preassessing students prior to instruction.	"I guess just trying to predict what are some of the things that they might misunderstand", "If I can head off the students' misconceptions, I'm able to put more emphasis on difficult concepts"
Reactive	Refers to using reactive methods in the classroom to react to student misconceptions as they arise	"I have four classes….so that's when I'll open up with so last period we talked about…", "When you see multiple students make the

		same mistake …you change how you present it”
Content-Focused	Refers to the scientific content of the question and elates it to student misconceptions	“They think it was released form inside the coin.”, “The students forget that air also has molecules.”, “The students think that light is transformed by atoms.”
Teacher Experience	Refers to their own experience as a teacher as the reasoning behind why they know a student will have a misconception	“Voice of experience.” “I have been teaching for a long time.”, “I have experience with this.”
Question Issue	Refers to an issue inherent within the question as reasoning for the students’ misconceptions on the question	“There is no logic before and after the sentence pattern.”, “Influenced by graphics.”, “Because I feel students will be confused by the question.”
Student Issue	Refers to an issue with the student that causes the student misconception	“Lack of understanding the question.”, “Because they get confused.”, “Some students don’t read the question to understanding”, “Because it is easy for students to have fixed thinking and make wrong answers.”

APPENDIX E:

Distractor Analysis

Italics is scientifically correct answer. Bold answer is most common student wrong answer according to national data set.

Distractor Analysis Question 1

	Middle School				High School			
	A	B	C	D	A	B	C	D
Non-Honors	**29.5**	35.2	23.0	*12.3*	**20.7**	31.7	34.1	*13.4*
Honors	**16.3**	43.8	26.3	*10.0*	**25.2**	28.2	27.6	*11.0*

Distractor Analysis Question 2

	Middle School				High School			
	A	B	C	D	A	B	C	D
Non-Honors	18.9	*30.3*	**42.6**	8.2	25.6	*30.4*	**37.8**	4.9
Honors	15.0	*36.3*	**32.5**	12.5	25.8	*31.9*	**26.4**	11.7

Distractor Analysis Question 3

	Middle School				High School			
	A	B	C	D	A	B	C	D
Non-Honors	20.5	*36.9*	**21.3**	11.5	26.8	*28.0*	**37.8**	17.1
Honors	15	*41.3*	**27.5**	8.8	19.6	*33.1*	**27.0**	8.6

Distractor Analysis Question 4

	Middle School				High School			
	A	B	C	D	A	B	C	D
Non-Honors	18.0	**34.4**	*34.4*	13.1	20.7	**32.9**	*35.4*	9.8
Honors	12.5	**33.8**	*38.8*	11.3	18.4	**28.8**	*34.4*	14.1

Distractor Analysis Question 5

	Middle School				High School			
	A	B	C	D	A	B	C	D
Non-Honors	11.4	**42.6**	33.6	*13.1*	17.1	**37.8**	31.7	*12.2*
Honors	18.8	**30.0**	35.0	*16.3*	16.6	**33.1**	38.0	*12.2*

Distractor Analysis Question 6

	Middle School				High School			
	A	B	C	D	A	B	C	D
Non-Honors	20.5	19.7	*40.2*	**13.1**	34.1	28.0	*25.6*	**12.2**
Honors	18.8	31.3	*36.3*	**13.8**	17.8	35.0	*35.0*	**12.3**

Distractor Analysis Question 7

	Middle School				High School			
	A	B	C	D	A	B	C	D
Non-Honors	**18.9**	*29.5*	41.8	9.0	**23.2**	*29.3*	37.8	9.8
Honors	**11.3**	*35*	42.5	11.3	**20.2**	*27.0*	36.8	15.3

Distractor Analysis Question 8

	Middle School						High School					
	A	B	C	D	E	F	A	B	C	D	E	F
Non-Honors	20.5	30.3	19.7	*16.4*	**5.7**	3.3	32.9	28.0	20.7	*10.9*	**3.7**	2.4
Honors	16.3	26.3	31.3	*15*	**7.5**	3.8	23.9	27.0	19.0	*13.5*	**67.4**	8.6

Distractor Analysis Question 9

	Middle School				High School			
	A	B	C	D	A	B	C	D
Non-Honors	**15.6**	27.9	37.7	*19.7*	**23.2**	35.4	28.0	*13.4*
Honors	**13.8**	38.8	35	*12.5*	**16.0**	31.9	36.8	*15.3*

Distractor Analysis Question 10

	Middle School				High School			
	A	B	C	D	A	B	C	D
Non-Honors	20.5	**36.1**	*34.4*	9.0	15.9	**42.7**	*28.0*	13.4
Honors	11.3	**43.8**	*33.8*	11.3	15.3	**34.4**	*34.4*	16.0

Distractor Analysis Question 11

	Middle School				High School			
	A	B	C	D	A	B	C	D
Non-Honors	**19.7**	*34.4*	32.0	13.9	**29.3**	*24.4*	34.1	12.2
Honors	**20.0**	*26.3*	47.5	6.3	**15.3**	*31.3*	38.0	14.7

Distractor Analysis Question 12

	Middle School				High School			
	A	B	C	D	A	B	C	D
Non-Honors	**13.1**	40.2	*31.1*	15.6	**19.5**	29.3	*35.4*	15.9
Honors	**17.5**	35.0	*41.3*	6.3	**16.6**	23.3	*47.9*	11.7

Distractor Analysis Question 13

	Middle School				High School			
	A	B	C	D	A	B	C	D
Non-Honors	*17.2*	**40.2**	30.3	12.3	*22.0*	**41.5**	22.0	14.6
Honors	*12.5*	**32.5**	43.8	11.3	*19.0*	**40.5**	30.1	10.4

Distractor Analysis Question 14

	Middle School				High School			
	A	B	C	D	A	B	C	D
Non-Honors	*23.8*	47.8	**24.6**	4.1	*22.0*	43.9	**23.2**	11.0
Honors	*17.5*	38.8	**33.8**	10.0	*8.6*	46.0	**36.2**	9.2

Distractor Analysis Question 15

	Middle School				High School			
	A	B	C	D	A	B	C	D
Non-Honors	16.4	40.2	*27.0*	**16.4**	22.0	36.6	*26.8*	**14.6**
Honors	10.0	32.5	*47.5*	**10.0**	15.3	39.2	*36.2*	**9.2**

Distractor Analysis Question 16

	Middle School				High School			
	A	B	C	D	A	B	C	D
Non-Honors	*16.4*	**38.5**	32.8	11.5	*29.3*	**29.3**	32.9	8.5
Honors	*15.0*	**41.3**	35.0	8.8	*19.6*	**27.6**	39.9	12.9

Distractor Analysis Question 17

	Middle School				High School			
	A	B	C	D	A	B	C	D
Non-Honors	*16.4*	**32.8**	29.5	20.5	*26.8*	**30.5**	26.8	15.9
Honors	*10.0*	**33.8**	43.8	12.5	*17.8*	**30.7**	38.7	12.9

Distractor Analysis Question 18

	Middle School				High School			
	A	B	C	D	A	B	C	D
Non-Honors	**21.3**	33.6	34.4	*10.7*	**39.0**	26.8	23.2	*11.0*
Honors	**15.0**	20.0	51.3	*13.8*	**22.7**	25.2	42.3	*9.8*

Distractor Analysis Question 19

	Middle School				High School			
	A	B	C	D	A	B	C	D
Non-Honors	28.7	**31.1**	24.6	*14.8*	28.0	**36.6**	25.6	*9.8*
Honors	16.3	**38.8**	28.8	*10.0*	23.9	**33.7**	30.7	*7.4*

Distractor Analysis Question 20

	Middle School				High School			
	A	B	C	D	A	B	C	D
Non-Honors	**18.9**	31.1	*36.0*	13.1	**22.0**	40.2	*24.4*	13.4
Honors	**18.8**	33.8	*33.8*	13.8	**12.9**	38.7	*39.3*	9.2

Distractor Analysis Question 21

	Middle School				High School			
	A	B	C	D	A	B	C	D

Non-Honors	**21.3**	39.3	*28.7*	9.8	**28.0**	35.4	*28.0*	8.5
Honors	**16.3**	37.5	*37.5*	8.8	**19.0**	39.9	*38.0*	3.1

Distractor Analysis Question 22

	Middle School				High School			
	A	B	C	D	A	B	C	D
Non-Honors	*24.6*	29.5	**32.8**	13.1	*23.2*	39.0	**23.2**	14.6
Honors	*18.8*	36.3	**32.5**	8.8	*19.6*	33.7	**27.6**	12.9