The Use of Construct Maps in Understanding 7th Grade Students' Learning of Chemical Reaction

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Abstract

Recent reports stress that students need an integrated understanding of science, particularly to understand the big ideas or core concepts. Chemical reaction is one such “big idea”. Despite considerable research regarding students’ learning of chemical reaction, studies have focused mainly on common high-school student difficulties at a certain stage of learning, usually after completing study of the topic. Few studies have analyzed the acquisition process of these scientific ideas during the learning process for middle-school students. Furthermore, unlike other studies that focused on separate ideas as opposed to their interrelationship, this study examines how students’ understandings of early concepts relate to their understanding of later concepts and investigates the understanding of separate sub-ideas in relationship to their contribution to the understanding of a big idea.

This study characterizes 7th grade students’ learning of a core idea in scientific literacy as they participate in a coherent curriculum. The study explores the prior knowledge, new knowledge, challenges, and development of the students’ understanding of chemical reactions as they study the chemistry unit from the IQWST curriculum entitled “How Can I Make New Stuff From Old Stuff?”

I used construct maps to guide the development and analysis of assessment items aimed at finding evidence for learning utilizing both quantitative and qualitative data from sources collected before, during and after instruction.

The main findings show that students' understanding of chemical reaction comprises many components and that each alone is important for student growth and further learning. The results also show that understanding the chemical reaction construct, which is fundamental to the field, is a markedly more complex and difficult process than it might seem.

Beyond the difficulties in understanding, this study highlights what students can learn and at different stages of the learning process as opposed to what they can do only after the instruction. This knowledge can enable teachers and educators to adjust the curriculum instruction. Thus, the proposed construct maps and the related findings provide input for curriculum development, helping instructors to break down the concept of chemical reactions into the elements that contribute to this big idea.

Chapter 1

Study Rationale

Recent reports have stressed that students need to develop an integrated understanding of science throughout their education, particularly with a focus on big ideas or core concepts in science (Linn, 2007; NRC, 2006, 2007; Roth et al., 2006; Stern & Roseman, 2004). By integrated understanding I refer to "the desired set of connections among scientific ideas that students need as they progress through school" (Roseman, Linn, & Koppal, 2008). In recent years there has been also growing concern about science education in the United States.

One area, for example, where current science education in the United States falls short, is that students continue to languish in international comparisons of science achievement; this situation is even worse at higher grade levels (Linn, 2007). Another concern is that key ideas are not at the focus of science instruction. For instance, in analyses of middle-school science textbooks, researchers have demonstrated that instructional materials are not always presented in a logically connected way, making it difficult for students to understand the major concepts being taught (Kesidou & Roseman, 2002; Stern & Roseman, 2004).

Taking Science to School, a National Academy of Sciences report (NRC, 2007), argues that one of the weaknesses of current science curricula in the United States is that they are unfocused and rarely framed around big ideas. Consequently, the big ideas, which are the core principles and concepts in science that are central to explain scientific phenomena and are fundamental for further understanding of other chemical concepts, get treated equally as other less important concepts.

According to the report, current curricula load students with too many facts with little attention to building links across concepts. Further, current curricula contain too many disconnected topics that are given equal priority without providing guidance about which topics may be most central or important. Moreover, science curricula include many classroom activities that are either irrelevant to key science ideas or not connected well enough to allow students to relate what they were doing to the fundamental ideas. In short, science curricula lack sufficient focus for students to grasp the big ideas.

These recent reports also criticize current district, state and national science standards such as the National Science Education Standards (NRC, 1996) and the Benchmarks for Science Literacy (AAAS, 1993) for failing to provide a sufficient basis for designing effective curriculum sequences. First, science standards contain too many topics. Second, they do not identify the most important topics in science learning, and finally, the standards and benchmarks provide limited insight into how an understanding of scientific concepts needs to be grounded in scientific practice (NRC 2006, 2007).

To reverse this trend and significantly improve science achievement, the reports suggest that rather than teaching isolated ideas, curricula and instructional practices should build on and be organized around core concepts (big ideas) over a period of time and in a coherent way that builds and connects one activity to the next, and with connections to students' everyday lives.

Students learn by connecting ideas to their previous knowledge and by relating various pieces of information toward a clearer picture in their mind (AAAS 2001; 2007; Roseman et al., 2010). Research indicates that learners actively construct meaning from their own experience as they attempt to merge new experiences with already existing knowledge (Bodner et al., 2001; NRC, 2000; Roth, 1993). Students are no longer viewed as passive absorbers of knowledge as facts are poured into their brains; rather they assimilate and make sense of new ideas by connecting them to what they already know. The main assumption is that students do not enter the learning situation as a tabula rasa. Through interaction with the physical and social worlds, students construct knowledge prior to being exposed to formal instruction. Current work in assessing what students know and do not know reflects a growing sensitivity to the importance of students' prior knowledge and to the interconnection and the interrelatedness of ideas. Studies from the expert-novice literature also support the dominant role that richly connected understanding play in learning (e.g., Chi et al., 1981; Markham et al., 1994) and in helping student to refine their understanding and grasp a more sophisticated understanding of new ideas. Clearly, obtaining a richly connected and integrated understanding of science is not naturally developed by learners and, therefore, need to be developed through proper instruction.

This perspective on student learning is embraced by and fundamental to the reform efforts of the American Association for the Advancement of Science (AAAS), the National Research Council (NRC), the National Science Teachers Association (NSTA), and others, directed at helping students to formulate a coherent understanding of big ideas (Roseman & Koppal 2006; Roseman et al., 2010). Interestingly, this is not a new idea. In fact, already in 1960 Bruner (1995) discussed the importance of interconnection and interrelatedness of ideas in obtaining new knowledge. In his view, new ideas must be transmitted to the learner using language and concepts that are familiar to and within the grasp of the learner to enable the learner draw proper inferences of the new ideas. He explained that “if everything is not related to everything else, at least everything is related to something. The only possible way in which individual knowledge can keep proportional pace with the surge of available knowledge is through a grasp of the relatedness knowledge.” (p. 334). While the need to help student create an interconnected understanding is clear, it remains unclear how we go about establishing the “relatedness of knowledge” as proposed by Bruner. Although many approaches exist, one way is through the use of coherent curriculum.

A coherent curriculum[1] is a curriculum that align its content with a set of specific key learning goals that are identified by the national and state standards as being important for science literacy, make clear connections between those key learning goals, make connections to evidence that support the key ideas, and attempt to minimize unnecessary and often distracting details that go beyond the knowledge specified in the key ideas (Roseman, Linn, & Koppal 2008; Roseman, Stern, & Koppal, 2010). In addition, coherent curriculums are aimed to make important connections among ideas outside the specific unit and create sequences of knowledge across units. In the Investigating and Questioning our World through Science and Technology (IQWST) curriculum (Krajcik, McNeill, & Reiser, 2008), for example, big ideas are revisited

[1] Curriculum here refers to all aspects of the instruction through which students experience a certain course. This includes the content knowledge and the skills that the students are expected to learn, the lesson plans, materials (e.g., textbooks, audio, video, online sources, models) provided, pedagogical guidelines, the

across units aimed to construct a more sophisticated and integrated understanding. In 7th grade students learn chemical reactions of observable phenomena in physicals systems (e.g., burning, electrolysis). Then, in 8th grade they learn chemical reactions in living things (e.g., photosynthesis and respiration) where the phenomena are more difficult to observe. Research also indicates that one of the best ways for students to learn the fundamental concepts and skills of science is to learn successively more sophisticated ways of thinking about and practicing these ideas/skills over multiple years at increasingly higher proficiency levels (Corcoran et al. 2009; Michaels et al., 2008; NRC, 2007; Smith et al., 2006). Therefore, a big idea such as chemical reaction should be taught frequently and revisited at different difficulty levels of sophistication over multiple years and in different contexts toward a more integrated understanding.

In an attempt to achieve a more richly interconnected understanding, coherent curriculums also make connections to perquisite knowledge and tie to student difficulties that are reported in the literature.

Coherent curricula are needed to help students develop a deep understanding of important ideas in science, creating consistency across time, topics, and disciplines. Activities should be connected to the learning goals creating a coherent story line (logic of argument, content links, relevance of story to content) to support the learning process, and present accurate content in a comprehensible manner, addressing all appropriate science ideas in the lesson (Roseman et al., 2008). Although the arguments for a coherent science curriculum are clear, how students acquire key concepts within such a curriculum has not been elaborated.

Because a coherent story involves connecting prior knowledge to new ideas (Roseman et al., 2008), the analysis of student prior knowledge is important to develop a more sophisticated and integrated understanding of the ideas.

Furthermore, research indicates that knowledge is acquired overtime and that one of the best ways for students to learn the fundamental concepts and skills of science is to learn successively more sophisticated ways of thinking about and practicing these ideas/skills over multiple years at increasingly higher proficiency levels (Corcoran et al. 2009; Michaels et al., 2008; NRC, 2007; Smith et al., 2006). Therefore, big ideas should be offered frequently and revisited at different competence levels over multiple years toward a more sophisticated competence and understanding.

By looking at student learning over time researchers can better connect the many pieces of information that are taught and in doing so, create a more coherent story line for the students. Furthermore, research has emphasized that students' pre-existing knowledge plays a crucial role in learning (Chinn & Brewer, 1993, 2001; Driver et al., 1996; Edelson, Gordin, & Pea, 1999; Lehrer & Scauble, 2006; Maichle, 1994; Roth 2003a, 2003b; Roth & Bowen, 2003; Schwartz et al., 2007; Shah 2002; Shah & Hoeffner, 2002), but only few empirical studies have documented changes (if any) in students' conceptions as a result of being exposed to formal instruction about core ideas such as chemical reactions. Recently, studies such as the present study monitor the development in understanding of a core idea (e.g., chemical reactions) as a result of instruction. Such research can help characterize students' understanding at key points in time and thus contribute to curriculum development and offer students an opportunity to gain more sophisticated understanding of the topic to improve student learning. *Taking Science to*

School (NRC, 2007) in their report concluded that many national, state and local standards in the USA "contain too many disconnected topics given equal priority. Too little attention is given to how students' understanding of a topic can be supported and enhanced from grade to grade" (p. 11-7).

Considering that middle school is the stage at which students are increasingly exposed to the complexity of the scientific inquiry process (Krajcik et al., 1998), "big ideas" in science ought to be taught early in the science learning to lay a foundation for continuous learning. Chemical reaction is one such "big idea". Chemical reaction is one of the central concepts in chemistry and other disciplines as well and is fundamental for learning throughout all chemistry levels of study and other related chemical and scientific concepts. Looking ahead toward high-school (and beyond), middle-school understandings of the changes in the arrangement and motion of atoms and molecules include foundations for understanding how countless biological, chemical, geological, and physical phenomena can be explained by chemical reactions (e.g., photosynthesis, cell function, transformation and conservation of matter in the ecosystems). Given the importance of chemical reactions in science learning, it is unfortunate that many middle school and high school students have difficulties in understanding this concept as demonstrated by empirical studies (e.g., Andersson, 1986, 1990; Ben-Zvi et al., 1982, 1987; Driver, 1985, 1994; Gable, 1998; Krajcik, 1991). Prevalent difficulties regarding the chemical reaction process found in the literature often center on: Distinguishing between chemical reactions and non-chemical reactions such as *phase changes* and *mixtures* (Eilks et al., 2007; Ahtee & Varjola, 1998; Stavridou & Solomonidou, 1998), difficulties with understanding conservation of mass during a chemical reaction (Hesse &

Anderson, 1992; Özmen & Ayas 2003; Pyke & Ochsendorf, 2004), difficulties with moving among macroscopic-microscopic-symbolic levels (Hinton & Nakhleh, 1999), and failure to acknowledge the particular matter model instead of continuous matter models (Harrison & Treagust, 2002; Merritt, 2010), among others, which will be further elaborated in chapter 2.

Although considerable research regarding students' learning of chemical reaction exists, studies have focused mainly on common student difficulties and at high school level at a certain stage of the learning, usually after completing study of the topic. Little has been done to analyze the acquisition process of these scientific ideas during the learning process for middle school students and what instructional ideas can help students learn these ideas.

Therefore, the aim of the study is to characterize 7^{th} grade students' learning as they participate in a chemistry unit from the IQWST curriculum entitled "How Can I Make New Stuff From Old Stuff?" (Stuff) (Krajcik, McNeill, & Reiser, 2008; McNeill et al., 2004). It explores the prior knowledge, new knowledge, challenges, and development of middle school students' understanding of chemical reactions, which is one of the central concepts in chemistry and fundamental for learning other related chemical and scientific concepts.

The Study Purpose and Research Questions

This study characterizes students' learning of a core idea in science necessary to build scientific literacy (the interactions of matter to form new substances), as they participate in a coherent curriculum. The specific research questions addressed in this study are:

1. What prior knowledge do 7^{th} grade students have regarding chemical reactions? Particularly, what prior knowledge and difficulties do they have in relation to:
    a. Change of properties that occur as a result of a chemical reaction
    b. Rearrangement of atoms during a chemical reaction
    c. Mass conservation during a chemical reaction
2. How does 7^{th} grade students' understanding of chemical reactions develop as they go through a coherent chemistry unit on chemical reactions? During this learning process, what do they understand? With what sub-ideas do students have difficulty? In particular, what are students able to learn and what difficulties do they face in understanding the following:
    a. Change of properties that occur as a result of a chemical reaction
    b. Rearrangement of atoms during a chemical reaction
    c. Mass conservation during a chemical reaction

To address these questions I used pre/post-tests and interviews, to be further detailed in the methods section. In addition to these data, I also made classroom observations and took notes on issues that arose in relation to students' learning. For example, I noted questions asked by both teachers and students during the lessons as well as responses to those questions. Although not a primary data source, I used these observations to help explain my results.

The Context of the Study

To address these research questions, this study focuses on *Investigating and Questioning our World through Science and Technology* (IQWST), which is an example of a coherent science program tightly aligned with learning goals (Krajcik, Reiser, Fortus, & Sutherland, 2008). It is a middle-school science curriculum project that consists of a set of units in Physics, Earth Science, Biology, and Chemistry for each of the three-year middle school grade levels. IQWST is built on five key aspects of coherence: 1) learning goal coherence, 2) intra-unit coherence between content learning goals, scientific practices, and curricular activities, 3) inter-unit coherence supporting multidisciplinary connections and dependencies, 4) coherence between professional development and the curriculum to support classroom enactment, and 5) coherence between science literacy expectations and general literacy skills (Shwartz et al., 2008).

In each IQWST unit, the context for the inquiry is created through the use of driving questions based on real world experience. A driving question is rich, open-ended, and connects with authentic interests and curiosities students have about the world. The driving questions serve to organize concepts and principles, and motivate students' investigations (Krajcik, McNeill, & Reiser, 2008; McNeill et al., 2006). The driving questions create a coherent story line and help to connect the activities along the curriculum and link them to the learning goals in a coherent manner. Each unit in IQWST is divided into learning sets, each composed of lessons. Each learning set deals with a single aspect of the driving question. In that way, each unit progresses so that students develop more sophisticated understanding of the key idea, exploring responses to the driving question throughout the unit (Krajcik & Sutherland, 2009). The driving question in the seventh grade IQWST chemistry unit, for example, is “How can I make new stuff from old stuff?” (Krajcik, McNeill, & Reiser, 2008; McNeill et al., 2004). This unit focuses on three central ideas in chemistry—the conservation of matter, substances and their properties, and chemical reactions. To help students learn the big idea of chemical reactions in this unit, students complete several investigations, each time cycling back to soap and fat. Each cycle helps them dive deeper into the science content to initially understand substances, then properties, then that substances interacting to form new substances (i.e., chemical reactions), and finally the conservation of mass.

The content of the IQWST curriculum is necessary for understanding the process of chemical reactions in which atoms rearrange to form new substances with new properties, while within this process mass is conserved. To develop this level of understanding requires learners to distinguish between atoms and molecules, describe what a property is, and distinguish between open and closed systems (further details are provided in the methodology section). This science content is aligned with learning goals from the *Benchmarks for Science Literacy* (AAAS, 1993) and *National Science Education Standards* (NRC, 1996) that expect middle school students to know for example that[2]:

> *Benchmarks*, 4D6-8#1: All matter is made up of atoms, which are far too small to see directly through a microscope. The atoms of any element are alike but are different from atoms of other elements. Atoms may stick together in well-defined molecules or may be packed together in large arrays. Different arrangements of atoms into groups compose all substances.

> *NSES*, 5-8 p.154: A substance has characteristic properties, such as density, a boiling point, and solubility, all of which are independent of the amount of the

[2] The code at the beginning of the statements indicates the relevant chapter, section, grade span, and item number in the *Benchmarks* book. Statements taken from *NSES* include similar information and page numbers.

sample. A mixture of substances often can be separated into the original substances using one or more of the characteristic properties.

NSES, 5-8 p.154: Substances react chemically in characteristic ways with other substances to form new substances (compounds) with different characteristic properties.

Benchmarks, 4D6-8#7: No matter how substances within a closed system interact with one another, or how they combine or break apart, the total weight of the system remains the same. The idea of atoms explains the conservation of matter: If the number of atoms stays the same no matter how they are rearranged, then their total mass stays the same.

An integrated understanding of chemical reactions and other fundamental big ideas in chemistry such as the particulate nature of matter and the kinetic molecular theory is further related to students developing an understanding of other chemical concepts (Krajcik, 1991).

Study Contribution to the Field

This study intends to shed light on the prior knowledge the students come with before starting the curriculum, how students' understanding of chemical reactions changes over a ten week period as they participate in a coherent chemistry curriculum, and the challenges middle school students have in understanding chemical reactions.

Moreover, many existing studies on student understanding of chemical reactions are on student understanding of balancing equations at the symbolic level, which is the more common focus in the research literature and is beyond the expectations for middle-school students. This study is different in that it centers on student understanding at the macroscopic and microscopic levels of understanding.

This research contributes to educators' understanding of students' learning of chemical reactions at the middle school level and how this understanding develops. This work highlights how students' understanding of chemical reactions and related sub ideas may change and the challenges they face regarding that "big idea" as they go through a coherent curriculum, as well as the remaining difficulties in understanding after completion of the unit. As a core concept, educators have to know what leads to students learning and where the difficulties arise so as to address them and establish a foundation for future science learning. Thus, this study contributes to the small, but growing body of literature on middle school students' understanding of chemical reactions. Previous work has investigated student understanding of separate ideas that are part of the understanding of chemical reactions (e.g., particulate nature of matter, burning); however, most of these studies focused on isolated ideas rather than how this idea relate to the larger understanding of a big idea. Recent studies such as this study intend to demonstrate how students' understandings of early concepts relate to their understanding of later concepts. Delving into higher sophisticating understanding is valuable to show student growth of their understanding and how the different understandings are related to each other in contrast to some existing studies that focus solely on isolated ideas, for example, on a specific example of an open system reaction (e.g., burning).

Further, this study is one of the first studies that look at growth in student understanding of chemical reaction across time (unit's instruction duration) rather than focusing on student understanding of that core concept at some point.

The findings can also contribute to efforts to characterize students' understanding at different ages. The findings of this research may also contribute to the larger efforts to enhance current efforts to create larger continuous coherent science curricula. Further discussion of these and other contributions can be found in Chapter 5.

The remainder of this dissertation is organized as follows: Chapter 2 reviews the literature on students' conceptions of chemical reactions and outlines the major reform movements of science education that have occurred over the past few decades, and Chapter 3 then discusses the study methodology describing the development of the construct maps that are the foundation for this study and are used to guide the development and analysis of assessment items, the research population, the data collection, and its analysis. In Chapter 4 the focus turns to the study findings, which are organized according to the students' understanding of each of the three sub constructs (change of properties, rearrangement of atoms, and mass conservation) and associated sub-levels at three points in time, the beginning, middle, and end of the unit's instruction. This dissertation concludes in Chapter 5, in which I discuss the main findings in relation to their contribution to the field followed by a discussion on the study limitations and suggestions for further research.

Key Ideas Central to the Dissertation

The key ideas featured in this dissertation are the following.

Big ideas.

Big ideas are the core principles and concepts in science that are central to explain scientific phenomena and are fundamental for further understanding of other chemical concepts.

Chemical reaction.

Chemical reaction is one of the central big ideas in chemistry literacy. At the middle-school level chemical reaction refers to the chemical phenomenon in which substances are changed into completely different substances. Substances interact and/or break down (atoms rearrange) to form new substances with a new set of properties while the mass is conserved. Beyond middle-school the definition of chemical reaction would be much more detailed and include such aspects as reverse reactions.

Construct.

A construct is a latent idea (it is in the minds of people). We cannot observe latent ideas directly and therefore need to create measures to inform what the learners understand. A construct is what the measurer intends to measure. A construct includes the ideas or concepts that we wish to learn about and measure (Wilson, 2005); it can be efficiently expressed by a construct map. A construct may include more than one sub-construct, where each of the sub-constructs is represented by a construct map. In this study, for example, the construct is “chemical reaction”, which is divided into three sub-constructs, namely, the change of properties, rearrangement of atoms, and conservation of mass.

Construct map.

A construct map is a graphical representation of a consecutive continuum of the understanding of a specific construct (Wilson, 2005). The map displays hierarchical levels of students’ understanding progressing from lesser understanding towards more sophisticated understanding of the construct. The construct map to be used in this research is sequenced by the logical growth in comprehension level represented in the item responses. Each level describes what students are expected to know as they develop successively more sophisticated understanding of the specific construct. According to Wilson (2005), while the sub-levels are important and useful for interpretation, learning is a continuous process; thus, as the students move from less toward a more sophisticated understanding of the specific construct, they can also be at any point in between the levels.

Curriculum.

Curriculum here refers to all aspects of the instruction through which students experience a certain course. This includes the content knowledge and the skills that the students are expected to learn, the lesson plans, materials (e.g., textbooks, audio, video, online sources, models) provided, pedagogical guidelines, the learning goals, learning performances, the sequences for teaching the ideas, and the educational theories contributing to the teaching epistemology and how these theories are embedded in all class activities.

Coherent curriculum.

A coherent curriculum is a curriculum that align its content with a set of specific key learning goals that are identified by the national and state standards as being important for science literacy, make clear connections between those key learning goals, make connections to evidence that support the key ideas, and attempt to minimize unnecessary and often distracting details that go beyond the knowledge specified in the key ideas (Roseman, Linn, & Koppal 2008; Roseman, Stern, & Koppal, 2010). In an attempt to achieve a more richly interconnected understanding, coherent curriculums also make connections to perquisite knowledge and tie to student difficulties that are reported in the literature, are aimed to make important connections among ideas outside the specific unit, and create sequences of knowledge across units.

Integrated understanding.

By integrated understanding I refer to "the desired set of connections among scientific ideas that students need as they progress through school" (Roseman, Linn, & Koppal, 2008).

The three levels of chemical representation (macroscopic, microscopic, and symbolic).

The macroscopic level of chemical representation refers to the scientific phenomena. Phenomena might be observable or might be even invisible or untouchable. The microscopic level of chemical representation refers to the understanding of models such as those of atoms and molecules that are used to predict and explain the scientific phenomena. The symbolic level of chemical representation refers to the understanding of signs, symbols, equations and formulas that are the language of science and central to the understanding of scientific phenomena.

Chapter 2

Literature Review

In this chapter I review what research informs us about students' conception of chemical reactions followed by a historical review of recent reform movements in science education to situate the current reform efforts in context and therefore get a better perspective where we are in history, where we are moving from and what are we moving to.

Students' Conceptions of Chemical Reactions

Chemical reaction is one of the central big ideas in chemistry literacy. At the middle-school level chemical reaction refers to the chemical phenomenon in which substances are changed into completely different substances. Substances interact and/or break down (atoms rearrange) to form new substances with a new set of properties while the mass is conserved[3].

Challenges for Students

Understanding chemical reactions depends on understanding whether substances become other substances or are conserved during a given process. Thus, in order for students to understand chemical reactions, they must first understand the particulate nature of matter, being able to differentiate among the concepts such as element,

[3] Beyond middle-school the definition of chemical reaction would be much more detailed and include such aspects as reverse reactions.

compound, mixture, atom, and molecule. They must understand that chemical reactions involve a process of atomic rearrangement. If students are unable to distinguish atoms from molecules it may cause, among other issues, difficulties in distinguishing physical from chemical changes. Students may mistakenly think that during chemical reactions atoms can change their type while molecules keep their identity (Andersson 1990; de Vos & Verdonck, 1985; Smith et al., 2006). For example, mistakenly think that iron turns into carbon during combustion.

Challenges with understanding the particulate nature of matter.

The particulate nature of matter is a fundamental basis for learning many chemical concepts such as chemical reactions; the effects of pressure, volume, and temperature on gases; phase changes; dissolving; and equilibrium (Johnston, 1991; Krajcik, 1991). Unfortunately, many students of all ages struggle with applying the scientifically accepted model that matter is made of discrete particles that are in constant motion and have empty space between them (de Vos & Verdonk, 1996; Gabel, et al., 1987; Novick & Nussbaum 1978, 1981).

Instead, many students from all age groups often view matter as being made of a continuous medium that is static and space-filling (Maskill & Pedrosa De Jesus, 1997; Nussbaum, 1985). Although some students may think that substances can be divided into small particles, they do not necessarily realize that those particles are like building blocks that form the basis of matter, but perceived them as continuous substances (Pfundt, 1981). Very recently, Merritt (2010) tracked middle school students' understanding of the particle nature of matter, more specifically, how students move from a continuous view of matter to a particle view moving through four major levels of understanding where at the least sophisticated level of understanding students describe substance exactly as they appear, moving through the stage of using both particle and descriptive views when explaining everyday phenomena. Then, students use particles (may use atoms and/or molecules) to explain phenomena, and at the highest sophisticated level of understanding students use particles (molecules) to explain phenomena. At the highest level students can also explain that different substances have different properties because they are made of different atoms or have different arrangements of same atoms and are able to distinguish spacing and motion relevant to the particular state they are in.

Reviewing the research pertaining to students' notions of chemical reactions, Andersson (1990) finds that normal everyday thinking in which matter is perceived as still and continuous, and the particulate model are somewhat incompatible. The acceptance of particle level processes in matter is quite challenging. Students find that the perception of matter disappearance or the explanation of chemical reactions in phase change terminology more agreeable.

In order to fully comprehend chemical reaction it is necessary to first understand what matter is made of. Therefore, a firm understanding of the particulate nature of matter is essential and part of the chemical reaction construct examined in this study.

The confusion of chemical reaction with phase change or mixtures.

The confusion of chemical reaction with phase change or mixtures is a misconception well documented in the literature. These misconceptions include describing burning as "melting"; or explaining "evaporating" or boiling and dissolution processes as chemical reactions (Andersson, 1990; Hesse & Anderson, 1992; Stavy, 1990). One relevant study in this area is Osborne and Cosgrove's (1983), the goal of which was to gain an understanding of children's (aged 12 to 17) perception of water phase changes. When asked "what the large bubbles in boiling water are made of" (p. 829) only 10% aged 12 to 15 chose the correct answer (steam). The majority of the students thought that the bubbles in boiling water are made of air, heat, or from oxygen and hydrogen (divided approximately equally between the three options). Another question in this study presented a sealed jar containing ice, and called upon the respondents to choose a reason why water condenses on the jar's exterior. The misconception chosen most often was "oxygen and hydrogen in the air to form water." Until the age of 16 this misconception scored significantly higher than the correct answer.

In Bodner's study, graduate students, some of them even majoring in chemistry, were asked about the composition of the bubbles rising from a beaker of water that has been boiling for one hour (1991). Twenty-five percent of the graduate students described the bubbles as air, oxygen, or hydrogen, rather than as water vapors (steam). A similar conclusion was presented by Briggs and Holding (1986), who found that fifteen-year-old students are unable to distinguish between an atom, an element, a compound, and a mixture. These students perceived phase change as a chemical reaction.

Distinguishing between chemical reaction, phase change, and mixtures is essential for a sophisticated understanding of the chemical reaction construct examined in this study. At the highest level students are expected to synthesize their learning to distinguish between chemical reactions from phase changes and mixtures.

Challenges with understanding properties.

At the macroscopic phenomena level students learn that a chemical reaction is a process in which substances interact to form new ones with different sets of properties.

To decide whether or not properties have changed, students first need to know what a property is, and that different substances have different set of properties. In physical sciences we distinguish between intensive and extensive properties. Intensive properties (e.g., density, color, boiling point, melting point) are properties that do not depend on the size or the amount of the matter present. By contrast, extensive properties (e.g., mass, volume, length, shape) do depend on the size or the amount of the matter.

At the middle-school level, the curriculum commonly does not explicitly use the intensive/extensive terminology, and commonly differentiates between properties that do not depend on size and amount and non-properties that do depend on size and amount. Distinguishing between properties and non-properties is not obvious especially in cases where the property/non-property is not directly observed or when it depends on a relationship between two (or more) pieces of information such as in the cases of pressure, defined as a ratio of two non-properties (force and area), and density, the ratio between mass and volume. A wealth of research demonstrated how difficult it is for students to come to a scientific understanding of properties involve causal relationships (e.g., Fassoulopoulos et al., 2003; Kariotoglou & Psillos, 1993; Kennedy et al., 2006; Smith et al., 1986; Snir et al., 1992). Density, for example, is a property (intensive property, independent of quantity)—you can't see or measure it directly. It must be inferred from the relationship between mass and volume. Understanding density involves understanding relational causality. Students need to reason about the relationship between mass and volume and understand that if the relationship between them changes, the density changes. Understanding the role of density in everyday life phenomena, such as in sinking and floating, can be even more problematic for learners as they need to use relative densities, need to reason about the relationship between the densities involved either between object and fluid or fluid and fluid.

Understanding what is a property and that properties change as a result of a chemical reaction is a central idea that is not investigated much in the research literature. A few studies were found that are related to the understanding characteristic properties, but do not delve into further understanding beyond whether or not the students provide examples of observed phenomena to indicate that a chemical reaction has taken place such as bubbles, color change, and formation of a solid precipitate (e.g., Ahtee & Varjola, 1998; Hinton & Nakhleh 1999). Previous studies have suggested that this idea of characteristics properties that are changed during chemical reaction should be explored (Driver et al., 1994; Vogelezang, 1987), but only a few studies have actually been conducted; however, interest in this area is growing. Recent studies, such as the assessment development project being conducted by the AAAS 2061 project (DeBoer et al., 2007, 2009) and the extant study delve deeply into student understanding of that idea. In their study (DeBoer et al., 2009) they delve deeply into student learning of two key ideas that are relate to characteristic properties: (A) A pure substance has characteristic properties that are independent of the amount of the substance and can be used to identify it, and (B) Many substances react chemically in predictable ways with other substances to form new substances with different characteristic properties. Smith and colleagues (Smith et al., 2006) also suggest that this understanding is important to student understanding of matter and the atomic molecular theory and provide relevant example of assessment items as part of their comprehensive descriptions of learning progression of the nature of matter for grades six through eight.

At the macroscopic phenomena level, students in middle-school learn that a chemical reaction is a process in which substances interact to form new ones with a different set of properties. To decide whether or not properties have changed, students first need to know what a property is, and that different substances have different sets of properties, and at the highest level, students are expected to synthesize their learning to distinguish between chemical reactions from phase changes and mixtures.

Linguistic challenges.

Products of chemical reactions are often considered as mixtures of the initial substances, and their properties as a combination of the properties of the initial substances (Ebenezer & Erickson, 1996; Solomonidou & Stavridou, 2000). This difficulty may arise also from the use everyday language. As Andersson (1986) pointed out, language must be chosen very carefully when talking about substances. For example, when the teacher says that water consists of hydrogen and oxygen or that water is built up of hydrogen and oxygen, students might interpret the teacher's statement as mixing of the gases oxygen and hydrogen. These difficulties with understanding what a water molecule is might results from referring to the macroscopic world. Another possible reason for the chemical reaction/mixture confusion may center on the difference between the field-specific differentiations between them, which are not fully distinguished in language. For example, the words "combine" and "mix" are often used interchangeably in everyday language, while in science they are far from identical (Abell & Smith, 1994; Schmidt, 1998).

Challenges with understanding the conservation of mass.

To fully understand the conservation of mass during a chemical reaction students are expected to understand that during a chemical reaction in a closed system, matter (atoms) does not appear or disappear and the total number and type of atoms before a chemical reaction is equal to the total number and type of atoms after a reaction. The number and type of atoms stays the same no matter how they are rearranged, so their total mass stays the same. This principle is particularly challenging in systems involving gas, either as a reactant (e.g., oxygen from the air reacts in a burning reaction) or as a product (e.g., releasing of oxygen and hydrogen gas into the air in electrolysis reaction).

At the middle school level students are expected to begin to learn the conservation of matter law, which along with the energy conservation law (taught later in upper grades) is a fundamental concept in science literacy. The *Benchmarks for Science Literacy* (AAAS, 1993), state that by the end of 8th grade students should know that:

> No matter how substances within a closed system interact with one another, or how they combine or break apart, the total weight of the system remains the same. The idea of atoms explains the conservation of matter: If the number of atoms stays the same no matter how they are rearranged, then their total mass stays the same. (p. 79).

In upper grades, the mass conversation principle is fundamental to more advanced concepts such as the balancing equations and chemical equilibrium.

Mass conservation is part of the chemical reaction construct under investigation. To grasp a solid understanding of chemical reaction, students need to understand the conservation of mass at both the macroscopic level (during a chemical reaction in a closed system, no material can enter or leave the system) and the microscopic level (during a chemical reaction in a closed system, atoms cannot enter or leave the system).

Although the understanding of mass conservation is essential to understand chemical reactions and a prerequisite for the subsequent understanding of other topics in chemistry until now, a thorough search of the literature reveal not much in the research literature at the middle school level. But, interest in this area is growing. Project 2061, for example, includes the understanding of mass conservation at both the macroscopic and microscopic levels in their new assessment development project and in their maps (DeBoer et al., 2007, 2008, 2009).

There are few studies on student understanding of mass conservation at the middle school level, but in relation to mixtures and phase changes (e.g., Lee et al., 1993; Stavy, 1990). Stavy (1990), for example, investigated students' problems with understanding mass conservation using the processes of translocation, melting, dissolving and evaporation; none of the processes is an example of a chemical reaction. She studied students' ability (aged 9-15) to recognize mass conservation and the reversibility of process and discovered that while children pass some conservation tasks, they fail the others. In addition, students who recognized mass conservation were not necessarily aware of the reversibility of the process. There exists a lot of research that points out the existence of students' difficulties with understanding the conservation of matter at the high school level and most of these studies also focused on the symbolic level (chemical equations). Özmen and Ayas (2003), for example, studied students understanding of mass conservation among high school students (10^{th} graders) and much of their study focused on student understanding at the symbolic level (chemical equations). Ramsden (1997) and Barker and Millar (1999) studied students' thinking about conservation of mass using the same question asking to predict whether the mass of two solutions mixed together to form a precipitate would change. Participants were high school students and the phenomena presented and discussed at the symbolic level. Hesse and Anderson (1992) is another example for a study at the high school level. In their study, the students completed a unit on chemical change and were asked about oxidation-reduction reactions, which is much above and beyond the middle school level expectations. They concluded that many students could not anticipate or describe mass changes in the chemical reactions. Out of eleven students who were interviewed, four students consistently failed to acknowledge the existence of gases products or reactants and additional four students sometimes did this. Most common difficulties included the confusion between chemical changes such as rusting and physical changes such as phase changes and the difficulties with understanding the role of invisible gases in the reactions as either reactants or products.

There are also many other studies on students' understanding of specific chemical reactions in an open systems of which oxygen is involved (e.g., the formation of rust (oxidation), burning reactions (combustion)) examining, for example, student understanding of the effect of the oxygen on the total mass of the resulting product (e.g., Meheut et al., 1985; Pyke & Ochsendorf, 2004). BouJaoude (1991), for example, investigated student understanding of the burning reactions using the interview-about-events technique. During the interviews the researcher showed the students experiments like burning a candle, lighting an alcohol burner, and burning wood. Twenty middle-school students were asked to predict the change in weight when a candle burned. Twelve of them predicted no change, and eight predicted a decrease. Those students who predicted no change thought that only a phase change was taking place. In another scenario students were asked to predict the change in weight when wood burn. All the students predicted a decrease. Many studies investigated also students understanding of the formation of rust (reaction of iron and oxygen in the presence of water or air moisture), which is another example of a reaction that occurs in an open system and is most likely familiar to the students from everyday life. Schollum (1981) used interviews about events to learn about students' ideas of five given chemical reaction events. One of his findings was that students have difficulties in understanding the origin of rust on an iron nail. Students had difficulties in understanding that rust occurs as a result of a chemical reaction. Instead, many students thought that rust is a coating on the top of the nail, that some impurity in the nail "comes out" and creates the rust together with the water, that rust appears once the shiny outer surface of the nail is removed, that rust occurs when water eats away at the nail or rust just happens when a nail is in water. Students also had difficulties in understanding the gain of mass. Most of the students thought that when a nail goes rusty, the rusty nail decreases in weight or stays the same. In a more recent literature review Kind (2004) reported a similar conclusion, many students do not ascribe the rust to a chemical reaction, and the involvement of oxygen is not clear for the students resulting difficulties in understanding the phenomena and in understanding the change of mass.

Understanding mass conservation is challenged not only for the students, but also for prospective teachers. Haidar (1997), for example, studied prospective chemistry teachers' ideas about conservation of matter and related concepts. He found that some participants (about 17%) showed partial understanding with specific difficulties; most of the participants (about 80%) had no understanding of this concept.

Viewing chemical reaction as a static process and the additive misconception.

Another frequent difficulty arises when students view chemical reaction as a static process rather than a process of bond formation and breakdown. In this regard, students have difficulties perceiving chemical reaction as an interactive and dynamic process in which particles/molecules react with each other and produce new particles/molecules by rearrangement of the atoms through the breakage and formation of bonds (Ben-Zvi et al., 1982, 1987; Andersson, 1986).

Another related misconception has been highlighted by Ben-Zvi, Eylon, and Silberstein (1982, 1987) who showed that students (aged 15 years) had difficulties with the dynamic and the particulate model of chemical reactions. In their study, many students appeared to view chemical reaction as additive rather than interactive; that is, they view the chemical reaction as a process of gluing and ungluing of reactants, rather than as a process of bond breaking and formation involving many particles. For example, considerable numbers of students represented the molecular compound Cl_2O as two separate entities, Cl_2 and O, and in another example failed to predict possible products of a reaction between N_2 and O_2. Some students thought N_2O_5 could not be formed because of the need for three additional O atoms; others thought NO could not be formed, mistakenly thinking that the mass of the products would be less than that of the reactants. The resulting erroneous concept is that a molecule of a compound cannot be viewed as a new entity with new properties, but rather is a mixture of its components.

In reference to the additive/interactive misconception, Andersson (1990) was concerned about a common technique for modeling chemical reactions—drawing circles in different colors distinguishing one atom type from another. One example (Figure 2.1) is the symbolization of carbon in black and oxygen in white in the formation of carbon monoxide from carbon and oxygen ($2C+O_2 \rightarrow 2CO$). While using color coding may help to track the different atoms in a reaction, it may also lead students to formulate the additive misconception. Following the representation before them, they focus on the atomic components and miss the bigger picture—a new molecule with different characteristics—seeing the oxygen atom and carbon atom as glued rather than a new entity as a whole- carbon monoxide.

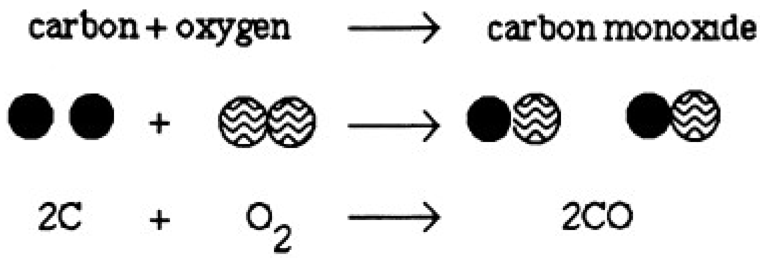


Figure 2.1: Different ways of symbolizing a chemical reaction (from Andersson, 1990, p. 74)

Without a solid understanding of the dynamic process of chemical reaction, students also have difficulties interpreting chemical equations (Krajcik, 1991) and the process of balancing chemical equations since they view them as mathematical puzzles without having a conceptual comprehension of the phenomena (Ben-Zvi et al., 1987; Nakhleh, 1993; Yarroch, 1985).

Understanding that chemical reaction is dynamic (rather than static) and interactive (rather than additive) is part of the advanced construct in this study, and is important for continuous chemistry learning beyond middle school expectations.

The challenge of linking macro, micro, and symbolic levels.

Linking macro, micro, and symbolic levels is another challenge in learning chemical reactions. A chemical reaction is associated with changes at a macroscopic level, which can be either observed directly (e.g., color change, bubbles, heat, precipitation of solid formed) or with the aid of specific instruments (e.g., changes of melting point). The macroscopic view refers to scientific phenomena. Phenomena might be observable, such as the bubbles in the boiling of water, but they may also be unable to be observed through direct experience such as tectonic plate drift. Such phenomena might be even invisible or untouchable.

To better understand and predict some scientific phenomena, scientists delve into the microscopic level, using models such as those of atoms and molecules. Students, too, can benefit from using models, which are widely used in science education because their values as pedagogical tools in the development of scientific ideas (Gilbert & Boulter, 1998; Justi and Gilbert 2002; Schwarz & White, 2005). For instance, students can use molecular models of substances before and after a chemical reaction to reason and represent that during the reaction atoms combine in new ways to form new substances. Research indicates, however, that models may also mislead and the use of models and modeling may be challenging and confusing for students. There is abundant evidence demonstrating that many middle- and high-school students have difficulties in understanding the value or role of models (Grosslight et al., 1991; Harrison & Treagust, 1996, Treagust et al., 2001). Specifically, they have difficulties in differentiating between the models and reality, instead viewing models, for example, as copies of the scientific phenomena and/or struggling with expressing differences between the model and reality (Grosslight et al., 1991; Schwartz & White, 2005; Treagust et al., 2001). Many students also struggle with comprehending that different models might represent different aspects of the same phenomenon and tend to view each model form (e.g., two dimensional drawing, ball and stick model, computer simulations) as something new to learn rather than various ways of visualizing and communicating ideas in order to develop a better understanding of the phenomena (Harrison & Treagust, 1996, 2000).

While a wide variety of microscopic representations exist, symbolic representation—symbols, equations and formulas have emerged as a convenient finite common language, understood by scientists, bridging inter-model differences. Symbolic representation serves as a universal means of communication for the particle level concepts. The abstraction provided by a language-type representation accommodates the inclusion of relatively limitless amounts of information in a significantly more communicable way. In addition to being localized by nature, models require not only considerable work in comparison to symbolic representation, but also cost in terms of time used for representation decisions and alterations (in order to demonstrate changes and processes). Symbolic representation on the other hand simply requires forms of revision (adjusting the formula to represent a different scenario, balancing an equation, representing a phase change) the written material.

Signs and symbols are the language of science and central to the understanding of scientific phenomena, particularly complex phenomena that are not directly perceivable. This language of signs and symbols is very difficult to understand, since it is very complex and includes a lot of specialized notations, a substantial body of unfamiliar logic, and requires dynamic and abstract thinking. It is an efficient way for communicating one’s ideas, providing that both the writer and the reader are in consensus regarding the interpretation of the symbols (Ben-Zvi et al., 1987). The language of chemistry has a special difficulty, since the students are not familiar from previous learning with the logic it represented by it. In arithmetic, the simple operatives such as addition and subtraction are learned first and are familiar to the students from everyday life, having been gradually developed for years. When students begin to learn chemistry they need to reconceptualize such operations. For example, while in mathematics we do 2+1=3, in chemistry $2H_2+O_2 \rightarrow 2H_2O$. This example illustrates the difference in the logical thinking required by chemistry, in which 2A+1B = 2C. This (balancing chemical equations) is not only the conceptual understanding of the new logic and new symbols but also the expected pace of the learning. In chemistry the students are exposed to this new logical thinking (of counting atoms rather than molecules) only in a comparatively late stage along the K–12 continuum as opposed to mathematics in which students are exposed to addition and subtraction calculations throughout their whole life.

Each of the three separate representation levels—macro, micro, and symbolic, presents a complex system within itself. Therefore, linking these three levels of thinking and simultaneously fully comprehending them is a formidable challenge significantly hindering the progress of a student continuing to study science, considering the importance of this synergetic system in science literacy. In some cases the students understand separately each of the components, but fail to integrate them. Two possible reasons for this are information overload and a student's cognitive ability (Eylon et al., 1987).

One of the learning goals of the unit investigated in this study (namely, Stuff) is for students to explore macroscopic phenomena and delve into molecular models, which help explain the phenomena. That is why linking the macroscopic view and the microscopic view is part of the construct examined in the extant study. At the macroscopic level students learn that a chemical reaction is a process in which given (old) substances interact to form new ones with properties different from those of the original substances. At the microscopic level students learn that a chemical reaction is a process in which two or more substances interact and their atoms combine in new ways to form new substances that are made of the same atoms as the old substances, but the atoms are arranged in new ways.

Attribute properties of macroscopic substances to microscopic particles.

Part of the problem of mobility between levels of presentation (macro, micro, symbolic) is students' tendency to simplify the perception of the microscopic level to a size-reduced copy of the macroscopic level.

In many cases students hold misconceptions in which properties of macroscopic substances are assigned to microscopic particles (Ben-Zvi et al., 1990). For example, students believe a water molecule is wet and a molecule of iron capable of rusting. The development of such ideas may be a natural and unavoidable stage in the cognitive development of the child (de Vos, 1989). A common cause of this problem is faulty definitions found in some of the textbooks, in which atoms are defined as the smallest particles still possessing the properties of the substance to which they belong (de Vos & Verdonk, 1987). Similarly, Ben-Zvi et al. (1986) found that many students tend to think of microscopic particles, such as atoms, in terms of a piece of substance carrying all of the properties of this substance, for example, atom of copper will be viewed as a small piece of the solid metal while an atom of mercury will mean a small drop of the liquid. In their research, de Vos and Verdonk (1987) looked into students' ideas on substances and reaction concepts. In their study, students transferred properties of macroscopic entities to the microscopic particles in their descriptions. They related to molecules and atoms smaller instances of the discussed matter. Examples of student responses (in interviews): “even in hot water the molecules are cold inside”, “molecules of water cannot be solid objects, but must be tiny little droplets”, “A soft substance cannot be made up of hard molecules” (p. 693). References to the atomic world as extrapolation of the macroscopic was also found in Anderson’s (1986) research. When students were asked to describe the burn process of steel wood, one of the explanations provided was: “If, for example, wood burns up, then wood molecules also burn up” (p. 553). More recently, Maskill and Pedrosa De Jesus (1997) found that it is easier for students to maintain an intuitive model of the atom as a small portion of a substance (as the way of thinking about very small things from the macroscopic world) rather than to accept the idea of atoms as a useful model to explain phenomena.

This confusion between substance properties and particle properties is an obstacle in the way to comprehensively grasping the chemical reaction concept, in which identification of properties and changes thereof is fundamental. Distinguishing properties of macroscopic substances from microscopic particles is necessary for a solid grasp of the chemical reaction construct investigated in this study, in which students are often expected to determine whether or not a chemical reaction occurred based on changes in the properties of a substance.

Summary.

In summary, while chemical reaction is a significant main concept in which considerable educational investment has been and is being made, there are still a few persistent pitfalls requiring programmatic attention. Students are still struggling with the understanding of the particulate nature of matter model, the distinction and relation between representation levels, the interactive aspect of the process (the additive misconception), the change of matter properties and complete change into a new substance. They struggle to differentiate chemical reaction from other familiar phenomena such as mixtures and phase changes; understand chemical reaction as a dynamic process, and fully comprehend the conservation of mass principle.

To provide a clear backdrop for my work the next section outlines the major reform movements of science education that have occurred over the past few decades. This background is necessary to better understand how my work fits the recent calls for emphasizing big ideas in science instruction.

Reform Movements in Science Education in the United States

This study aims to characterize 7th Grade students' learning of a big idea (chemical reaction) as they go through a coherent curriculum and intends to contribute to current reform efforts in science education. To place this work in context, I review a historical perspective of previous reform efforts of science education to better understand what led to the current movement.

Science education in the United States went through several influences and reform movements throughout the last century. Since the beginning of the 20th century until the 1960s, science was taught in the United States as a collection of facts and rules, based on descriptive textbooks where according to critics the content was badly out of date, and included laboratories that focused on following procedure ("cookbooks" style experiments). This, however, changed after October 1957 when the Soviet Union launched the first-ever earth-orbiting satellite, the Sputnik. In response, the US federal called for an urgent need for a shift in the way that science is taught, which led to a reform movement in science education. This reform movement described by Pea & Collins (2008) "the curriculum reform movement", is known also as the "golden age" of science education or as "the Sputnik era" beginning in the 1950s and 1960s and continuing into the early 1970s. This shift reacted to the belief that students were not challenged enough and was an attempt to keep the United States as a scientific knowledge center (DeBoer, 1997; Pea & Collins, 2008). Besides substantial national movements such as the formation of the National Aeronautics and Space Administration (NASA) in 1958 and the creation of the National Defense Education Act (NDEA) also in 1958, this era in science education was characterized by the formation of the National Science Foundation (NSF). The NSF was instrumental in making significant changes in the science education teaching approach, moving from more descriptive science textbooks to a more inquiry approach through self-experience, and allocating tremendous amount of budget toward writing new curricula led by scientists in major research universities in an attempt to motivate more students to future career in science and related occupations. Despite the significant effort toward developing new textbooks, investing in teacher professional development training, and modifying the learning experiences in the lab, the number of students that chose to specialize in science and related areas did not increase, at least not significantly for many reasons. The programs, which were written by expert scientists, were too hard for both students and teachers to process. Further, professional development programs did not adequately prepare the teachers to cope with and adjust to the inquiry teaching method that was new to them. Other drawbacks were that the materials were targeted mainly to the strongest science students and not for heterogeneous student population, the curricula were not relevant to students everyday life such as technology and society, the programs did not consider students' prior knowledge and ability, and the development process barely involved educators and teachers leading to impractical assumptions about what the curriculum include and how it should be implemented. Finally, teachers did not sense ownership of the curriculums since they had little flexibility to make adjustments to fit their own teaching style (Bybee, 1997; Hofstein, 1985 (in Hebrew); Pea & Collins, 2008).

Given the lack of meaningful progress, this movement was then followed by a new movement that emphasized understanding and fostering student learning in the 1970s and 1980s. Newly developed programs in the 1970s and the 1980s stressed also students' overall ability, not only on the topics or the subjects being taught. This movement described by Pea & Collins (2008) "the cognitive science movement", initiated in the 1970s and 1980s and characterized by cognitive science studies of the learners, studying, for example, differences between expert and novices understanding assuming that identifying common alternative conceptions among students will help in designing new curricula that take into account that knowledge and develop teaching techniques that can be used in an attempt to overcome such difficulties, for instance, the use of analogies and the use of computer-based learning environments to motivate and enhance learning. Research into learners' ideas has produced evidence of alternative conceptions in various areas of science assuming that finding out what the students know can help teachers and educators to adjust instruction accordingly. According to the critics, findings from the studies were not implemented broadly in curricula and were not incorporated enough in professional development activities.

In addition to research into student understanding, the curriculum programs of the 1980s were characterized by the science, technology, and society (STS) approach, integrating social aspects of scientific and technological developments in the science curriculum, supplemented the learning with more everyday life examples to make the learning more relevant to the students.

The report of the National Commission on Excellence in Education, *A Nation at Risk* (National Commission on Excellence in education, 1983) raised questions about the quality of the American educational system and is considered to be a turning point in the next movement in science education. This report has driven the development of national and states standards in the late 1980s and the 1990s to specify what students should know and be able to do to be scientific literate in each grade level in specific content areas. This reform called for clear, measurable standards for all school students focusing on the need to teach science as part of the personal scientific literacy of all students. Project 2061 is an example outcome of this reform movement. The project was founded in 1985 to help all Americans become literate in science, mathematics, and technology.

Logically, after developing national and state standards needs were recognized to align curriculum and assessment with those standards leading to the next reform movement in the beginning of the 21st century, calling focusing on big ideas and coherent curriculum for promoting coherent understanding. In addition to the need for better alignment with the standards, problems of disconnection and incoherence in present curricula, as well as disconnection between curriculum, instruction and assessment aroused. As a possible answer, recent reports (NRC, 2006, 2007; Smith et al., 2006) called for the science education community to identify big ideas and develop effective and coherent curricula to be extensively tested in classrooms; those would be used to guide instruction and assessment in science education.

Other concerns that are widely discussed in recent reports (NRC, 2006, 2007; Smith et al., 2006) is that the national, state, and local standards contain disconnected topics without a perspective of development of understanding and too little attention is given to how students might develop in their understanding of the isolated ideas over time. *Taking Science to School* (NRC, 2007) in their report discussed, for example, the concern that in contrast to other countries that perform better on international science tests, in U.S. curriculums the topics are more isolated from each other and there is little attention to making connections and building links across topics over time.

As a possible answer to the problems of disconnection and incoherence in present curricula, as well as disconnection between curriculum, instruction and assessment according to recent reports, these reports called for the science education community to identify big ideas and develop effective curricula to be extensively tested in classrooms and call for large-scale efforts to characterize students' understanding at key points in time and in doing so, mapping student understanding over time and across grade levels. Consequentially, the popularity of such studies is spreading increasingly among science education researchers. In their attempt to address the continuity issue the AAAS complemented their Benchmarks (AAAS, 1993) by publishing the two-volume *Atlas of Science Literacy* (AAAS, 2001, 2007). The Atlas contains strand maps and related commentary that organize and connect ideas and skills essential for constructing students' understanding of important science, mathematics, and technology topics from kindergarten through 12th grade in a logical manner. The two-volume Atlas include 100 strand maps that are graphically display how students might develop in their understanding of important topics based on logic of the discipline and on reported learning difficulties. The connections themselves are ideas to be learned. Project 2061 continues to look for empirical evidence for the connections. In their recent assessment work of ideas related to chemical reactions and conservation of matter, DeBoer and colleagues from the project (DeBoer et al., 2009) did a path analysis that showed dependencies of understandings from one idea to another. Likewise Project 2061, there are an increasing number of studies, although usually in a smaller scale, on student understanding of core ideas over time to help weave the set of ideas into a coherent story.

The following chapter outlines the methodology for the study. Specifically, I describe the development of the construct maps that are the foundation for this study and are used to guide the development and analysis of assessment items, the research population, the data collection, and its analysis

Chapter 3

Methods

Overview

This study utilizes both quantitative and qualitative data from sources collected before, during and after the teaching of the 7^{th} grade IQWST chemistry unit titled “How Can I Make New Stuff From Old Stuff?” (Stuff) (Krajcik, McNeill, & Reiser, 2008; McNeill et al., 2004). This unit is part of the Investigating and Questioning our World through Science and Technology (IQWST) project (Krajcik, McNeill & Reiser, 2008), a three-year middle school science curriculum, whose aim is to build students’ ideas over time.

The main purpose of the study was to characterize students’ learning of a core idea in science literacy, chemical reaction, as the students participate in a 7^{th} grade chemistry unit that was designed to be a coherent Chemistry curriculum that focuses on helping students understand that idea. To explore students’ prior knowledge, what they are able to learn, what difficulties they face, and the remaining challenges in understanding chemical reactions, the study uses quantitative (e.g., pre and post-tests) along with qualitative (e.g., interviews, open-ended portion on the pre and post-tests) data sources. The pre/post-tests consisted of pre-existing items complemented with new ones, specifically designed for this study. The student interviews were conducted several times throughout the study and mostly follow the flow of ideas in the construct maps developed for this study (further explained in the next section) in order to obtain more insight into students' conceptions and provide indication for learning.

Methodology Approach - The Use of Construct Maps

In this study I used construct maps (Wilson, 2005) to guide the development and analysis of assessment items aimed at finding evidence for learning and monitoring student progress in learning of a specific idea at specific points in the curriculum. A description of the design of the assessment items is described in detail later as part of the discussion on the data collection method.

A construct is a latent idea (it is in the minds of people). We cannot observe latent ideas directly and therefore need to create measures to inform what the learners understand. A construct is what the measurer intends to measure. A construct includes the ideas or concepts that we wish to learn about and measure (Wilson, 2005); it can be efficiently expressed by a construct map. A construct map is a graphical representation of a consecutive continuum of the understanding of a specific construct. The map displays hierarchical levels of students' understanding progressing from lesser understanding towards more sophisticated understanding of the construct. The construct map to be used in this research is sequenced by the logical growth in comprehension level represented in the item responses. Each level describes what students are expected to know as they develop successively more sophisticated understanding of the specific construct. According to Wilson (2005), while the sub-levels are important and useful for interpretation, learning is a continuous process; thus, as the students move from less toward a more sophisticated understanding of the specific construct, they can also be at any point in between the levels. A construct may include more than one sub-construct, where each of the sub-constructs is represented by a construct map. In this study for example, the construct is “chemical reaction”, which is divided into three sub-constructs, namely, the change of properties, rearrangement of atoms, and conservation of mass, to be further explained in the next sub-section.

The first step of this study was the development of the construct maps, in which I laid out what students are expected to learn in each sub-idea. The construct maps then served as a guide for how I thought student learning would develop and guided the design and analysis of assessment items, whose purpose was to find evidence for learning for each part of the construct map.

The construct maps used in this study.

A solid grasp of the chemical reaction construct includes the understanding that as a result of a chemical reaction the properties of the substance change and that atoms rearrange while mass is conserved. The specific sub-constructs used in this study are:

- Change of substance properties as a result of a chemical reaction
- Rearrangement of atoms during a chemical reaction
- Conservation of mass during a chemical reaction

A separate construct map was developed for each of the above sub-constructs to demonstrate what students know or should know (Figure 3.1, Figure 3.2, and Figure 3.3). The maps were then used for developing and refining the assessment items and subsequent analysis of those items to track student progress across the unit. The proposed construct were implemented as the foundation for this study and have been used to guide the design and the analysis of the study to characterize what students know and what they still struggle with. The construct maps are based on the national standards and benchmarks and organized based on the logic of how students possibly developed, on what the literature says about student learning of these ideas and on reported difficulties in the literature.

The development of the construct maps began by identifying key content standards from the American Association for the *Benchmarks for Science Literacy* (AAAS, 1993, 2009) and *National Science Education Standards* (NRC, 1996) documents at the macroscopic and the microscopic levels that are essential for understanding each of the three sub-constructs of chemical reactions. The next step was clarifying prior knowledge that is needed to better understand the key idea and identifying later ideas that are based on the understanding specified by content standard as well as incorporating potential student difficulties and alternative conceptions that are related to further understanding of the key idea.

The initial stages of the construct maps development process were part of a final project for a course on constructing measures. During the course, I received considerable amount of feedback from Professor Wilson who was the instructor and is an expert in measurement and applied statistics. The construct maps underwent considerable revisions before the final form was reached. The first version of the construct maps was based on the key content standards that were identified as essential for understanding macroscopic and microscopic aspects of chemical reaction (two construct maps, one for macroscopic and one for microscopic). However, this perspective failed to capture some necessary prior understanding such as the distinction between open and closed systems. Since this (and other necessary prior understandings) is a key piece of understanding, the construct maps were revised to reflect the knowledge to obtain a full understanding of chemical reaction. This resulted in the construct maps of the three sub-constructs: the change of properties, the rearrangement of atoms, and the mass conservation. This revised version was submitted as the final class project. The next step was further refinement of the construct map content based on feedback from one science education expert. One significant change was the additions of level 0 reflecting what students brought to the learning process. The final stage was the validation of the construct maps content, which was established by one science education expert (A professor of Science Education). A summary of the development of the construct maps used in this study and the related key standards can be found in the appendices (Appendix I). Next, I describe in more detail the development of each of the construct maps used in this study.

The development of the "change of properties" construct map.

The starting point for the "change of properties" construct map were the key ideas that a substance has characteristic properties and that chemical reactions result in new substances with new characteristic properties based on the following standards:

> *NSES*, 5-8 p.154: A substance has characteristic properties, such as density, a boiling point, and solubility, all of which are independent of the amount of the sample. A mixture of substances often can be separated into the original substances using one or more of the characteristic properties.
>
> *NSES*, 5-8 p.154: Substances react chemically in characteristic ways with other substances to form new substances (compounds) with different characteristic properties.

The next step was adding the prior knowledge that is necessary to grasp a better understanding of the above content standard. Specifically, to better understand that "a substance has characteristic properties", students first need to know what a property is, which was added as the first sub-level in the construct map. The last step was adding the fourth level based on difficulties that were reported in the literature. Previous studies show that students have difficulties differentiating chemical reactions from phase changes and mixtures. Many students incorrectly think, for example, that a chemical reaction occurs during a change of state (Ahtee & Varjola, 1998; Stavridou & Solomonidou, 1998) or when a substance dissolves (Abraham et al., 1994; Ahtee & Varjola, 1998; Eilks, et al., 2007; Stavridou & Solomonidou, 1998; Valanides, 2000). Since the "change of properties" sub-construct focuses on the changes that occur in a chemical reaction at the macroscopic level (except mass conservation that is detailed in a separate construct map), I added this difficulty in distinguishing the different types of phenomena at the macroscopic level to the construct map to be the fourth level at the map.

To sum up, the two parts of the standard content knowledge were placed as the second and third sub-levels. Before that, I placed the prior knowledge that is important to gain a better understanding of the standard content knowledge as the first sub-level, and above the two parts of the standard content knowledge, at the upper (forth) sub-level, I placed the learning difficulty (a continuous understanding) that is reported from the literature.

The development of the "rearrangement of atoms" construct map.

The starting point for the "rearrangement of atoms" construct map based on the key idea that when substances interact to form new substances, the atoms rearrange and form new molecules:

> *Benchmark*, 4D/M13: The idea of atoms and molecules explains chemical reactions: when substances interact to form new substances, the atoms that make up the molecules of the original substances combine in new ways to form the molecules of the new substances. *(New AAAS Learning Goal)*

To better understand that atoms rearranged to form the molecules of the new substances (level 3 at the construct map), students need the prior knowledge of distinguishing atoms from molecules, which require a basic understanding of the particulate nature of matter. Thus, those two pieces of understandings were placed at the bottom of the construct map (levels 1 and 2). These two sub-levels are also related to benchmark 4D6-8#1:

> *Benchmarks*, 4D6-8#1: All matter is made up of atoms, which are far too small to see directly through a microscope. The atoms of any element are alike but are different from atoms of other elements. Atoms may stick together in well-defined molecules or may be packed together in large arrays. Different arrangements of atoms into groups compose all substances.

The upper (fourth) sub-level was added based on difficulties that were reported in the literature concerning differentiating chemical reactions from phase changes and mixtures. In similar to the "change of properties" wherein this understanding was added as the upper sub-level at the macroscopic level, it was added to the "rearrangement of atoms" construct map as the upper sub-level at the microscopic level since this sub-construct focus on the changes that occur in a chemical reaction at the microscopic level (except mass conservation that is detailed in a separate construct map).

The development of the "mass conservation" construct map.

The starting point for the "mass conservation" construct map was the key idea that during a chemical reaction (in a closed system) the total number and type of atoms remains the same and thus the mass is conserved. This key idea is based on the following Benchmark:

> *Benchmarks*, 4D6-8#7: No matter how substances within a closed system interact with one another, or how they combine or break apart, the total weight of the system remains the same. The idea of atoms explains the conservation of matter: If the number of atoms stays the same no matter how they are rearranged, then their total mass stays the same.

Then, the next step was breaking the content into two levels of understanding, the macroscopic and the microscopic. The next step was adding prior knowledge that is necessary to grasp a better understanding of the topic, the distinguishing between open and closed systems. The resulting map ended up with three sub-levels that together build-up the understanding of mass conservation in chemical reactions.

The connection of the construct maps to the unit investigated in this study.

In addition, the development of the construct maps was also based on, but not exclusively so on what is taught in the unit investigated in this study. The 7th grade IQWST chemistry unit focuses on three central ideas in chemistry - substances and their properties, chemical reactions, and the conservation of matter. The main curriculum learning goal is to help students to understand chemical reactions. A further goal is for students to explore macroscopic phenomena and delve into molecular models, which help explain the phenomena.

At the macroscopic level students learn that a chemical reaction is a process in which given (old) substances interact to form new ones with properties different from those of the original substances. At the microscopic level students learn that a chemical reaction is a process in which two or more substances interact and their atoms combine in new ways to form new substances that are made of the same atoms as the old substances, but the atoms are arranged in new ways.

In middle-school, the chemical reaction curriculum focuses on both the macroscopic view of the scientific phenomena and the microscopic view, which is used to explain and predict the scientific phenomena. In advanced grades the symbolic representations of chemical reactions using symbols and formulas is added to the two aforementioned concepts; considering that the focus of this study is middle school, symbolic representation is therefore not a central learning goal. Nevertheless, IQWST curriculum introduces the students to symbolic representation, but do not delve into stoichiometry and balancing equations. Understanding each level (macroscopic/microscopic/symbolic) by itself is complex and linking between the different levels requires dealing with large body of connected knowledge. Therefore, linking these two levels (macroscopic and microscopic) of comprehension, (and adding a third in later grades) can be very challenging. The construct maps specify what students should know for both the macroscopic and the microscopic levels of understanding. These then can help us seek evidence for learning.

The "change of properties" sub-construct.

At the macroscopic phenomena level, students learn that a chemical reaction is a process in which substances interact to form new ones with a different set of properties (level 3). To decide whether or not properties have changed, students first need to know what a property is (level 1), and that different substances have different sets of properties (level 2), and that is why comparing a single property is not always enough to determine whether or not a substance is the different/same. At the highest level, students can use that knowledge to distinguish between chemical reactions from phase changes and mixtures (level 4).

Respondents' level of understanding	Direction of understanding the "change of properties" sub-construct	Responses to items
4	More sophisticated understanding	**At the macroscopic phenomena level**: Students can distinguish chemical reaction from mixture and/or from phase change. In both phase change and mixture no new substance is formed. In phase change the substance has the same properties (for same temperature) but has a different form, while in mixtures substances are mixed and do not chemically interact but exist separately between each other.
3		**At the macroscopic phenomena level**: A chemical reaction creates new or different substances with a different set of properties.
2		**At the macroscopic phenomena level**: Different substances have a different set of properties. Therefore, when substances have a different set of properties they are different substances.
1		**At the macroscopic phenomena level**: A property is a characteristic of a substance. Properties are consistent and not determined by the amount of a substance.
0 (assumed prior knowledge)	Less sophisticated understanding	**At the macroscopic phenomena level**: Students can describe substances, but cannot yet distinguish properties from non-properties.

Figure 3.1: Construct map for the "change of properties" sub-construct

The "rearrangement of atoms" sub-construct.

As with all construct maps, the "rearrangement of atoms" construct map assumes that the students possess prior knowledge. Students are assumed to understand the basic particulate nature of matter, the properties of substances, and phase changes. Explicitly, they are expected to know that a substance is composed of particles, differentiate atoms from molecules and that each substance presents a unique set of properties. This prior knowledge is taught in the 6^{th} grade IQWST curriculum. However, since the 7^{th} grade students in this study did not have the 6^{th} grade IQWST chemistry unit, these concepts are revisited in the 7^{th} grade unit as students learn about what happens in a chemical reaction.

In order to fully comprehend chemical reaction it is necessary to first understand what matter is made of. Therefore, a firm understanding of the particulate nature of matter is essential. This is presented in the construct map as assumed prior knowledge (level 1). This assumption is reasonable because the student had a brief review of the particulate nature of matter before starting the unit's instruction.

To decide whether or not new molecules have been formed (atoms have been rearranged) students need to be able to distinguish between atoms and molecules (level 2) and to be aware that molecules can break apart and atoms can combine in new forms (level 2).

At the microscopic level, students learn that a chemical reaction is a process in which two or more substances interact and their atoms combine in new ways to form new substances that are made of the same atoms as the old substances; however, the atoms are arranged in new ways (level 3). At the highest level students are expected to synthesize their learning to distinguish chemical reactions from phase changes and mixtures (level 4). Specifically, they are expected to understand at the microscopic level that in contrast to a chemical reaction where molecules break apart and atoms re-arrange to form new molecules, in mixture and phase changes, molecules remain unchanged.

Respondents' level of understanding	Direction of understanding the "rearrangement of atoms" sub-construct	Responses to items
4	More sophisticated understanding ↑	**At the microscopic level:** Students can distinguish chemical reaction from mixture and/or from phase change. In both phase change and mixture, molecules remain unchanged.
3		**At the microscopic level:** Students understand that a chemical reaction creates new substances that are made of the same atoms as the old substances, but the atoms are arranged in new ways. The same atoms form different molecules.
2		**At the microscopic level:** Students differentiate between different types of particles, such as atoms and molecules. Matter can change, molecules can break apart and atoms can combine in different ways.
1		**At the microscopic level:** Students understand the basis of the particulate nature of matter**.** All matter is made of particles; all matter is made of atoms, and molecules (or ions in upper grades). Matter can be found in three main forms (states or phases): solid, liquid, and gas. Adding/removing heat may cause a change of state of matter
0 (assumed prior knowledge)	↓ Less sophisticated understanding	**At the microscopic level:** Students can describe what constitutes matter, but use everyday terms and not scientific ideas (such as molecules, atoms, or particles). Some students use scientific terms, but struggle to distinguish the different types of particles or give any hierarchic levels (such as molecules are made of atoms or vice-versa).

Figure 3.2: Construct map for the "rearrangement of atoms" sub-construct

The "Mass Conservation" sub-construct.

In order to form a solid grasp of the chemical reaction concept, students need to understand that during a chemical reaction in a closed system, no material (atoms/molecules) can enter or leave the system and that no material (atoms/molecules) can appear out of nowhere, nor can it disappear. The number and type of atoms stays the same in both sides of the reaction - the reactant side and the product side. As a result, the mass in the system remains constant.

Based on the literature (e.g., Ben-Zvi, Eylon, & Silberstein, 1988; Wu, Krajcik, & Soloway, 2001), it is most likely that the macroscopic understanding of a specific idea, in this case, mass conservation, comes before the microscopic one, and both come before the symbolic one. Thus, I hypothesized that macroscopic comes before microscopic in the construct map (levels 2 and 3). Because mass conservation applies only to a closed system, the first level of understanding requires that students be able to distinguish the two types of system (level 1).

Respondents' level of understanding	Direction of understanding the "mass conservation" sub-construct	Responses to items
Advance levels that are beyond the expectations at the middle school level	More sophisticated understanding	**At the symbolic level:** Students understand that in a closed system the number and type of atoms stays the same on both sides of the reaction, the reactant side and the product side.
3	↑	**At the microscopic level:** Students understand that the total number and type of atoms before a chemical reaction is equal to the total number and type of atoms after a reaction in a closed system. The number and type of atoms stays the same no matter how they are rearranged, thus, total mass stays the same.
2		**At the macroscopic phenomena level**: Students understand that the total mass before a chemical reaction is equal to the total mass after a reaction in a closed system. The total mass of the system always remains the same no matter how substances interact with each other, or how they combine or break apart.
1	↓	Students can distinguish a closed system from an open system in a process, understanding that in a closed system no material (atoms/molecules) can enter or leave the system, and in open system material (atoms/molecules) can enter (react/combine) or leave the system. Matter (atoms) is neither created nor destroyed in chemical reactions.
0 (assumed prior knowledge)	Less sophisticated understanding	Students are not familiar with open and closed systems or their meaning and are not able to distinguish the two types of systems. They cannot explain open system phenomena (e.g., rust) and do not realize that matter cannot disappear or be added.

Figure 3.3: Construct map for the "mass conservation" sub-construct

Context

School.

The study was administered in seventh grade science classrooms taught by two teachers at an independent school in a Midwest university city. This school is a sixth to twelfth grade school with a student enrollment of approximately 75 students per grade, 340 high school students (grades 9-12), and 198 middle school students (grades 6-8). It is not a school for gifted students, but does have an admission process, and the students admitted tend to be in the upper two-thirds of standardized test norms. This school was chosen as a research site because there is an existing relationship between the teachers and the university researchers.

School Year, students and teachers.

Data was collected during the 2008-2009 school year, starting on January 2009. During that school year, 64 seventh grade students were taught in five separate classes by two different teachers (12-13 students/class in average). The Stuff unit was taught from January through March. In this study, class observations and data collection were made during the unit instruction while interviews continued until June 2009. For more details about the specific timeline for the instruction and the data collection see Figure 3.4.

Two classes (26 students total) were taught by "teacher A" who at the time of this research had been teaching for seventeen years, including fifteen years at the current school (7^{th} and 8^{th} grade science). Teacher A has a Bachelor of Science (BS) with a major in Broad field Science and Education, a minor in biology and health with certification 7-12 in science, health education and psychology, and a Master of Art (MA) in Human Development with a focus on pre- and early adolescents. Teacher A has been working with university researchers to develop and implement the IQWST unit used for this study and has taught this unit for 6 years, since the introduction of this curriculum.

Three classes (38 students total) were taught by “teacher B” who has ten years of teaching experience, the last two at the current school (7^{th} grade science). She was in her second year of teaching the IQWST unit used for this study. Teacher B has a Bachelor of Science (BS) with a major in biology, and a minor in chemistry, an advanced teaching certificate K-8, and a Doctor of Dental Surgery (DDS) specialized in Oral and Maxillofacial Surgery. Before starting her teaching career, the teacher was a clinical surgery in a self-owned practice and an instructor in oral surgery at a major Midwestern university. The two teachers met regularly to plan their lessons as well as share handouts and tests.

The unit used for the Study.

The IQWST Chemistry unit that is used for this study is an eight to ten-week unit designed for 7^{th} grade students. Before starting the unit’s instruction the student had a brief review (two lessons) in which teacher introduced basic concepts of the particulate nature of matter including particles, atoms, molecules, and phase changes. The overall instruction duration (including the brief introduction to the unit and school breaks) was twelve weeks.

The Stuff unit is divided into three learning sets, each composed of lessons. The driving question for the unit is: “How can I make new stuff from old stuff?” Each learning set deals with a single aspect of the driving question. The first learning set (five lessons) deals with “How is stuff the same and different?” The major learning goal in this learning set is to help students to understand the concepts of substances and properties.

The second learning set (five lessons) deals with "How can I make new substance?" This learning set centers on the concepts of substance and properties to introduce the concept of chemical reaction. The third learning set (four lessons) deals with "Do substances always come from old substances?" In this final learning set, students use their understandings to explore what happens to mass during chemical reactions.

The Stuff unit provides multiple opportunities for students to practice all three levels of representation (macroscopic, microscopic, and symbolic levels) when demonstrating chemical reactions such as chemical equation and molecular models. For instance, at the microscopic level, students use molecular models (gumdrops and tooth sticks models) of substances before and after a chemical reaction to reason that the number of each type of atom is the same before compared to after the reaction, which is why mass is conserved. Considering that the focus of this unit is middle school, symbolic representation is not a central learning goal. An understanding of chemical reactions at the symbolic level is expected only in advanced grades. For more details about the curriculum see the Appendices (Appendix H). Before the stuff unit, the students learned about pH, solvent, solute, dissolving, and how particles of the solute fit in between the particles of the solvent. Specifically, the water was the solvent and there were pollutants that are dissolved in it.

Data Collection Method

As indicated earlier, the first step of this study was to create the construct maps, laying out what students are expected to learn. This in turn guided the development of assessment items as previously described at the beginning of this section.

I collected data from two principle sources including pre/post-tests (January/March 2009) and interviews (January through May, 2009). In addition to these data, I also made classroom observations and took notes on issues that arose in relation to students' learning. I observed both teachers' lessons (one lesson of each) every day over a twelve weeks period. For example, I noted questions asked by both teachers and students during the lessons as well as responses to those questions. Although not a primary data source, I used these observations to help explain my results.

The number of participants for each data source utilized in this study is summarized in the following table (Table 3.1). Following the table, I provide the specific timeline for the instruction and the data collection (Figure 3.4).

Table 3.1: Summary of participants and data sources

Data Source	Participants	Reference to research questions*
Pre & post tests	64 7th graders (all 7th graders in the school) from one school (5 classes) taught by two different teachers	Used to answer both research questions (Q1 refers to students' knowledge prior to the instruction & Q2 refers to the knowledge that gained during and after instruction)
Interviews	16 students (voluntary based, out of the five classes participated in the study)	Used to answer both research questions (1&2)

*The actual contribution of each data source to answering the research questions is discussed in the data analysis in the following section.

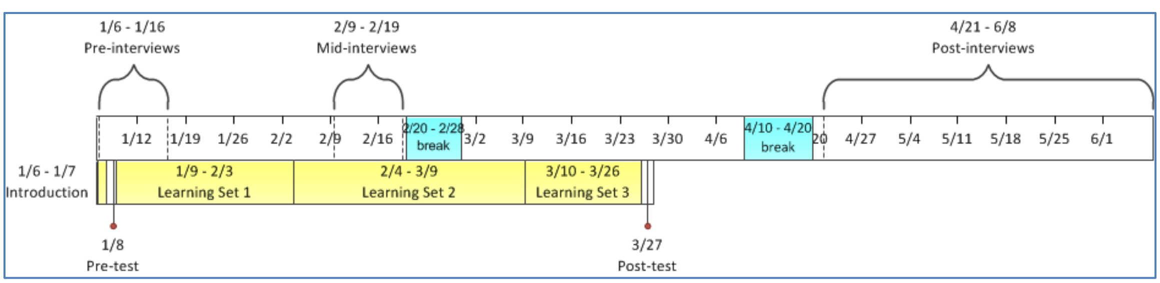


Figure 3.4: Timeline for the instruction and the data collection

The pre/post-tests and the interviews before and after the instruction process were used to evaluate students' understanding prior to and post unit's instruction (research questions 1 and 2). To learn more about students' learning during the instruction process (research question 2) interviews were conducted at a middle-point in the curriculum's duration, after completing the first part of the curriculum in which the students learned about substances and properties, but before they learned that substances interact to form new substances (i.e., chemical reaction) and conservation of mass. Together, the pre/post-tests and the interviews were used to assess what students understand and with what sub-ideas do students have difficulty at different stages of the learning process.

Interviews.

The interviews conducted in this study were designed to learn about students' conceptual understanding of chemical reactions and were conducted at various stages of the learning process, namely, before starting the unit, throughout the unit and at the end of the unit. The interviews were designed to explore students' understanding of chemical reaction more deeply, which help to ensure the validity of the assessment items developed for this study and to identify students' difficulties.

Semi-structured interviews[4] with individual students were conducted and audio recorded for later transcription and analysis. The duration of each interview was planned at about twenty minutes for the first and second sets of interviews (Time 1 and Time 2) and at about forty minutes for the third set of interviews (Time 3). Students were selected for interviews on a voluntary basis. Sixteen students volunteered from three different classes, nine girls and seven boys. Students who volunteered for interviews represented a range of achievement levels in the classroom. More specifically, eight students received

[4] Pre-designed interview questions along with spontaneous questions

A (1A+, 4A, and 3A-) as their final letter grade for the semester; six students received B (4B+, 1B, 1B-); one student received C, and one student received D.

The interviews allow for a more in-depth understanding of the students' performance than in the pre and post-tests. Although the interviews contain guiding questions, the interviewer can adapt questions according to the interviewee's responses, allowing for a more complete assessment than a pre-determined written response set of questions. During the interviews, students were asked to elaborate on their assessment tasks and their choice of answers, focusing mainly on the three sub-constructs described earlier:

a. Change of properties that occur as a result of a chemical reaction
b. Rearrangement of atoms during a chemical reaction
c. Mass conservation during a chemical reaction

The interview questions were designed in an attempt to cover full range of the construct maps. For instance, the first set of the interviews is targeted to gain more insight into students' understanding of the lowermost levels of the construct maps. From the "rearrangement of atoms" construct map, the first set of interviews delves into students' understanding that substance is composed of particles; matter is made from atoms and molecules, and distinguishing between atoms from molecules. From the "change of properties" construct map, the interview delves into students' understanding that a property is a characteristic of a substance and that each substance presents a unique set of properties. The second and third sets of the interviews delve into students' understanding of more levels from the lowermost level to the upper levels of the construct maps.

The design of the interview assessment items.

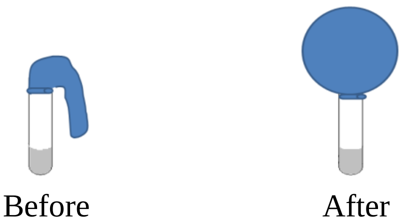
The main goal in the design of the interview assessment items was to create questions that could reflect the content knowledge of the sub-levels given in the construct maps. The interviews included both open-ended and closed-ended questions. By closed-ended questions I refer to questions that can be answered using a simple "yes" or "no", a specific simple piece of information, or a selection from multiple choices. Closed-ended questions contrast with open-ended questions that cannot be simply answered and allow the person answering the question to response with the information that seems to them to be relevant. Closed-ended questions were supplemented by open-ended ones to more fully understand the students' responses. All the closed-ended questions were obtained from or modified from other sources (e.g., question 12 is from Project 2061). These questions were selected because they focus on sub-levels of the construct map in which I had an item missing or when I needed more items to obtain more information. For all the solely open-ended questions, I created scenarios followed by one major question or by multiple questions (all related to the same scenario). Each sub-question was designed to explore student understanding of at least one specific sub-level in the construct map.

The content of the scenarios was based on difficulties that are reported in the literature (e.g., burning reactions), student difficulties observed in the class, experiences students had in the class, modifications of questions that were found in the literature (e.g., question 11 is based on a multiple-choice question given in TIMSS exam), modifications of questions from the pre/post tests on which the students did poorly (in previous years), or everyday phenomena (e.g., boiling and melting points) that focus on ideas that are correlated to the content of the sub-levels in the construct map.

One example of a scenario is in question 17, which focuses on a reaction between baking soda (placed in a balloon) and vinegar (in a test tube) in which the balloon inflates. This scenario is based on students' classroom experience. In class they did a reaction between Alka-Seltzer tablets with water in a similar system set-up (where a balloon contains the tablet and a soda-pop bottle contains the water). The three subsequent sub-questions refer to each of the three sub-levels of the mass conservation construct map, namely, open vs. closed system, the macroscopic level of understanding of the mass conservation law (mass remains the same), and the microscopic level understating of the same law (number and type of atoms remain the same). Question 17 including the scenario and the subsequent sub-questions is given in Figure 3.5.

Question 17 (3rd set of interviews):

A test tube is half filled with vinegar. Baking soda is placed in a balloon. The opening of the balloon is wrapped around the opening of the test tube, while making sure that the balloon contents are not released into the test tube (see Figure below labeled “before”). The contents are then released into the test tube. The balloon inflates (see Figure below labeled “after”).



Specific questions asked on the above scenario	Reference to the construct maps
1. Would you describe this scenario as occurring in an open or closed system? a. Open system b. Closed system c. There is not enough information to decide Why? 2. What caused the balloon to inflate? a. The atoms changed into other atoms that take up more space. b. The number of atoms increased. c. The molecules changed into other molecules that take up more space. d. The mass in the system increased. Explain your choice: 3. Is the number of atoms in the system after the balloon inflated the same, less or more than the number of atoms before? a. More b. Less c. Same d. There is not enough information to decide Why? Why not the other choices?	In order to answer the question correctly, students should master all three levels of the “mass conservation” construct map. Students should know that the reaction is taking place in a closed system (level 1 in the construct map) because nothing can get in or out, assuming of course that the balloon is airtight and nothing can get in or out. They also need to know that the mass doesn’t change (level 2 in the construct map) and the number and type of atoms do not change (level 3). Q2: Students who choose options “a” or “b” do not understand that in a closed system the number and type of atoms do not change. Students that choose option “d” have difficulties to understand that during a chemical reaction in a closed system, the mass remains the same. The question on purpose doesn’t explicitly say whether or not mass has been changed. At the highest level I expect students to say that the system is seemed to be closed but we can’t know for sure unless we get mass measurements before and after verifying that the mass of the system did not change. Students at that level will indicate that there is not enough information to decide (in both Qs 1&3) and will support their choice reasoning that we are missing information whether or not mass has been changed. Through the explanations I hope to learn also to learn more about possible misconceptions.
4. Are the properties of the system before and after the balloon inflated the same/different? Why?	This part refers to the third level in the “change of properties” construct map, in which students are expected to know that a chemical reaction results in new substances with a new set of properties.

Figure 3.5: A sample interview question (Question 17)

Another example of a scenario is in question 16, which focuses on a burning reaction. In the research literature, this type of reaction is reported to be hard for students (e.g., BouJaoude, 1991; Kind, 2004). Question 16 including the scenario and the subsequent sub-questions is given in Figure 3.6.

<u>Question 16 (3rd set of interviews)</u>:

Wood is placed on a scale (on fireproof containers), set on fire and burns. A pile of powder is left. The powder weighs less than the wood prior to burning.

Specific questions asked on the above scenario	Reference to the construct maps
1. Would you describe this scenario as occurring in an open or closed system? a. Open system b. Closed system c. There is not enough information to decide Explain your answer:________________________ What information did you use to support your decision?	Q1 refers to level 1 of the "mass conservation" construct map – whether or not students' responses indicate that they can distinguish between an open and a closed system. Through students explanations I also identified students' misconceptions about this matter. This Q is similar to Q1 in part 3 of the pre/post-tests, but in this case mass left the system rather than being added to the system as in the case of the pre/post-tests Q. Through students explanations I checked whether or not the students understand the meaning of open/closed systems. Choosing the correct answer by itself without a reasonable explanation does not reflect understanding but only the knowledge of terminology or successful guessing.
2. What best describes the cause of the weight difference? a. Some of the atoms in the wood burned out and disappeared b. The atoms in the wood changed and became smaller. c. Some of the atoms in the wood reacted with oxygen and formed gas that went into the air. d. The wood reacted.	This part delves into the next level in the construct map, level 2 where students need to understand at the macroscopic level, the reason for the change in mass.

Why? Why not the other choices?	
3. Are the number of atoms of the powder the same, less or more than the number of atoms in the wood? a. More b. Less c. Same Why? Why not the other choices?	This part delves into the next level, level 3 in the construct map (microscopic level), where students make the connection between the mass change and the change with the number of atoms.
4. Are the properties of the system before and after burning the wood the same/different? Why?	This part refers to the third level in the "change of properties" construct map, in which students are expected to know that a chemical reaction results in new substances with a new set of properties.
Comment: the scenario in this question occurs in an open system. Students are expected to provide evidence listed for open systems. However, providing additional evidence why the system is not a closed one indicates a more advanced level of understanding.	

Figure 3.6: A sample interview question (Question 16)

In some questions in addition to the scenarios, I used models (3D balls & sticks model) to determine whether and to what extent students have made a connection that students may have between the macroscopic view of the demonstrated phenomena (e.g., mass is conserved while volume change) and the microscopic view of the same phenomena. Another example of a question in which I used models is question 4, which refers to student understanding of sub-level 2 in the "rearrangement of atoms" construct map, specifically, the understanding that matter is made of molecules, made of many molecules, that molecules is made of atoms, and distinguishing between molecules and atoms. Question 4 is given in Figure 3.7.

Part 4 (Question 4): I show a molecular structure (and a 3D model consisting balls and sticks) of a sugar molecule to the student and ask: - Can you describe the sugar molecule to me? Can you tell me something about the sugar molecule?	
Possible Responses	Prompts
Does not know OR gives no response	• Have you heard of molecules before? • What can you tell me about the molecule presented in the model?
Made of atoms	• What do you mean by atoms? • What's the difference between an atom and a molecule? • How many atoms? • How many types of atoms • Do all sugar molecules will have the same number and type of atoms? • What is in between the atoms?
Other response rather than atoms	• Do you know the scientific name/term for that? • Try to prompt the students to get to the atom term, if not ask - have you ever heard of atoms? And then go to the related prompts for the "atom" response

Figure 3.7: A sample interview question (Question 4)

Because the interview time was generally limited to 20[5] minutes, only a small number of questions could be asked. Typically, I had two major questions and a few short questions. Regardless of the amount of time or the number of prepared questions, it was imperative to ensure that there were questions for each sub-level of the construct maps. Thus, not all prepared questions were used. Questions were eliminated to avoid repetitions. Questions were added to cover all sub-levels in the construct map.

The next step was to determine possible responses including the correct answers as well as potential incorrect answers. This allowed to the development of the follow-up questions. For example, in question 4, some of the follow-up questions were: What do

[5] 20 minutes was the maximum amount of time that the students could take from their busy school day.

you mean by atoms, how many atoms, how many types of atoms, what is the difference between an atom and a molecule, do all sugar molecules made of the same atoms.

Content validity of the interview assessment items was established by one science education expert. Below, I list all questions in the interviews and to which level in the construct maps they refer to (Table 3.2). The full Interview protocol is presented in the Appendices (Appendix A).

Table 3.2: Interview items and their reference to the construct maps

		Description	Interview questions
"Change of properties" construct map	Level 4	A chemical reaction can be distinguished from phase changes and/or mixtures	Q5, Q15
	Level 3	A chemical reaction results in new substances with a new set of properties	Q16, Q17
	Level 2	Different substances = different set of properties	Q7, Q9
	Level 1	A property is a characteristic of a substance	Q1, Q2, Q7, Q8, Q11
"Rearrangement of atoms" construct map	Level 4	A chemical reaction can be distinguished from phase changes and/or mixtures	Q5, Q13
	Level 3	A chemical reaction results in new substances with a new arrangement of atoms	Q13, Q14
	Level 2	Atoms and molecules are different	Q4, Q13, Q14
	Level 1	Basis of particulate nature of matter	Q3, Q5, Q6, Q10, Q11, Q12, Q13
"Mass conservation" construct map	Level 3	In a chemical reaction molecules change but the number and types of atoms do not	Q16, Q17
	Level 2	The total mass before and after a chemical reaction depends on the type of system (open or closed)	Q5, Q15, Q16, Q17
	Level 1	A closed system and an open system are different	Q16, Q17

Interviews were conducted at different times. At the beginning the interviews were conducted following the pre-test, but before instruction or at the onset of the unit's instruction, to learn about students' knowledge of chemical reactions. The goal of this interview was to learn more about the students' prior knowledge regarding chemical reaction. Specifically, this set of interviews probed students' understanding of substances and the properties of substances before they start the curriculum or during the first days of the unit instruction.

The second set of interviews was conducted after students completed Learning Set 1 (how is stuff the same and different?), and was intended to probe students' understanding of properties before the start of Learning Set 2 (how can I make new substances?). These interviews at these time points were necessary to better understand students' learning after completing the instruction of basic ideas such as what a property is, but before the instruction probes more deeply to the chemical reaction phenomena. Mid-interviews data was collected on the points related to the instruction up to the time of the interview. Due to students' time constraints (maximum 20 minutes per interview), the interviews did not delve into many aspects of sub-constructs to be learned.

The final set of interviews took place subsequent to the post tests, after the students completed the unit's instruction. The gap in time between the second and the last set of interviews was necessary because of the student schedule. This set of interviews targeted students' understanding of chemical reactions, which is the main idea taught in Learning Set 2 and mass conservation during a chemical reaction, which is the main idea taught in the third Learning set (do new substances always come from old substances?). This interview shed light on what students learned by the end of the curriculum. Together, the data of all interviews helped to better determine how students' understanding of chemical reactions evolves as they move through the curriculum and where the 7^{th} grade students face the greatest challenges for learning chemical reactions as they go through a coherent chemistry unit.

Pre/post-tests.

Pre and post-tests evaluate students' understanding at a given stage (before and after the unit's instruction), as well as track the overall changes in students' understanding from the beginning to the end.

Although the pre and post-tests do not provide insight as to how learning occurs and can only point to knowledge at the beginning and end of instruction, they are beneficial for many reasons. Benefits include the ability to evaluate a large population (e.g., the entire group of students rather than selected students) in an efficient timely manner and maintain consistent objective scoring standards.

The pre and post tests were taken by all the 7^{th} graders (64 students) enrolled in the school where the research was conducted. The pre and post tests are identical and consist of existing test and supplementary items. All IQWST students were already taking pre and post tests on a regular basis. For the purpose of this study, students participating in the study received additional assessment items newly and specifically developed with the study's goals in mind. The main goal in the design of supplementary assessment items was to create questions that could reflect the content knowledge of the sub-levels given in the construct maps in which I had an item missing or when I needed more items to obtain more information.

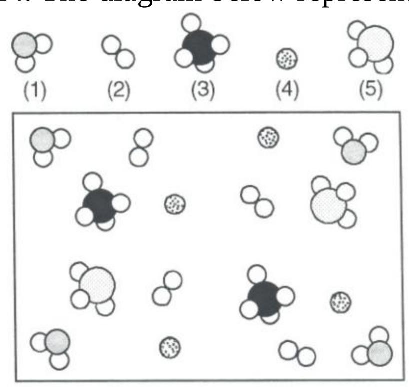
The tests include fifteen pre-existing multiple choice questions (Part 1), three pre-existing written-response (open ended) questions plus additional items that are given in all IQWST tests to measure students' explanations across IQWST units and are not used for this study (Part 2), and ten supplementary questions developed for this study (Part 3). Some of the newly prepared questions require students to provide an explanation to support their decision. For example, none of the pre-existing assessment items referred to the 2nd level in the "rearrangement of atoms" construct map (differentiate between atoms and molecules). Therefore, I added two assessment items (questions 23 and 24) that associate with that understanding. The assessment items are presented in Figure 3.8 below.

23. When sulfuric acid, H_2SO_4, is broken down into separate atoms, how many different atoms are there?

a. Two
b. Three
c. Six
d. Seven

(Correct answer: b)

24. The diagram below represents a mixture of gases.



Which of the following represent **ALL** of the examples of molecules in the diagram?

a. 2,4
b. 3,4,5
c. 1,3,5
d. 1,2,3,5

(Correct answer: d)

Figure 3.8: Assessment items that were added to the test (Questions 23 and 24)

As mentioned earlier, supplementary questions were added to the pre-existing items in an attempt to cover the full range of the construct maps and by this gain more insights into students' learning. Content validity of the pre-existing items was established by two science education experts, two scientists, and one psychologist. In addition, the test items were pilot tested and refined over several years (Krajcik, McNeill, & Reiser, 2008). Content validity of the new test items was established by one science education expert. Below, I list all questions in the pre/post-tests and to which level in the construct maps they refer to (Table 3.3). The full pre/post-test is presented in the Appendices (Appendix B).

Table 3.3: Pre/post-tests items and their reference to the construct maps

		Description	Pre/post questions
"Change of properties" construct map	Level 4	A chemical reaction can be distinguished from phase changes and/or mixtures	Part 1: Q5 Part 3: Q20, Q21, Q22
	Level 3	A chemical reaction results in new substances with a new set of properties	Part 1: Q1
	Level 2	Different substances = different set of properties	Part 1: Q3, Q8
	Level 1	A property is a characteristic of a substance	Part 1: Q12
"Rearrangement of atoms" construct map	Level 4	A chemical reaction can be distinguished from phase changes and/or mixtures	No questions. This was addressed through the interviews
	Level 3	A chemical reaction results in new substances with a new arrangement of atoms	Part 1: Q2, Q9, Q10, Q13, Q14
	Level 2	Atoms and molecules are different	Part 3: Q23, Q24
	Level 1	Basis of particulate nature of matter	Part 1: Q4, Q6 Part 3: Q25
"Mass conservation" construct map	Level 3	In a chemical reaction molecules change but the number and types of atoms do not	Part 1: Q2 Part 3: Q19
	Level 2	The total mass before and after a chemical reaction depends on the type of system (open or closed)	Part 1: Q7, Q11 Part 3: Q17, Q18
	Level 1	A closed system and an open system are different	Part 1:Q15 Part 3: Q16

The next section describes how the data was analyzed.

Data Analysis

The data was analyzed at both the micro and macro levels. The micro level is the question level analysis, which will be described in detail later. The macro level analysis is the synthesis of the students' overall understanding based on both the interviews and the tests. The macro level analysis was done by the construct maps. Specific details on this analysis are given later in this chapter.

Table 3.4 summarizes the research questions and how each of the data sources was used to answer those questions. Each analysis will be further explained in the next section.

Table 3.4: Summary of research questions, data sources and the analysis to be used

Research questions	Data source	Micro analysis	Macro analysis
1. What prior knowledge do 7th grade students have regarding chemical reactions? Particularly, what prior knowledge and difficulties do they have in relation to: a. Change of properties that occur as a result of a chemical reaction b. Rearrangement of atoms during a chemical reaction c. Mass conservation during a chemical reaction	Pre-test (N=64)	Analysis 1: Correlate each test item with the proper sub-level in the construct maps. Then, for each of multiple-choice questions, do a percentage of success analysis. Open-ended items are analyzed using the interview indicators for learning. Then, looking for trends for what the students seemed to understand and seemed to not understand in each question and draw conclusions for overall understanding of all students of the idea as revealed by the question.	Synthesize overall understanding for each sub-level of the construct maps. This was based on the data from all the questions that probed student understanding of the specific idea at the three points in time in the curriculum. Then, draw conclusions for the overall understanding of the specific ideas at the relevant point in time and use evidence from the

	Pre-interviews (N=16)	Analysis 2: Correlate the content of each interview section with the proper sub-levels in the construct maps. Then, each relevant section of a student interview was evaluated for evidence of understandings, using the indicators for understanding in each construct map. Then, looking for trends for what students seemed to understand and what difficulties they experienced.	questions (from both interviews and tests) to support my conclusions about student understanding. The findings were then organized according to the students' understanding of each of the three sub constructs (change of properties, rearrangement of atoms, and mass conservation), and associated sub-levels at the relevant point in time (beginning of the unit's instruction).
2. How does 7th grade students' understanding of chemical reactions develop as they go through a coherent chemistry unit on chemical reactions? During this learning process, what do they understand? With what sub-ideas do students have difficulty? In particular, what are students able to learn and what difficulties do they face in understanding the following: a. Change of properties that occur as a result of a chemical reaction b. Rearrangement of atoms during a chemical reaction c. Mass conservation during a chemical reaction	Mid-interviews (N=16)	Analysis 3: Similar analysis as for the pre-interviews (see Analysis 2 above), but at a different point in time (middle).	
	Post-interviews (N=16)	Analysis 4: Similar analysis as for the pre-interviews (see Analysis 2 above), but at a different point in time (end of the unit's instruction), plus overall progress from beginning through the middle and to the end.	
	Post-test (N=64)	Analysis 5: Similar analysis as for the pre- tests, but at the end of the unit's instruction, plus overall progress analysis from beginning to end.	

Micro analysis of the questions.

Interviews.

The first step in the interview analysis was to transcribe the recorded interviews. Overall, I had about 22 net hours of recorded data (16 students, each had three interviews where the first and second interviews last about 20 minutes and the last interview last about 40 minutes). Then, before analysis students' responses, I re-sorted the transcribed data according to the interview questions making sure that the identity of each student remained. To illustrate, the entire transcript of two questions (questions 16 and 17) is given in the Appendices (Appendix D).

To analyze the interviews for evidence of student understanding within each construct map, I created a list of indicators of student learning that specified what I would accept as evidence for each level of understanding in each construct map. The indicators emerged from the construct maps. Each relevant section of a student interview was evaluated for evidence of understanding, using the indicators. For example, for a student to provide evidence for understanding that a property is a characteristic of a substance, he or she would explain during their interview that: a property does not change with amount, or a property is consistent throughout the substance. In addition, the student would need to provide example/s of a property, and of what is not a property.

Below, I list the indicators (possible evidence) for each level in the three construct maps to be used for the analysis (Table 3.5, Table 3.6, and Table 3.7).

Table 3.5: Indicators for learning at each level of the "change of properties" construct map:

A property is a characteristic of a substance (level 1)	Different substances = different set of properties (level 2)	A chemical reaction results in new substances with a new set of properties (level 3)	A chemical reaction can be distinguished from phase changes and/or mixtures (level 4)
a. Property does not change with amount b. Provide correct example/s of a property c. Provide correct example/s of what is not a property d. Property is consistent throughout the substance	e. Comparing a single property is not always enough to determine whether or not two samples are the same/different substance (e.g., looking only at boiling point is insufficient)	<u>In chemical reactions</u>: f. new substances are made g. new properties - ending products are different (properties) from the beginning reactants h. Support with clues (signs) such as: color change, new odor, bubbles/fizzing, temperature changed without adding/removing heat, precipitate formed	<u>In chemical reactions</u>: Same list of evidence as described in level 3 <u>In phase change</u>: i. The same substance exists before and after j. Same properties (for the same temperature) exist before and after k. Substances change the state of matter (from solid to liquid to gas to liquid to solid) by removing or adding heat l. Easily reversed m. Support with clues/signs such as, bubbles, solid, liquid <u>In mixtures</u>: n. Made of 2 or more substances that do not chemically interact. The 2 substances are together but in between each other o. No set proportion p. Support with specific reference to example in the question

Table 3.6: Indicators for learning at each level of the "rearrangement of atoms" construct map:

Basis of particulate nature of matter (level 1)	Atoms and molecules are different (level 2)	A chemical reaction results in new substances with a new arrangement of atoms (level 3)	A chemical reaction can be distinguished from phase changes and/or mixtures (level 4)
a. Matter is anything that takes up space and has mass b. All matter is made of particles c. All matter is made of atoms and molecules d. Matter can be found in three main forms (states, phases): solid, liquid, and gas e. Adding/removing heat may results change of state of matter (from solid to liquid to gas to liquid to solid), in which molecules moves faster/slower, spread further/closer and move from orderly (in solid) to disorderly (in gas) arrangement	f. Molecules are made of atoms (same or different atoms) g. Each molecule of the same substance is identical h. Correct counting of the number of atoms i. Correct counting of the types of atoms j. Listing of different atoms k. Correct counting of the number of molecules l. Correct counting of the types of molecules m. Listing different molecules n. Reference back to specific atoms/molecules in the question	o. Atoms can combined in different ways p. Molecules break apart and/ or combine in new ways q. Atoms rearrange r. New molecules s. Same number of atoms before & after t. Same type of atoms before and after	<u>In chemical reactions</u>: Same list of evidence as described in level 4 <u>In phase changes</u>: u. Same molecular arrangement, molecules do not break apart/combine v. Atoms do not rearrange w. Same number of atoms before and after x. Same types of atoms before and after y. Molecules are faster or slower z. Easily reversed aa. Reference to specific example from the question such as freezing, melting, boiling, evaporating, and condensing. <u>In mixtures</u>: bb. Same molecular arrangement, molecules do not break apart/combine cc. Atoms do not rearranged dd. Same number of atoms before and after ee. Same types of atoms before and after ff. Molecules do not interact with each other, they are together but in between each other gg. No set proportion hh. Refers to specific example from the question such as: solutions, alloys

Table 3.7: Indicators for learning at each level of the "mass conservation" construct map:

A closed system and an open system are different (level 1)	The total mass before and after a chemical reaction depends on the type of system (open or closed) (level 2)	In a chemical reaction molecules change but the number and types of atoms do not (level 3)
In a closed system: a. no material (atoms) can enter the system b. no material (atoms) can leave the system c. Reference back to specific example from the question d. Reference to the system set-up	In a closed system: i. Total mass before and after remains the same j. Reference back to specific example from the question	In a closed system: m. the total number of atoms before and after remains the same n. The types of atoms before and after remain the same o. Reference back to specific example from the question
In an open system: e. material (atoms) can enter the system f. material (atoms) can leave the system g. Reference back to specific example from the question h. Reference to the system set-up	In an open system: k. Total mass before and after changes (either increase or decrease) l. Reference back to specific example from the question	In an open system: p. the total number of atoms before and after changes q. Different types of atoms (may be introduced or may escape) r. Reference back to specific example from the question

The next step was summarizing the data in table form based on the indicators for learning (Table 3.5 through Table 3.7). For each student I looked for evidence for learning. Table F.1 in the Appendices (Appendix F) summarizes student responses to a sample question (question 16, 3rd set of interview).

Very often, questions checked student understanding of more than one idea. Besides the understanding of the conservation of mass, Question 16 and 17 checked, for example, student understanding of properties. Thus, the portion of the question that focused on properties was analyzed separately and is not part of the data on student understanding of the conservation of mass (Tables F.1 and F.2, Appendix F).

The next step was looking for overall trends in student understanding on the specific idea under investigations as revealed by the relevant section of the question.

Evidence for difficulties in understanding was collected and categorized for further analysis. For instance, data was collected when students said the opposite of what is considered an indicator for understanding. Next, I looked if there is any consistency in what students seemed to have difficulties with in the relevant section of the interview.

Using the interviews, I characterized what students did understand at that point in the curriculum when the interview was conducted, what students initially did not understand but later did, and identified what they have difficulties with at that point and at the end. Since the interviews were conducted at different times throughout the curriculum I also looked for students' development in understanding from beginning to end. Findings from the interview analysis were used as evidence for trends in student understanding, which is discussed in more detail in the macro level analysis section.

Pre/post-tests.

The first step in the analysis of the pre/post-tests is to correlate the question with the construct maps and the relevant level within the construct maps to which the test item refers. Then, for each of multiple choice questions, I did a percentage of success analysis (given in Appendix E), more specifically; I found the percentage of the students that responded correctly and the percentage of responses to each of the distracters in order to find out trends in student understanding. By doing the percentage of success analysis, I could find out how many students mastered the idea/principle presented in the questions and what difficulties the students hold (e.g., when a noticeable percentage of students chose one or more of the distractors as the correct answer/s). After completing the percentage of success analysis for each question I assessed the overall understanding of all the student of the particular idea under investigation as revealed by the question and then also assess the overall progress of all students from beginning to end, identifying what students initially did not understand but later did, and identifying what students still have difficulties with at the end.

The open-ended portion of the tests provided more insight into students' understanding, offering supplemental insight and feedback through the elaboration opportunity and opportunity to identify students' difficulties in understanding. Open-ended items are analyzed using the interview indicators of student learning as was done with the interview data. For each question I used the indicators to identify what students had learned and had not yet learned. This information was organized in a table for each student. See Tables G.1 and G.2 in the Appendices (Appendix G) for an example of how the data was organized for questions 16 and 19.

The next step was looking for trends in student understanding to generalize their overall comprehension of the particular idea as revealed by the question. For example, overall, three students on the post-test mentioned both letting matter leave and enter the system, two of them also mentioned the system set-up and one of them did not. On the whole, more students referred to matter leaving the system (with or without referring to the system set-up, in comparison to those who referred to matter entering the system. Matter leaving the system is also a more familiar scenario from class activities (e.g., smoke).

Analysis of what students know and what they do not know helped to characterize students' prior knowledge, using the construct maps as a guidance to characterize where the students are in the learning process at the time the test was taken. Findings from the pre and post- tests analysis were used as evidence for patterns in student understanding, which is discussed in more detail in the next section.

Macro level analysis - synthesizing the results from the interviews and the tests.

After completing the micro analysis for each question in the interviews and on the tests, identifying what students understood and what difficulties they experienced, I synthesized overall understanding for each sub-level of the construct maps. This was based on the data from all the questions that probed student understanding of the specific idea at the three points in time in the curriculum. The next step was to draw conclusions for the overall understanding of the specific ideas at the relevant point in time and use evidence from the questions to support my conclusions about student understanding. These evidence included relevant statistical analysis such as a percentage of success analysis (given in Appendix E) and students' quotations from relevant question/s from the interviews and/or the tests, which is discussed throughout the Results chapter as relevant.

The findings then were organized according to the students' understanding of each of the three sub constructs (change of properties, rearrangement of atoms, and mass conservation), and associated sub-levels at three points in time, the beginning, middle, and end of the unit's instruction. The outcome is presented in the next chapter.

Chapter 4

Results

This chapter presents the findings of the student interviews and tests. In addition to giving the overall findings, this chapter highlights what students understood about chemical reaction and what difficulties they experienced. The findings are organized according to the students' understanding of each of the three sub constructs (change of properties, rearrangement of atoms, and mass conservation), and associated sub-levels at three points in time, the beginning, middle, and end of the "How can I make new stuff from old stuff?" (Stuff) (Krajcik, McNeill, & Reiser, 2008; McNeill et al., 2004) unit's instruction. Although all three sub-constructs are related and collectively contribute to the understanding of chemical reaction, the different sub-constructs will be discussed separately (for analytic purposes) over time. The reason for this organizational strategy is that the construct maps are the foundation of this research. Following the results for each sub-construct, the results will be pulled together to reveal student understanding of chemical reaction over time.

Section one discusses student understanding of the first sub-construct, change of properties, at the three points in time in the curriculum. It also discusses the associated sub-levels. Section two describes student understanding of the second sub-construct, "rearrangement of atoms", at the three points in time in the curriculum. Section three focuses on student understanding of the third sub-construct, mass conservation, at the three points in time in the curriculum. Each section discusses the interviews and the tests constructed at the three relevant time points. Section four will then summarize all findings over time.

The three points in time discussed here highlight pre-test data collected before the unit's instruction; post-test data collected after completing the unit's instruction; and interview data collected at relevant points. Thus, indications of learning and difficulties of each sub-level could be found only in reference to the relevant sub-levels that were discussed in the interviews.

In addition to the quantitative and qualitative data related to the sub-constructs, additional interesting findings emerged, although not directly related to any of the specific sub-levels of the construct maps. These additional findings are still worthy of discussion and will be presented in the Appendices (Appendix C).

Figure 4.1 displays the organization of the findings throughout the Results chapter. Periodically, I will refer to this Figure to indicate to the reader which aspects of the results are being discussed.

Results

Step 1 — Section One: Sub-construct 1 - Change of Properties
- 1.1 Time 1 (before instruction)
- 1.2 Time 2 (during instruction)
- 1.3 Time 3 (after instruction)

Step 2 — Section Two: Sub-construct 2 - Rearrangement of Atoms
- 2.1 Time 1 (before instruction)
- 2.2 Time 2 (during instruction)
- 2.3 Time 3 (after instruction)

Step 3 — Section Three: Sub-construct 3 - Mass conservation
- 3.1 Time 1 (before instruction)
- 3.2 Time 2 (during instruction)
- 3.3 Time 3 (after instruction)

Step 4 — Section Four: Summary of Results
- 4.1 The research questions
- 4.2 Visualization trends over time

Figure 4.1: The organization of the findings throughout the Results chapter

Section One: Sub-construct 1 - Change of Properties that Occur as a Result of a Chemical Reaction

Section one discusses student understanding of the first sub-construct, “change of properties”, at the three points in time in the curriculum (Step 1 in Figure 4.1). It also discusses the associated sub-levels.

Overall, prior to the curriculum experience or at the very beginning of the unit’s instruction, students had limited knowledge regarding the “change of properties” sub-construct. More specifically, students used properties to describe substances, but in general they used everyday terms rather than scientific terminology and they had problems distinguishing properties from non-properties. Students were not yet able to explain that properties could be used to distinguish one substance from another, and could not clarify that one property is not enough to distinguish one substance from another. Students also did not understand that a chemical reaction creates new or different substances with a different set of properties, and most students could not distinguish chemical reactions from mixtures and/or phase changes.

After completing the first part of the curriculum in which the students learned about substances and properties, but before they learned that substances interact to form new substances (i.e., chemical reaction) and conservation of mass, most of the students could provide examples of properties (e.g., density) and could provide example/s of what is not a property (e.g., volume, mass). However, only about half of the students could use the change/no change in size/amount/shape to justify if an attribute is a property or not. Students had a mixed understanding regarding the fact that comparing only one property is not always enough to know if substances are the same or not.

After completing the unit's instruction, most of the students could distinguish properties from non-properties and seemed to understand that a property is a characteristic of a substance. Most of the students also understood that comparing a single property is not enough to determine if two given samples are the same substance or different ones, but thought that as a result of a chemical reaction every single property changes. Most of the students could correlate specific phenomenon with its type, namely, chemical reactions, mixtures, or phase changes.

Overall findings are summarized in Table 4.1 at the end of this section. Here, I further elaborate the findings and provide evidence to support the claims made about student understanding at the three relevant time points. Claims have been numbered for clarity.

Time 1 (Change of Properties): Before or at the very beginning of the unit's instruction.

This section discusses students understanding of the "change of properties" sub-construct revealed from the pre-test and from the pre-interviews (Step 1.1 in Figure 4.1). Overall, prior to the experience of the curriculum (or at the very beginning of the unit's instruction) students had not yet mastered any of the levels in the "change of properties" construct map (Figure 3.1).

Level 1: A property is a characteristic of a substance (Time 1).

This section discusses student understanding of the first level of the change of properties construct map before or at the very beginning of instruction.

1) Students used properties to describe substances. This is seen in the pre-interviews where all students could describe the sugar substance. The most common descriptions of the sugar were: white (all students), grainy (two-thirds of the students), and shiny (about half of the students). Additional descriptions included: reflective, crystals, like a mineral, cold, and sparkly. Only one student referred to its state of matter in his initial description, saying that it is solid.

2) Most students had difficulties distinguishing properties from non-properties and understanding that properties are consistent and not determined by the amount of the substance. Most students offered, for example, non-properties such as mass and volume as properties. A student explained, for example, "if the masses are different, you can tell that they are not the same substance", and another student thought that color is not a property, saying that "the color doesn't necessarily mean anything when it comes it trying to see if they are the same substance."

Level 2: Different substances have different set of properties (Time 1).

This section discusses student understanding of the second level of the change of properties construct map before or at the very beginning of the unit's instruction.

3) Students were not able to explain that properties could be used to distinguish one substance from another. This is seen in the first pre-interview question when students were asked to suggest ways to test if the substance presented to them is sugar. Although all students mentioned the color (white) in their description of the substance, only two students suggested color as a possible test to identify the substance. Some students suggested tests such as smell, taste (if allowed), but most of the students did not know what to do with this data (e.g., should the data be compared with a known substance).

4) Students were not able to explain that one property is not enough to distinguish one substance from the other. Most of the students had not yet mastered the idea that in order to distinguish between substances different properties need to be considered rather than only one property. Only one student mentioned in her pre-interview that one kind of test is not enough. In the pre-interviews, for example, students were asked how they could test if the sample presented to them is sugar or not. Most of the students suggested tasting it (if allowed) or suggested smelling it. Only one student explained that we need more than one test saying that "we could check for if they smell the same, if sugar and the substance smell the same. …I would probably do some more tests that I don't really know what they are yet because we are still running them. But, I would probably assume that it was sugar."

Level 3: A chemical reaction results in new substances with a new set of properties (Time 1).

This section discusses student understanding of the third level of the change of properties construct map before or at the very beginning of the unit's instruction.

5) Students did not understand that a chemical reaction creates new or different substances with a different set of properties. Only one question on the pre-test, question 1 (Figure 4.2), focused on this idea. Specifically, in that question students were asked to choose what they should measure to determine if a chemical reaction had occurred.

1. To determine if a chemical reaction occurred, you should measure and compare which of the following?

a. volume of the materials
b. shape of the products
c. properties of the substances
d. mass of the reactants

(Correct answer: c)

Figure 4.2: Question 1 on the pre/post tests

About half of the students chose the correct answer (properties of substances) and the other half of the students chose volume, shape, or mass, which are examples of non-properties as they change with the amount of the substance and cannot indicate a chemical reaction. Furthermore, choosing only one measurement reveals that even if those measurements were properties, students still did not understand that they need to consider a set of properties as opposed to only one. This is of course a cautious claim since the data is based only on one pre-test question.

Level 4: A chemical reaction can be distinguished from phase changes and/or mixtures (Time 1).

This section discusses student understanding of the fourth level of the "change of properties" construct map before or at the very beginning of the unit's instruction.

6) At this point many students could not distinguish chemical reactions from mixtures and/or phase change. In pre- interview question 5, for example, students were asked how to change sugar solid to liquid and about one-third of the students suggested putting the sugar in water. A typical response for those who suggested this was: "you could put it in water and it would dissolve." Another student suggested that he could "add water… or any sort of solvent." Another student explained: "the molecules in the sugar were like, because it got so hot that it let go. So some molecules got out into the water, becoming a liquid." When asked about how can we change it back to solid, the student said "you could like remove the heat from the glass by like putting it outside or something, and then it will become a solid again by removing heat it becomes colder and like freezing the water becoming a solid once again." When asked what she means by removing heat, the student said "making it colder. Like putting it in a refrigerator… it'll become ice, which is a solid." Then, when asked how to get the sugar solid she said that she is not sure. This struggle to understand phase change was also seen in pre-test, in which distinguishing chemical reactions from mixtures and/or phase change was very problematic for students, which is, of course, understandable at this point in the curriculum. Students had difficulties with all the three questions that were associated with this idea. Specifically, question 5 was the hardest question for students in the pre-test (13% answered correctly). The question provided examples of phenomena (mixing

lemonade powder with water, burning marshmallows over a fire, melting butter in a pan, and boiling water on a stove) and asked which one is an example of a chemical reaction. The most common mistake (62%) was thinking that "mixing lemonade powder with water" is a chemical reaction, and the second common mistake (16%) was thinking that "boiling water on a stove" is a chemical reaction. These responses indicate that when the students took the pre-test they were not yet familiar with the different types of phenomena and clearly had difficulties in distinguishing chemical reactions from mixtures and/or phase changes. This was consistent with students' responses to two other questions about this idea, questions 20 and 22, which a minority of students answered correctly (40% and 47% respectively). Question 20 asked about the bubbles that appear when an electric current is passed through water. The most common statement here was thinking that those bubbles are "air" (27%). Question 22 was very similar to question 5, but focused on different phenomenon. On this question the most common mistake was considering "the melting of ice" as a chemical reaction.

Time 2 (Change of Properties): During the unit's instruction.

This section discusses students understanding of the "change of properties" sub-construct revealed from the mid-interviews[6] (Step 1.2 in Figure 4.1) identifying what students understood at the mid-point in the curriculum and identifying what difficulties they hold.

[6] The mid-interviews were conducted after the students completed the first part of the curriculum in which they learned about substances and properties, but before they learned that substances interact to form new substances (i.e., chemical reactions) and conservation of mass.

Level 1: A property is a characteristic of a substance (Time 2).

This section discusses student understanding of the first level of the “change of properties” construct map at the mid-point of instruction.

At this point students seemed to have a general idea that a property is a characteristic of a substance. However, the data reveals some gaps in their understanding.

1) Most of the students could provide examples of properties (e.g., density) and could provide example/s of what is not a property (e.g., volume, mass). In the mid-interviews, for example, most of the students could articulate that volume alone is not enough to decide if two rings that look alike are made of the same substance, explaining that we also need to know the mass. While most of them explained that the mass by itself is also not enough, and we need to calculate the density based on the mass and the volume, a few students did not explicitly use the term density, but their explanations made it apparent that they were taking both volume and mass into consideration. Although most of the students indicated that they also need to check the density, some of them could not clarify why density provides information different from only volume or mass. One student, for example, was asked why she thinks that she should check the density, not only mass or only the volume. She said that “because the density is kind of like a final answer… it shows both mass and volume.” She knew that it gives more information, but did not refer to density as something that does not change with the amount or is consistent throughout the substance.

2) Students had a mixed understanding with respect to the idea that a property is size/amount/shape independent. While some students can use the change/no change in size/amount/shape to justify if an attribute is a property or not, many students

had difficulties. None of the students at this point used the notion of consistency or inconsistency throughout the substance as evidence to justify whether an attribute was a property or a non-property. Although most of the students knew that density is a property and explored this idea in class, a few students (3 out of 16) were still confused, thinking that density does change with the amount. One student, for example, who explicitly said that he was told in class that density is a property expressed his confusion and said that because density depends on the mass it does change with the amount. He said that "you would want to test more properties because the mass, which is part of the equation for density, changes depending on the size. That means the density could also change depending on size. Hardness cannot. Hardness can't change no matter what. But some other properties could change. So you would want to test." Two students could not use the change/no change in size/amount to explain if mass is a property. Both students could clarify that volume can change with the amount, but thought that they also need mass because mass does not change. One of the students explained, for example, "It doesn't really necessarily matter whether you find the mass or the density. Because if the masses are different, you can tell that they are not the same substance."

3) Another student difficulty was thinking that different substances cannot share the same properties, especially when the property is not familiar from every-day life. In mid-interviews, for example, students were asked whether "crad" is a property based on given data. One-third of the students thought that it was not a property because two different substances share the same values. A typical explanation was that it is "not a property because it is the same for two different things", or "it's not a property because they (nickel wire and copper wire) are two different substances that have the same crad of

31.” Student intuitive understanding is understandable since normally, two substances do not share exact same properties, but it is still possible; for instance, two substances could have the same color.

4) Students did not have difficulties understanding that a property refers to the material that the object is made of and not its use. When students were asked if “crad” is a property based on a given list of objects and the measures of their “crad”, only one student explained that “crad” is a property because the copper wire and the Nickel wire have the same values. About half of the students (7 out of 16) answered correctly, saying that it is not a property since two objects that are both copper, have different “crad” values. A typical response was: “I don’t think it is a property because two things that are copper are different.” In another question students were given a list of objects and their “specific heat” and were asked whether or not “specific heat” is a property. To clarify that specific heat is a property students needed to refer to (1) the specific heat measurements of a nickel wire and nickel door handle, which are the same because they are made of the same substance, nickel, and (2) are different from the specific heat measurements of objects that are made of different substances. About two-third of the students (10 out of 16) could explain that based on the data, specific heat is a property, but only four of them mentioned both pieces of evidence, that (1) two nickel items have the same value, and (2) the value is different from other substances. The other six students used only the first piece of data (the same values for both nickel items). No one used the second piece of evidence only.

Level 2: Different substances have different set of properties (Time 2).

This section discusses student understanding of the second level of the "change of properties" construct map at the mid-point of instruction.

5) Students had a mixed understanding regarding the fact that comparing only one property is not always enough to know if substances are the same or not. Slightly more than half of the students (9 out of 16) could clarify that when a single property differs the substances are different; however, if a single property is the same for two samples, more tests need to be done to determine whether the samples are the same substance. However, almost half of the students (7 out of 16) thought either that a single property is always insufficient (2 students) or that a single property is always enough (5 students). This group of students did not refer to the actual value of the single measurement, whether or not the measurement values of two items are the same (and then more tests are needed) or different (and then the items are made of different substances).

Level 3: A chemical reaction results in new substances with a new set of properties (Time 2).

Mid-interviews did not deal with this sub-level.

Level 4: A chemical reaction can be distinguished from phase changes and/or mixtures (Time 2).

Mid-interviews did not deal with this sub-level.

Time 3 (Change of Properties): After completing the unit's instruction.

This section discusses students understanding of the "change of properties" sub-construct revealed from the post-test and from the post-interviews (Step 1.3 in Figure 4.1). Overall, there was a noticeable increase in students' understanding that properties changed as a result of chemical reactions. Even so, by the end of the unit's instruction, students still had some difficulties. Student understanding of properties is described below in terms of the sub-levels of the construct map.

Level 1: A property is a characteristic of a substance (Time 3).

This section discusses student understanding of the first level of the "change of properties" construct map after completing the unit's instruction.

1) Overall, by the end of the curriculum most of the students could distinguish properties from non-properties and seemed to understand that a property is a characteristic of a substance. But as can be seen in the post-interviews, some students still struggled to understand this idea. In their responses to questions 16 and 17, for example, about one-third of the students considered volume and mass as properties when asked to give examples of properties.

Level 2: Different substances have different set of properties (Time 3).

This section examines student understanding of the second level of the "change of properties" construct map after completing the unit's instruction.

2) Overall, most of the students understood that comparing a single property is not enough to determine if two given samples are the same substance. Question 3 on the post-test, for example, asked the students to choose which of the four given methods a

student needs to use to figure out if the two green powders that he found are the same or different. The majority of the students (93.5%) answered correctly that he needs to "determine the density, solubility, and melting point of each powder and compare."

Level 3: A chemical reaction results in new substances with a new set of properties (Time 3).

This section describes student understanding of the third level of the "change of properties" construct map after completing the unit's instruction.

3) Most of the student could state that properties change as a result of a chemical reaction, but could not elaborate why; i.e., could not make a connection to the formation of a new substance with a new set of properties. In question 17 on the post-interviews, for example, students were given a scenario in which a test tube was half filled with vinegar. Baking soda was placed in a balloon that was fit onto the opening of the test tube, while making sure that the balloon contents were not released into the test tube. The contents were then released into the test tube, and the balloon inflated (see Figure below labeled "after").

Before After

Students then were asked if the properties of the system before and after the balloon inflated were the same/different and why. Most of students (two-thirds) thought that after the balloon inflated properties would change because of the chemical reaction, but only about half of them (about one-third of all students) could make the connection to a new substance with a new set of properties. Two of those students also referred back to the specific example, saying that the balloon inflated, meaning that a gas was created. The second half of that group of students (about one-third of all students) could only state that the properties changed because of the chemical reaction, but could not elaborate any further, and could not make a connection to the formation of a new substance with a new set of properties. One of those students was asked if there were any indications for a chemical reaction and she said that she does not know. Also, when explicitly asked if a new substance was formed, she said that she does not know, meaning that she could state that properties change, but did not make the connection to the formation of a new substance with a new set of properties.

The rest of the students (about one-third) thought that the properties would not change. A student explained, for example, that the properties will not change “because it’s still all in there because when you change states, it does not change mass.” Meaning, the student considered mass to be a property. Another student said that properties would stay the same and then said that some would change. The student then was asked what properties would change. He said that “volume obviously changed because it inflated.” When he was asked if volume is a property, he said that yes, volume is a property “because it affects the density and density is a property and you can tell if the mass is the same, let’s say the mass for water and alcohol is the same, the volume could be different to make depending on the density.” Both students had difficulties understanding that mass and volume are not properties while density is a property although mass and volume are components of the density equation; this is a hard, abstract transfer task for them.

In summary, at this point in the curriculum about one-third of the students thought that properties change and could support their decision with the formation of a new substance. About one-third of the students could only state that the properties changed, but could not provide a reason for their choice, and one-third of the students thought that the properties would stay the same; most of the latter group were also confused between what is and what is not a property, thinking that volume and mass are properties.

4) Many students still maintained that as a result of a chemical reaction every single property changes, and did not yet understand that new substances have different sets of properties. In question 17 on the post-interviews, for example, students were asked if after a balloon was inflated, as result of mixing vinegar and baking soda, the properties changed. Only one student mentioned that we should check several properties, because it is possible that one property, such as color, will not change. If we check a set of properties, some of them will sure change.

Level 4: A chemical reaction can be distinguished from phase changes and/or mixtures (Time 3).

This section discusses student understanding of the fourth level of the "change of properties" construct map after completing the unit's instruction.

5) Overall, by the end of the unit's instruction, most of the students could correlate a specific phenomenon with its type, namely, chemical reactions, mixtures, or phase changes. This might be because it was stressed in the class. In the conclusion discussion of the unit, the teachers provided, for example, a nice summary table organizing similarities and differences between chemical reactions, mixtures, and phase

changes accompanied by specific examples as relevant. Question 5, for example, was the most difficult one (12.7% successfully answered) on the pre-test, but by the end of the course instruction, 87% of the students answered it correctly, reflecting no major problems with understanding at the end of the unit's instruction. The question asked students to choose which of the given phenomenon is an example of a chemical reaction. The correct answer was "burning marshmallows over a fire", where the other alternatives were either mixture ("mixing lemonade powder with water"), or phase change ("melting butter in a pan" and "boiling water on a stove"). In another question (question 20) on the post-test students were asked to choose what bubbles appear as a result of an electric current being passed through water. Eighty-one percent of the students answered correctly, "oxygen and hydrogen gases." Since this was a classroom activity, it is not surprise that most of the students answered correctly. The more dominant mistake was "water vapors" (9%) and the rest of the wrong answers were distributed evenly among the other two choices, "air" and "heat" (5% each). Question 20 was relatively poorly answered on the pre-test (40%), but by the end of the unit instruction 81% of the students answered the question correctly. Although most of the students answered correctly, difficulties persist among one-fifth of the students, half of whom did not understand that an electric current causes a chemical reaction or still confused products of a chemical reaction (oxygen and hydrogen gases) and those of phase change (water vapors). The other students incorrectly thought that the bubbles are air or heat.

As a whole, at this point, the majority of the students could differentiate chemical reaction from phase changes; however, an indication of difficulty with that idea among a few students was seen in the post-interviews. In question 16 of the post-interviews, for example, students were given a scenario in which a piece of wood was placed on a scale (in fireproof containers), set on fire and burned to a powder. The students were then asked if the properties of the system before and after burning the wood the same/different and why. One student (out of 16) thought that there was no chemical reaction "because it's just a phase change from wood to ash, it's not a new substance, it's still wood, it's just burned."

Table 4.1: Student understanding of the "change of properties" sub-construct at the three time points in the curriculum.

"Change of properties" Sub-levels	Time 1: Starting-point understanding	Time 2: Mid-point understanding	Time 3: End-point understanding
Level 1: A property is a characteristic of a substance	Students used properties to describe substances, but had problems distinguishing properties from non-properties.	Most of the students could provide examples of properties and of what is not a property. While some students could use the change/no change in size/amount/shape to justify if an attribute is a property or not, many students had difficulties. Another student difficulty is thinking that different substances cannot share the same properties, especially when the property is not familiar from every-day life. Students did not have difficulties understanding that a property refers to the material that the object is made of and not its use.	Most of the students could distinguish properties from non-properties and seemed to understand that a property is a characteristic of a substance. But, about one-third of the students still struggled, considering volume and mass as properties.

Level 2: Different substances have different set of properties	Students were not able to explain that properties could be used to distinguish one substance from another, and not that one property is not enough to distinguish one substance from the other.	Students had a mixed understanding regarding the fact that comparing only one property is not always enough to know if substances are the same or not.	Most of the students understood that comparing a single property is not enough to determine if two given samples are the same substance or not.
Level 3: A chemical reaction results in new substances with a new set of properties	Students did not understand that a chemical reaction creates new or different substances with a different set of properties.	X	Many students thought that as a result of a chemical reaction every single property changes.
Level 4: A chemical reaction can be distinguished from phase changes and/or mixtures	Students could not distinguish chemical reactions from mixtures and/or phase change	X	Most of the students could correlate specific phenomenon with its type, chemical reactions, mixtures, or phase changes.

* X indicates that this sub-level was not dealt with

Having discussed the "change of properties" sub-construct, I now turn my attention to the next related sub-construct, the "rearrangement of atoms", to more fully reveal student understanding of chemical reaction.

Section Two: Sub-construct 2 - Rearrangement of Atoms during a Chemical Reaction

Section two describes student understanding of the second sub-construct, "rearrangement of atoms", at the three points in time in the curriculum (Step 2 in Figure 4.1).

Overall, prior to the curriculum experience or at the very beginning of the unit's instruction, the majority of the students did not yet master any of the levels in the "rearrangement of atoms" construct map. Some students, however, did have some background knowledge about the basis of the particulate nature of matter. Generally, understanding was mixed with respect to what constitutes matter, which is necessary for a solid understanding of the basis of the particulate nature of matter. Some students could use scientific terms to describe what matter is made of, but the majority of the students struggled to distinguish different types of particles, such as molecules and atoms. Many students were confused about whether molecules are made of atoms or vice-versa. All the students also had difficulties with understanding pure substances thinking that pure substances necessarily consist only of molecules of one type of atom. Among the students there was a mixed understanding in regard to phase changes and that heat must be added/removed to cause a change of state of matter. Many students were confused between phase change and mixtures as they suggested adding water in order to change sugar solid to liquid, and were confused between chemical reactions and phase changes at the microscopic level. None of the students had any background regarding the arrangement of atoms within a molecule and that during chemical reactions atoms are rearranged and create new combination/s of atoms. The study also revealed other gaps in understanding such as attributing properties of macroscopic substances to microscopic particles. Students also were not yet familiar with scientific terminology such as state of matter, reactants, and products, which are necessary later on for a solid understanding of chemical reactions.

After completing the first part of the curriculum in which the students learned about substances and properties, but before they learned that substances interact to form new substances (i.e., chemical reaction) and conservation of mass, students had difficulties understanding that molecules of different substances are different. Students also had difficulties picturing atoms and molecules and estimating their size. Many students still had difficulties distinguishing between atoms and molecules.

After completing the unit's instruction, students overall seemed to understand that a substance is made of the same types of atoms throughout. Students still had difficulties understanding that a pure substance is made of one type of molecule that has a fixed composition of one or more different types of atoms and does not necessarily consist only of molecules of one type of atom.

Most of the students could differentiate between atoms and molecules at the microscopic level (model), but could not fully understand the symbolic level (chemical equation), which is also not expected at the middle-school level. Generally, most of the students understood that a chemical reaction results in a rearrangement of the atoms and the formation of new combinations. Further, referring to a 3D balls and sticks model, most of the students were able to demonstrate the differences between a chemical reaction and a mixture. Two-thirds of the students (10 out of 15), for example, could demonstrate that in contrast to a chemical reaction where molecules break apart and atoms re-arrange to form new molecules, in mixture, molecules remain unchanged.

Overall findings are summarized in Table 4.2 at the end of this section. Here, I further elaborate the findings and provide evidence to support the claims made in relation to student understanding at the three relevant time points. Claims have been numbered for clarity.

Time 1 (Rearrangement of atoms): Before or at the very beginning of the unit's instruction.

This section discusses students understanding of the "rearrangement of atoms" sub-construct revealed from the pre-test and from the pre-interviews (Step 2.1 in Figure 4.1). Overall, prior to the experience of the curriculum (or at the very beginning of the unit's instruction) students had not yet mastered any part of the "rearrangement of atoms" construct map (Figure 3.2).

Level 1: Basis of particulate nature of the matter (Time 1).

This section discusses student understanding of the first level of the "rearrangement of atoms" construct map before or at the very beginning of the unit's instruction.

1) Students could describe what materials looked like, but they used everyday terms rather than scientific ideas. For instance, when asked in the pre-interviews what state of matter the stuff is, most of the students did not know what "state of matter" meant. After being prompted they could tell easily that the stuff presented to them is a solid.

2) Generally, understanding was mixed with respect to what constitutes matter (necessary for a solid understanding of the basis of the particulate nature of matter). In question 3 of the pre-interviews, for example, there was disparity in students' descriptions of to what sugar is made of. Students' responses can be divided into two main groups as follows:

a. About one-third of the students (5 out of 16) used no scientific terms such as molecules, atoms, or particles (4 students) or used only the particles term (1 student) without any further specifications. Three students, for example, said that sugar is made of stuff/something like sugar, but smaller, and two additional students just said that they do not know.
b. The remaining students (about two-thirds) used scientific terms, thinking that sugar is made of molecules (5 out of 16) or that the sugar is made of molecules and atoms (4 out of 16) or that the sugar is made of atoms that are made of molecules (2 out of 16, mixed up the hierarchy of atoms and molecules). However, the majority of them could not accurately describe what atoms and molecules are or distinguish between them, or indicate a hierarchy such as molecules are made of atoms or vice-versa. Students displayed several types of misunderstanding. Specific examples are provided in the next level (level 2) that explicitly highlights the difficulties when distinguishing different types of particles.

3) Student understanding with respect to what is in between the molecules ranged approximately equally between nothing/space, energy, air, and do not know/not sure.

4) There was mixed understanding with respect to the idea that heat must be added/removed to cause a change of state of matter. In pre-interviews, when students were asked what they could do to change sugar solid to a liquid (question 5) only about two-thirds of the students (10 out of 16) suggested adding heat, while the rest of the students (6 out 16) suggested putting the sugar in water. This clearly shows that students had difficulties understanding phase changes, which is necessary for a deep understanding of the particulate nature of matter. Out of the ten students who suggested adding heat, seven could also suggest ways to do it, such as in a microwave, in a pan over the stove, using a hot plate and a beaker, or putting a match under it, but 3 students were not clear about how to do it. After being prompted, one of them said "just warm it."

5) All students, even students who appeared to be the most knowledgeable, revealed lack of understanding that a pure substance is one made of a single type of molecule that has a fixed composition of one or more different types of atoms and does not necessarily consist only of molecules of one type of atom. To understand this, students need to have learned the basis of the particulate nature of matter, which, as seen in the pre-test was difficult for students. Pre-test question 25 (see Figure 4.4), for example, dealt with the understanding of pure substances. In this question, students were given diagrams of pure substances and mixtures and were asked to choose which of the diagrams represents a pure substance. Slightly more than twenty percent of the students answered correctly. Just over forty percent of the students chose D, which refers to a diagram of a pure substance, consisting of molecules with two identical atoms, but this was not the only pure substance alternative. The correct answer included this diagram and another one that consists of molecules of more than one type of atom. Students who did

not choose the latter diagram probably thought that pure substance consisted of molecules of one type of atom only.

Difficulty in regard to pure substances was also seen in the pre-interviews amongst those students who seemed to be the most knowledgeable and were queried about it. Two students who seemed to have a solid understanding of basic understanding of the two bottom levels of the construct map were asked supplementary questions beyond the original interview protocol. This supplementary portion of the interview revealed their difficulties with respect to pure substances. Both students thought that a pure substance consists of only one type of atom. One of the students offered an example saying that "pure hydrogen would only be made out of hydrogen atoms" and when she was asked if carbon dioxide, which is made of CO_2 molecules only, would be a pure substance, she said that "it would not be a pure substance because it would have both carbon and oxygen." In reference to the sugar model the other student explained that this is not a pure substance because "a pure substance would be, for instance, all reds. Or, they would be made up of one atom, all the way through." In a follow-up question he was asked if the molecule would be the same molecule if the balls were moved to different positions and he thought that it would be the same molecule. Those two students correctly answered all the questions in the planned interview protocol and knew that molecules were made of atoms and could recognize three different types of atoms in the 3D model, but had difficulties answering the questions that were beyond the original set of interview questions, specifically in relation to understanding pure substances and with understanding that a different arrangement of atoms within a molecule changes the molecule. Thus, it seems reasonable to assume that if those two solid students struggled with the concepts, other students would have as well; however, I did not probe this.

6) None of the students could estimate the number of molecules in a sample of a material. When asked how many molecules are in each grain of sugar the answers ranged from 2-3 molecules (about one-third of the students) to a thousand and all the way to about a million (about half of the students). None of the students said more than millions. All of the students mentioned, however, that is the molecules are too small to see it in a naked eye. This understanding; however, is not expected in middle-school, but only in advanced grades.

7) Students attributed properties of macroscopic substances to microscopic particles. Many students assigned macroscopic properties to microscopic particles, such as wet molecules. In the pre-interviews, for example, a student pointed to a sugar 3D molecular model that was presented to her saying that “the white things are probably what would give it the sweetness.” Difficulty in regard to assigning properties of macroscopic substances to microscopic particles was also seen in the pre-test. In question 14, for example, students believed that a water molecule is liquid and a molecule of salt is solid. Students were asked to choose the right explanation for why water (H_2O) cannot be turned into salt (NaCl) through a chemical reaction. Students’ responses distributed evenly among 2 of the 4 choices (36% each), the correct answer, “salt and water are made of different atoms” (alternative B), and one of the wrong explanations saying that “water contains liquid atoms and salt contains solid atoms” (alternative D), revealing a confusion between properties of substances and particles, thinking that atoms can be liquid or solid.

The other two alternatives were not related to this difficulty and also were not problematic since relatively few students chose them (17% and 11%).

Level 2: Differentiating between different types of particles (Time 1).

This section discusses student understanding of the second level of the "rearrangement of atoms" construct map before or at the very beginning of the unit's instruction.

8) Although in the pre-interviews most students could articulate that substances are made of particles or from molecules and atoms, most of them did not yet distinguish between different types of particles, such as molecules and atoms. In question 3 on the pre-interviews, for example, most students had difficulties distinguishing between different types of particles, such as molecules and atoms. All five students who used no scientific terms were asked if they had heard about molecules and atoms, and they said that they had, but do not really know what they mean. One of them could give examples of atoms such as Hydrogen and Oxygen. Of the remaining students who used scientific terms, the majority of them could not accurately describe what atoms and molecules are or the distinction between them, or give any hierarchic levels such as molecules are made of atoms or vice-versa. Students had displayed several types of misunderstanding. When explicitly asked if they know the difference between molecules and atoms all five students that thought that it made of atoms and molecules said that they do not know; they only know that the substance is made of both atoms and molecules. One student who thought that the sugar is made of molecules said, for example, that there are three molecules in water, two Hydrogen molecules and one Oxygen molecule. A

different student described that “there is normally one atom in each molecule.” When he was asked about water he knew that it is consists of “2 Hydrogens and 1 Oxygen”, but insisted that there is one atom in each molecule, showing that he does not understand that Oxygen/Hydrogen are examples of atoms and that there is more than one atom in a water molecule. Another student said initially that molecules are made of atoms, but referred to both molecules and atoms as if they are in the same hierarchic level. When she was asked to clarify what she means, she used water as an example, saying that “the molecule is what I said before, and the atom is the other part. So the H is the molecule and then the O is like the atom and together they are water… The H_2O makes water because molecules and atoms need to form to make water.” One student knew that molecules are made of atoms, but thought all of the atoms are identical. A student who switched between the atoms and molecules hierarchic levels explained, for example, that “if you put two molecules together it can make an atom.”

This difficulty distinguishing different types of particles was also shown in other questions. In question 4 of the pre-interviews, for example, students were presented with a molecular structure (and a 3D model consisting of balls and sticks) of a sugar molecule and were asked to describe the sugar molecule. A student pointed to the model and explained that he sees three types of molecules there, white, red, and black, and another student said that it made of “lots of sugar molecules”, although he was explicitly told that the model represents one sugar molecule. Another student who was asked to describe the sugar molecule model said: “there are smaller ones and bigger ones. So, I guess there could be smaller molecules that support the bigger molecules.” When asked to be more specific about how many different types of balls she sees in the model, she said that there are two types of balls, referring only to the size of the balls (2 sizes) and not to its colors (3 different colors): "there are smaller ones and bigger ones. So, I guess there could be smaller molecules that support the bigger molecules… I see like two different categories of molecules, which is red and black and the whites are a different category of molecule." When asked what she means by molecules, she pointed to the model referring to each ball as representative of a molecule and explained that "the red and the black are different types than the white." This student most likely did not know that we use color to distinguish atoms in the model, which is customary in chemistry education. This understanding is expected prior to the unit's instruction.

Level 3: A chemical reaction results in new substances with a new arrangement of atoms (Time 1).

This section discusses student understanding of the third level of the "rearrangement of atoms" construct map before or at the very beginning of the unit's instruction.

9) Students struggled with understanding that during chemical reactions atoms are rearranged and create new combination/s of atoms. This was seen in questions 2 and 10 on the pre-test, which are very similar questions yielding similar results. In both questions students were asked about possible products for given reactants. Question 2 presented the reaction at the symbolic level, using chemical formulas, while question 10 presented the reaction at the model level, using pictures (2D) of a balls and sticks model. For both questions 30% of the students chose the product to be exactly the same as the reactants, but in a different order, meaning $A+B \rightarrow B+A$, showing that they did not

understand that the molecules needs to break up and re-combine in a different way, and also that the order of the reactants/products does not make a difference.

Level 4: A chemical reaction can be distinguished from phase changes and/or mixtures (Time 1).

This section discusses student understanding of the fourth level of the "rearrangement of atoms" construct map before or at the very beginning of the unit's instruction.

10) Students struggled with distinguishing between chemical reactions and phase changes at the microscopic level. On the pre-test, for example, students were asked (question 19) to choose what will happen to the number of atoms as a result of a burning reaction and to support their choice with an explanation. A few explanations (3 out of 26 relevant explanations) involved confusion between burning reactions and evaporation. Students wrote, for example, "Because the molecules probably evaporated when it got put on fire" or "because the atoms flew up into the air and evaporated."

Time 2 (Rearrangement of atoms): During the unit's instruction.

This section examines student understanding of the "rearrangement of atoms" sub-construct at each level of the construct map, during the unit's instruction, revealed from the mid-interviews[7] (Step 2.2 in Figure 4.1).

[7] The mid-interviews were conducted after the students completed the first part of the curriculum in which they learned about substances and properties, but before they learned that substances interact to form new substances (i.e., chemical reactions) and conservation of mass.

Level 1: Basis of particulate nature of the matter (Time 2).

This section discusses student understanding of the first level of the "rearrangement of atoms" construct map at the mid-point of instruction.

1) Students had difficulties in understanding that molecules of different substances are different. They usually just draw circles to demonstrate molecules, but they did not think that circles of different substances could have different masses. This difficulty was seen on question 11 of the mid-interviews. Students were asked why a helium balloon floats upward. About two-thirds of the students (10 out of 16) used "relative density" in their explanation, saying that the helium balloon moves upward because the density of helium is less than the density of the air in the surrounding environment. The students were then asked to explain the density differences using the particles model. Those who suggested the difference in density between air and helium explained that the differences in density are due to the total number of molecules, either because the helium molecules are more spread out or because there are fewer molecules of helium than of air. Students knew that differences in density were affected by differences in mass, but in their view, more/less mass results only from more/fewer number of molecules. None of the students suggested that it is also possible that the mass of the individual molecules is not the same. After being prompted, only one student suggested that in addition to how tightly the molecules were packed, the molecules could be different, saying that "ones can weigh more because of the mass on its own, well have more mass, because mass on its own isn't a property, but mass in a set volume, which is density. The molecules could be different."
When specifically asked if air molecules weigh the same as helium molecules the

majority of the students (15 out of 16) said that they do not know and some of them added a comment that they never thought that molecules can have different masses. The students also mentioned that they usually just draw circles to demonstrate molecules, but they never thought that circles of different substances could have different masses.

One student only, the same student that suggested that differences in density could be due to different molecules, explained that all the helium molecules are the same because helium is a substance and added that because the composition of air might change, she is not sure if air molecules will be the same throughout the air. She said: "I think for the helium it would be because the helium is a substance, so it's made of the same type of molecules all the way through. I'm not sure about the air because the air would have a lot of different elements in it, but I think that the molecules would be pretty much the same."

2) Students had difficulties picturing atoms and molecules and estimating their size. Students knew that atoms and molecules are really tiny, but still had difficulties in estimating their size, as revealed in the mid-interviews. Students were asked, for example, to estimate the size of atoms compared to other "objects" from everyday life (a bacteria, the width of a strand of hair, and a cell in their body). Most of the students (14 out of 16) knew that atoms are the smallest, but could not estimate how small they are in compared with the other "objects" on the list. They could clarify that the width of a strand of hair is larger since we can see it with the naked eye and that they can see bacteria and cells using a microscope, but cannot see an atom. In a follow-up question, they were asked how many water molecules were in one single drop of water. About one-third of the students said a billion/billions, another one-third said a million/millions, and

the rest of the students said couple of tens/hundreds or that they have no idea. This is a difficult question and 7th grade students are not expected to know how to calculate the specific number of molecules.

Level 2: Differentiating between different types of particles (Time 2).

This section discusses student understanding of the second level of the "rearrangement of atoms" construct map at the mid-point of instruction.

3) Many students still had difficulties distinguishing between atoms and molecules. This, however, is a weak claim since this idea of distinguishing different types of particles was not explicitly asked as a separate item in the mid-interviews, but based on the students' responses on other items it seems that many of them were still confused between atoms and molecules. In the mid-interviews discussion about atoms and molecules, a student was asked, for example, if she could distinguish between atoms and molecules and she said that "not really." All she knew was that "they are both part of a substance, and they keep together a substance." She tried to state that it matters whether there are more molecules or more atoms, but got confused and then just said that she does not know. Another student used atoms and molecules interchangeably referring to the "all the balls together" as an atom and to the separate balls as molecules. This struggle to differentiate different types of particles was also seen in class observations. Toward the end of the second set of the unit, students did an electrolysis experiment in the class. Following the actual experiment, students were asked to create four gumdrop models of water molecules and then to disassemble the four water molecules to make hydrogen and oxygen molecules. Then, the students were asked to draw the models and to count the

total number of hydrogen atoms, the total number of oxygen atoms, and the total number of molecules before and after the electrolysis. Most of the students were very confused, and used the terms atoms and molecules interchangeably. The most common error was counting incorrectly four hydrogen atoms and two oxygen atoms (which is the total number of hydrogen and oxygen molecules) rather than eight and four respectively. This difficulty of distinguishing between atoms and molecules is noteworthy and is consistent with difficulties that are reported in research literature (e.g., Griffiths & Preston, 1992; Harrison & Treagust, 1996).

Level 3: A chemical reaction results in new substances with a new arrangement of atoms (Time 2).

4) Students thought that chemical reactions occur only when there are at least two reactants. This was seen, for example, in class observations. In the second set of the unit, students explored the boiling water phenomena, discussing whether or not boiling water makes a new substance. Students believed that boiling water is not a chemical reaction. Then, they were asked why boiling water is not a chemical reaction and the majority of the class voted that it is not a chemical reaction because there is only one reactant (water). Similar prediction was made before doing the electrolysis experiment. The teacher asked the students to predict if running electricity through water makes a new substance. The majority of the students voted "no new substance" providing two main reasons: (1) there is only one reactant, and (2) adding heat only changes the state of matter, which is not a chemical reaction.

Level 4: A chemical reaction can be distinguished from phase changes and/or mixtures (Time 2).

Mid-interviews did not deal with this sub-level

Time 3 (Rearrangement of atoms): After completing the unit's instruction.

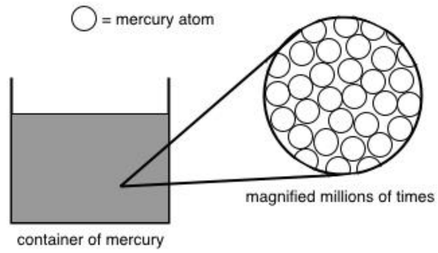
This section examines student understanding of the "rearrangement of atoms" sub-construct at each level of the construct map, after completing the unit's instruction (Step 2.3 in Figure 4.1).

Level 1: Basis of particulate nature of the matter (Time 3).

This section discusses student understanding of the first level of the "rearrangement of atoms" construct map after completing the unit's instruction.

1) Overall, students seemed to understand that a substance is made of the same types of atoms throughout. This was explored in two different questions on the post-test, which a noticeable number of students answered correctly. In Question 4 (Figure 4.3), for example, students were given a diagram and were asked what the diagram represents. Most of the students (92%) chose correctly that the diagram represents a substance.

Question 4:



The model above represents which of the following?

a. a phase change
b. a substance
c. a chemical reaction
d. a mixture

(Correct answer: b)

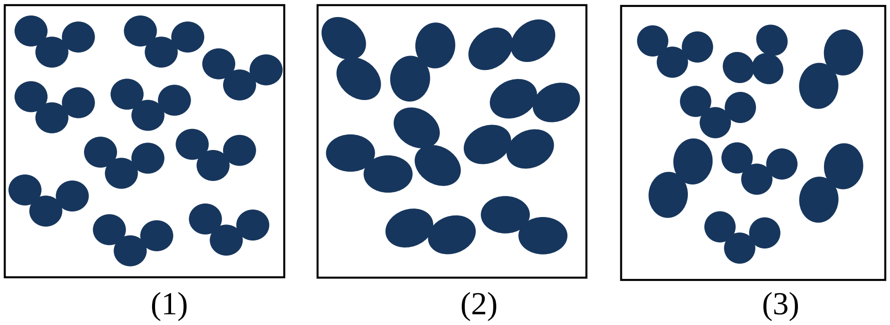
Figure 4.3: Question 4 on the pre/post tests

In question 6, students were asked why a piece of copper is a substance, and most of the students (90%) chose correctly that "is made of the same type of atom throughout." Student understanding was improved throughout the unit's instruction. While on the pre-test one-quarter of the students incorrectly answered that a piece of copper is a substance because it "consists of many different types of atoms", this error was reduced to only a few students (6%) on the post-test.

2) Students still had difficulties understanding that a pure substance is made of one type of molecule that has a fixed composition of one or more different types of atoms and does not necessarily consist only of molecules of one type of atom. This difficulty was seen in question 25 on the post-test (supplementary question, Figure 4.4), which only 45% of the students answered correctly. For this question students were given diagrams of pure substances and mixtures and were asked to choose which of the diagrams represents a pure substance.

Question 25:

The diagrams below represent either pure substances or mixtures.



Which of the diagrams represents a pure substance?

a. 1 and 2
b. 1 and 3
c. 1 only
d. 2 only

(Correct answer: a)

Figure 4.4: Question 25 on the pre/post tests

The dominant wrong answer (40%, alternative d) referred to a diagram of a pure substance, consisting of molecules with two identical atoms, but that was not the only pure substance option. The correct answer (alternative a) included this diagram and another one that consisted of molecules of more than one type of atom. Students who did not choose this diagram probably thought that a pure substance consists of molecules of one type of atom only.

Level 2: Differentiating between different types of particle (Time 3).

This section examines student understanding of the second level of the "rearrangement of atoms" construct map after completing the unit's instruction.

3) Most of the students could differentiate between atoms and molecules at the microscopic level (model), but could not fully understand the symbolic level (chemical equation), which is also not expected at the middle-school level. This was seen,

for example, in the post-interview questions 13 and 14. To probe students' knowledge of the microscopic level of substances, question 13 students were presented with a 3D balls and sticks model of water and alcohol molecules and were asked about the number and types of molecules and atoms showed in the model. Using the models, I checked if by the end of the unit's instruction students could differentiate between molecules and atoms.

Most of the students (11 out of 15) could identify the atoms and the molecules in the model. One student confused the molecules and the atoms, referring to the whole combination of balls and sticks (representing alcohol/water molecule) as an atom and to the individual balls as molecules, saying that there are three types of molecules: the black one, the red one and the white one.

A small number of students (3 out of 15) could not identify atoms and molecules. One student, for example, said that a substance is made of molecules and atoms, but could not identify them correctly. She pointed to the black and red balls in the 3D balls and sticks model as molecules and to the white balls as atoms. It is also possible that the student had representation difficulty (rather than content difficulty) because the students did not use the same kind of model in the class. This, however, it is unlikely because the students used a similar type of model made of gumdrops and tooth sticks.

Except for one student, the students could identify the atoms and molecules in the model and could also count the number and types of the atoms and molecules. The one student who could not count them could, however, point out that the whole combination is a molecule and the individual balls are atoms, but got confused when she was asked how many different types when she was asked to count.

In a follow-up question (question 14) I added student understanding of atoms and molecules at the symbolic level, asking the students to count atoms and molecules in a written chemical equation ($C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$). The IQWST curriculum introduces students to symbolic representations, but does not delve into stoichiometry and balancing equations. An understanding of chemical reactions at the symbolic level is expected only in advanced grades. Student responses varied, but only high achiever students (4 out of 16) were able to correctly count and list the atoms and molecules before and after the chemical reaction.

Figure 4.5 summarizes student understanding at the symbolic level, displaying student success in various tasks in question 14.

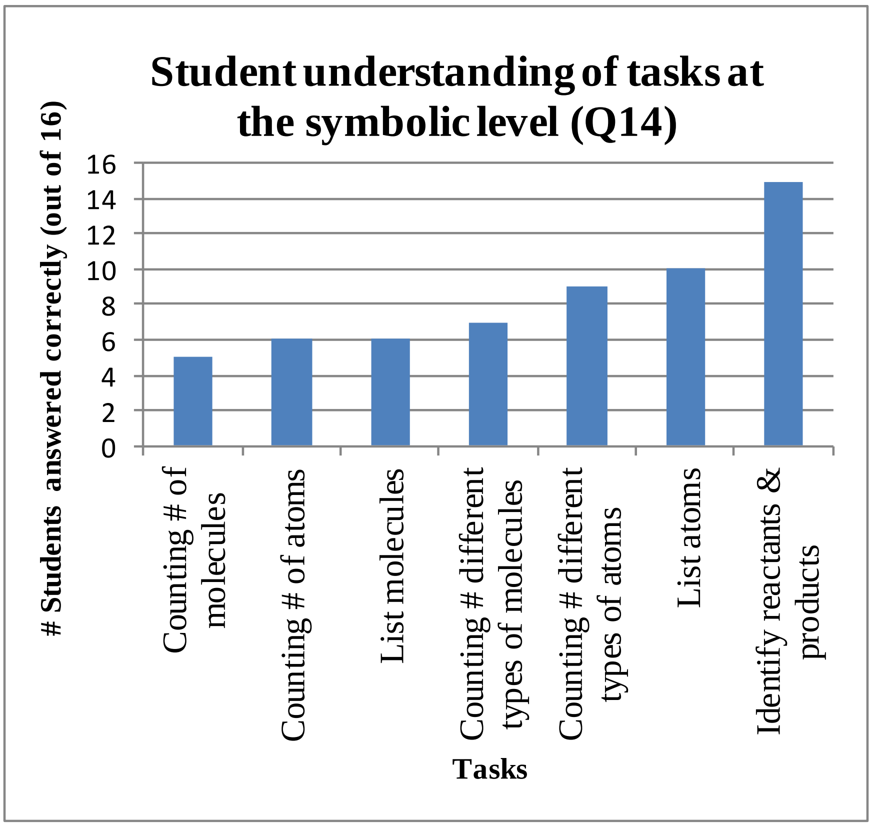


Figure 4.5: Student success in various tasks at the symbolic level

As can be seen in Figure 4.5, the least difficult task in question 14 was identifying the reactants and products in the written chemical reaction. All except one student could do that (15 out of 16). Also, one-quarter of the students (4 out of 16) could identify only reactants and products, but could not provide answers for any other task.

The next least difficult task (question 14) was the ability to list and count the number of different types of atoms. Slightly more than half of the students could list the atoms (10 out 16), and count how many different types of atoms are there (9 out of 16).

The next task (question 14) in term of difficulty level was the ability to count the number of different types of molecules. Slightly less than half of the students (7 out of 16) could do this. Three students incorrectly counted the C_3H_8 as two molecules: C_3 and H_8.

The most difficult task (question 14) was listing the molecules and counting the number of molecules and the number of atoms. Only about one-third of the students could list the molecules correctly (6 out of 16) and correctly counted the number of molecules (5 out of 16) and the number of atoms (6 out of 16). While four out of this latter group of students answered all tasks completely correctly, one student could do all tasks associated with atoms, but gave incorrect answers for all the tasks that were associated with molecules, and an additional student could count molecules, but was wrong about the atoms, thinking that the atoms in C_3H_8 are: C_3 and H_8.

Level 3: A chemical reaction results in new substances with a new arrangement of atoms (Time 3).

This section describes student understanding of the third level of the "rearrangement of atoms" construct map after completing the unit's instruction.

4) Generally, by the end of the unit's instruction, most of the students understood that a chemical reaction results in a rearrangement of the atoms and the formation of new combinations. In question 2 on the post-test, for example, students were given the reactants of a chemical equation (CO_2 + H_2O) and were asked to choose the possible products. The majority of the students answered correctly (H_2CO_3, 87%), and there was no dominant wrong choice. On the pre-test about one-third of the students chose a wrong answer in which the same reactants are listed as the products, but in a different order (H_2O +CO_2). Thus, the difficulty understanding that a chemical reaction results in the formation of new combinations did not exist by the end of the unit's instruction. In a similar question (question 10), students were asked to again choose the products of a reaction, but the reaction was given at the microscopic level (model), not at the symbolic level (chemical equation). Results were very similar. Eighty percent of the students answered correctly. The dominant mistake on the pre-test was choosing the products that are the same as the reactants, but in a different order. This difficulty was reduced from about one-third (28%, pre-test) to one-tenth (10%, post-test) of the students. In another question (question 9), students were asked to identify what happens to atoms in a chemical reaction. Most of the students (80%) chose that the atoms recombine. The other relatively dominant response was that atoms become new atoms (18%). In the pre-test, about one-third of the students (30%) chose that atoms become

new atoms. By the end of the curriculum, this error was reduced, but persists among about one-fifth of the students. In question 14 on the post-test students were asked to choose why water (H_2O) cannot turn into salt ($NaCl$). Most of the students answered correctly (82%) that salt and water are made of different atoms. Yet, one-tenth (10%) of students still incorrectly thought that atoms have a state of matter, choosing that "water contains liquid atoms and salt contains solid atoms" (alternative d). This small group of students assigned macroscopic properties to microscopic particles (atoms). Students, however, had less difficulty compared with the pre-test, in which about one-third of the students (36%) answered incorrectly. In summary, Most of the students understood that a chemical reaction results in a rearrangement of the atoms and the formation of new combinations, but all the questions on this idea had only about 80% of success (one question had 87% of success), meaning that about one-fifth of the students were still struggling thinking, for example, that atoms become new atoms or choosing the products that are the same as the reactants, but in a different order.

Level 4: A chemical reaction can be distinguished from phase changes and/or mixtures at the microscopic level (Time 3).

This section discusses student understanding of the fourth level of the "rearrangement of atoms" construct map after completing the unit's instruction.

5) Referring to a 3D balls and sticks model, most of the students were able to demonstrate the differences between a chemical reaction and a mixture. In question 13 on the post-interviews students were presented with a 3D balls and sticks models, of few molecules of water (H_2O) and a few molecules of ethanol (ethyl alcohol, CH_3CH_2OH).

They were then asked to use the models to demonstrate the formation of the water-alcohol mixture and to demonstrate what needs to be done to produce a chemical reaction between the water and the alcohol.

Two-thirds of the students (10 out of 15) could demonstrate that in contrast to a chemical reaction where molecules break apart and atoms re-arrange to form new molecules, in a mixture, molecules remain unchanged. Students explained, for example, that in the water-alcohol mixture the molecules "were just together, the molecular structure did not change for any of them, they just came together. They are close to each other." In contrast, if there was a reaction "all the atoms will get mixed up between each other, like these might add onto this", or "instead of all of it being separate they would be more mixed together... it's just a mixture, nothing happened to it", but, for a chemical reaction "you would have to rearrange the molecules and the atoms… **y**ou would take them apart and put them back together in different ways." Yet, one-third of the students (5 out of 15) still struggle with differentiating chemical reactions from mixtures at the microscopic (model) level. A few students (3 out of 15) gave unclear explanations and another two seemed to not understand the difference between a chemical reaction and a mixture. One of the students thought, for example, that there is no difference between a mixture consisting of water-alcohol or a chemical reaction between them. For both cases the student suggested "to combine the different substances …to rebuild it."

Table 4.2: Student understanding of the "rearrangement of atoms" sub-construct at the three time points in the curriculum.

"Rearrangement of atoms" Sub-levels	Time 1: Starting-point understanding	Time 2: Mid-point understanding	Time 3: End-point understanding
Level 1: Basis of particulate nature of the matter	Students could describe what materials looked like, but they used everyday terms and not scientific ideas. Generally, understanding was mixed with respect to what constitutes matter using no scientific terms (such as molecules, atoms, or particles) or using scientific terms, but struggling with distinguishing the different types of particles or give any hierarchic levels such as molecules are made of atoms or vice-versa. Students were not yet familiar with scientific terminology such as state of matter, reactants, and products, which are necessary later on for a solid understanding of chemical reactions. Student understanding with respect to what is in between the molecules was divided approximately equally between nothing/space, energy, air, and do not know/not sure. Students had difficulties	Students had difficulties in understanding that molecules of different substances are different and had difficulties picturing atoms and molecules and estimating its size.	Overall, students seemed to understand that a substance is made of the same types of atoms throughout. Students still had difficulties understanding that pure substances do not necessarily consist only of molecules of one type of atom.

	understanding that heat must be added/removed to cause a change of state of matter. Students lacked an understanding of pure substance and attributed properties of macroscopic substances to microscopic particles		
Level 2: Differentiating between different types of particles	The majority of the students struggled to distinguish different types of particles.	Many students still had difficulties distinguishing between atoms and molecules.	Most of the students could differentiate between atoms and molecules at the microscopic level (model), but could not fully distinguish between the two types of particles or count them at the symbolic level (chemical equation), which is also not expected at the middle-school level.
Level 3: A chemical reaction results in new substances with a new arrangement of atoms	Students did not master yet that during chemical reactions atoms are rearranged and create new combination/s of atoms	Most of the students think that chemical reactions occur only when there are at least two reactants.	Generally, most of the students understood that a chemical reaction results in a rearrangement of the atoms and the formation of new combinations.
Level 4: A chemical reaction can be distinguished from phase changes and/or mixtures	Students struggled with distinguishing between chemical reactions and phase changes at the microscopic level	X	Referring to a 3D balls and sticks model, most of the students were able to demonstrate the differences between a chemical reaction and a mixture.

* X indicates that this sub-level was not dealt with

Having discussed the two sub-constructs, the "change of properties" and the "rearrangement of atoms", I now turn my attention to the next related sub-construct, the "mass conservation", to reveal a more complete understanding of student understanding of chemical reaction.

Section Three: Sub-construct 3 - Mass conservation during a chemical reaction

Section three focuses on student understanding of the third sub-construct, "mass conservation", at the three points in time in the curriculum (Step 3 in Figure 4.1). Overall, prior to the curriculum experience or at the very beginning of the unit's instruction, students in general did not yet master any of the sub levels of the construct map. Students had not yet distinguished a closed system from an open one. Results show also lack of understanding "mass conservation" at both the macroscopic and the microscopic levels. In other words, the majority of the students did not yet understand that the total mass before and after a chemical reaction (macroscopic level) and that the total number and type of atoms (microscopic level) stays the same (in a closed system) or change (in an open system) during a chemical reaction.

After completing the unit's instruction, most students were able to choose the type of a given system (closed vs. open), but could explain the difference in only a limited manner. For example, some students referred only to the system set-up or the possibility of material (atoms) leaving/entering the system. Some did not take into account whether or not the mass has been changed. Overall, students understood that in a closed system mass is conserved during a chemical reaction, but still had difficulties understanding the "mass conservation" at the macroscopic level. Many of them did not yet understand how the type of the system (open vs. closed) affects the total mass before and after the chemical reaction. In regards to understanding “mass conservation” at the microscopic level, many students understood how the type of the system (open vs. closed) affects the total number and types of atoms before and after the chemical reaction, but many of them did not yet. Students, for example, thought that the number of atoms and the number of molecules always stays the same because of the “mass conservation law”, or as a result of difficulties distinguishing molecules from atoms had difficulties in understanding that as a result of a chemical reaction molecules change, while atoms do not. Another difficulty, for example, was in understanding that in an open system material can also enter the system, not only leave the system, which are the more familiar examples.

Overall findings are summarized in Table 4.3 at the end of this section. Here, I further elaborate the findings and provide evidence to support the claims in relation to student understanding at the three relevant time points.

Time 1 (Mass conservation): Before or at the very beginning of the unit’s instruction.

This section discusses students understanding of the “mass conservation” sub-construct revealed from the pre-test and from the pre-interviews (Step 3.1 in Figure 4.1). Overall, prior to the experience of the curriculum (or at the very beginning of the unit’s instruction) students had not yet mastered any of the levels in the “mass conservation” construct map (Figure 3.3).

Level 1: A closed system and an open system are different (Time 1).

This section discusses student understanding of the first level of the “mass conservation” construct map before or at the very beginning of the unit’s instruction.

1) Most students were not yet familiar with open and closed systems, their meaning and were not able to distinguish the two types of systems. Question 16 on the pre-test presented students a scenario of burning magnesium and were asked if it occurred in an open or closed system or there is not enough information to decide. The percentage of correct answers in the multiple-choice part shows that most of the students likely guessed. Forty-one percent of the students responded that there is not enough information to decide, and the remaining responses distributed almost evenly between the two types of systems. Specifically, 28% chose an open system (correct answer) and 31% chose a closed system. In this question students were also asked to provide an explanation for their choice. The majority of the students (52 out of 64) wrote that they do not know, or that they were guessing, or did not provide an explanation, or provided an irrelevant explanation. Eighteen students (28%) chose the correct answer that the system is open, but only seven of them showed some understanding in their explanation and the rest probably made a good guess. All seven students that provided a relevant explanation referred to the system set-up, saying that the system was not covered or that fire/oxygen could get in. None of them elaborated the system set-up to mention letting material (atoms) leave/enter the system. They did provide some evidence for closed vs. open systems, but their responses were not complete. One student who answered incorrectly, however, provided an explanation that reflects some understanding. This student compared open and closed systems, saying that “in a closed system, none of the magnesium molecules will escape, so you can gather them up and reweigh them. This isn't true in an open system.” Although he chose the wrong answer on the multiple-choice part, there is evidence that the student knows something about closed and open systems,

referring to the ability to leave the system. He did not mention anything about the ability to enter the system, however. He was also the only student who compared open and closed systems. Together, the percentage of success in the multiple choice part and the weak/missing explanations on the open ended part of the question, show that before starting the instruction (pre-test) the majority of the students did not know what open and closed systems are and could not distinguish the two.

Level 2: The total mass before and after a chemical reaction depends on the type of system (open or closed) (Time 1).

This section describes student understanding of the second level of the "mass conservation" construct map before or at the very beginning of the unit's instruction.

2) Prior to starting the curriculum, the majority of the students did not understand that at the macroscopic level mass is conserved during a chemical reaction or during phase change in a closed system. In the pre-interviews, students were asked (question 5) if the total mass of the sugar before and after phase change (solid to liquid in this example) stays the same. Nearly everyone thought that the mass will change and that the liquid will be heavier than the solid. Only one student said that the mass will be the same, but her response does not reflect an understanding of the topic as she could not support it with a reasonable explanation and her response is inconsistent with her answer to a previous question, in which she suggested adding water to change sugar solid to a liquid. The student said that "it would be the same as long as there are no added liquids." Her two responses are not consistent because if she adds water how can she measure the mass before and after without adding liquids. A student who thought that the mass will

change explained for example that “it would be different because usually like with water… the water expands, and when it melts it is going to be bigger. So yeah, it would probably be more when it’s liquid.” When asked if by “bigger” he means more space or more mass he said both: “I think it would be both because it’s just like the water, it becomes the ice, and it liquefies and it’s huge.” This student is clearly familiar with the freezing process and can make a connection to everyday life and even brought up an example in which a pop can left in his dad’s car froze and almost was almost going to explode. However, he did not interpret this process appropriately, and clearly did not understand that mass is not directly related to the space that the material takes and did not yet understand that mass is conserved during phase change. Another student explained that the mass would be “different, because this is a solid, and if you melt it, it would be a liquid, and so they wouldn’t have the same mass. And mass is not a property so it doesn’t stay the same.” Another student explained that the liquid will weigh more “because sugar is pretty light, and when it’s melted it gets thicker and heavier.”

A lack of understanding of “mass conservation” at the macroscopic level was also seen on the pre-test. In question 7 for example, students were given the total mass before a chemical reaction and were asked to choose what the mass would be after the reaction in an open system and what it would be if the reaction occurred in a closed system. Students’ responses were distributed almost equally among three out of the four alternatives (30% gave a correct answer) showing that students did not yet understand how the type of the system (open/closed) affects the total mass before and after a chemical reaction. On question 11, which provides different statements associated with the conservation of mass at the macroscopic level, students were asked to choose which statement is always true. Student responses were distributed almost equally among all four alternatives, showing that students probably guessed.

3) Students had difficulties understanding that material does not disappear. In the pre-test, for example, students were asked to choose the reason for the weight difference, if any, as a result of a burning reaction (question 18). About half of the students (48%) chose that the mass changed because "some of the burned magnesium disappeared" (Question 18, alternative C). In a follow-up question (question 19) students were asked to choose how the number of atoms will change as a result of a burning reaction and to explain their choice. Almost half of the students who provided a relevant explanation (11 out of 26) to the question thought that atoms can disappear or burned away. Typical explanations were: "when burned, some atoms disappear" or "less because they burned away."

Level 3: In a chemical reaction molecules change, but the number and types of atoms depends on the type of the system (open or closed) (Time 1).

This section examines student understanding of the third level of the "mass conservation" construct map before or at the very beginning of the unit's instruction.

At this point, most students did not yet understand that at the microscopic level the total number and type of atoms stays the same (in a closed system) or changed (in an open system) during a chemical reaction. This lack of understanding of "mass conservation" at the microscopic level was seen, for example, in question 19 on the pre-test, in which students were asked if the total number of atoms will increase, decrease or stay the same as a result of a burning magnesium reaction (in an open system). Very few students (16%) chose that the total number of atoms will increase. The majority of the students (35 students, 55%) said that the mass will decrease and 19 students (30%) said that the number of atoms will stay the same. In this question students were also asked to provide an explanation for their choice. Slightly more than half of the students (38 students, 60%) either wrote that they were just guessing or said that they do not know, leaving the explanation part blank, or provided no relevant explanation. The rest of students (26 students, 40%) provided some relevant explanation, but not necessarily complete one and more than half of the explanations revealed misunderstandings. Specifically, only one student reached the third level in the "mass conservation" construct map and got a full score (level 3). Six students (9%) offered a relevant explanation such as molecules/atoms escaped, but were missing the specific phenomena knowledge, and thought that mass decreases in a burning reaction. Nineteen students (30 %) gave some relevant explanation, but with errors. For example, "atoms burned away/disappear" or "atoms evaporated."

Time 2 (Mass conservation): During the unit's instruction.

Mid-interviews did not deal with this sub-construct (Step 3.2 in Figure 4.1).

Time 3 (Mass conservation): After completing the unit's instruction.

This section examines student understanding of the "mass conservation" sub-construct at each level of the construct map, after completing the unit's instruction (Step 3.3 in Figure 4.1).

Level 1: A closed system and an open system are different (Time 3).

This section discusses student understanding of the first level of the "mass conservation" construct map after completing the unit's instruction.

The analysis of post-interviews and post-test questions that refer to distinguishing the two types of systems (open vs. closed) shows that after completing the unit instructions most students were familiar with the open and closed systems terminology, and were able to choose the type of a given system (closed vs. open), but could explain the difference in only a limited manner. For example, some students referred only to the system set-up or the possibility of material (atoms) leaving/entering the system. Some did not take into account whether or not the mass has been changed. Specific examples from post-interviews and post-test conducted after the completion of the unit's instruction are presented next.

Question 17 on the post-interviews as described earlier (Figure 3.5) provided students a chemical reaction scenario of vinegar and baking soda and asked if the system is closed, an open, or there is not enough information to decide.

The question intentionally does not explicitly specify whether or not mass has changed. At the highest level students are expected to say that the system seems to be closed, but we cannot know for sure unless we obtain mass measurements before and after the balloon was inflated, verifying that the mass of the system did not change. Students at that level were expected, therefore, to choose that there is not enough information to decide if the system is closed and that there is not enough information to decide if the mass has changed and whether or not the number and types of atoms has remained.

Only one student out of 16 chose that there is not enough information to decide because the question does not provide mass data before and after. The student explained that "technically you do not have the data to figure that out yet." The rest of the students thought that the system is closed. After being prompted to consider how sure they are about their decision that the system is closed, four additional students (out of 16) suggested measuring the mass before and after to verify that the system is closed, but only one of them kept referring to the missing mass data when he discussed what will happen to the mass and to the number of atoms, saying that if it is a closed system the mass does not change.

To justify why the system is closed all 15 students referred to either the system set-up (the balloon is airtight and wrapped around the opening of the test tube), or to that nothing can get out (gas cannot escape) or to both pieces of evidence. Seven of them referred to both the system set-up and to the fact that nothing can get out (gas cannot escape). The remaining eight students offered only one of the two explanations; specifically, three students referred only to the system set-up, and five students mentioned only that nothing can get out. None of the students mentioned that nothing can enter the system.

An incomplete understanding of differentiating an open system from a closed one was also seen on the post-test. Students did provide some evidence for closed vs. open systems, but their responses were not complete. These incomplete answers were seen, for example, on questions referring to a given burning magnesium scenario that occurred in an open system where, as a result of the chemical reaction, the mass increased. The scenario was as follows:

Two pieces of magnesium are placed on opposite sides of a scale (on fireproof containers). The scale is balanced, indicating that the weights of each piece are identical. The magnesium on side A is set on fire and burns completely.

Questions 16 through 19 refer to the burning magnesium scenario. Each question is discussed according to the specific discussed sub-level as relevant. In the first post-test question of the scenario (question 16), students were asked if the system is an open system, a closed one, or there is not enough information to decide. In addition to the multiple-part of the question, students were also asked to explain their choice.

The percentage of success on this pre-test question was very low (28%). By the end of the curriculum the percentage increased to 76%, which is a noticeable improvement, but still reflects difficulties. For this question students were also required to provide an explanation for their choice.

This question reflects the first level in the “mass conservation” construct map, namely understanding that a closed system and an open system are different and the ability to distinguish between the two types of the systems, as well as providing relevant evidence.

Student success on the multiple-choice part of the question 16, focusing on the type of system, improved from 28% on the pre-test (18 out of 64 students) to 76% on the post-test (44 out of 58 students). The distribution of student responses also changed from a similar distribution among all three alternatives (28% for an open system, 31% for a closed system, and 41% for not enough information) to a dominant choice of the correct alternative (76% for an open system, 7% for a closed system, and 17% for not enough information). The percentage of correct answers in the multiple-choice part shows that in contrast to the pre-test, in which most of the students likely guessed, after completing the unit’s instruction about three-quarters of the students could choose the correct type of the system. Although most of the students answered correctly, about one-quarter of the students were still struggling in their choice of a closed system (4 students, 7%) instead of an open one, and in some cases thinking that there is not enough information to decide (10 students, 17%).

Level 2: The total mass before and after a chemical reaction depends on the type of system (open or closed) (Time 3).

This section discusses student understanding of the second level of the "mass conservation" construct map after completing the unit's instruction.

The analysis of post-interviews and post-test questions that refer to "mass conservation" at the macroscopic level shows that overall students understood that in a closed system mass is conserved during a chemical reaction, but even after completing the unit instructions, students still had difficulties. Many of them did not yet understand how the type of the system (open vs. closed) affects the total mass before and after the chemical reaction.

This difficulty was seen, for example, in the vinegar – baking soda balloon inflation scenario (question 17 on the post-interview) described earlier (in level 1). This question also asked students what happened to the total mass of the system after the balloon was inflated. Three-quarters of the students (12 out of 16) thought that the mass did not change, where only two out of this latter group of students also said that the mass did not change only if we verify that the system is closed. The rest of the students (4 out of 16) thought that the mass changed. A student who thought that the mass decreased explained that it is "because the gas formed by it is lighter so it would probably weigh less after that." One student who thought that the mass increased explained that it is "because between the baking soda and vinegar, a chemical reaction happened and so when the chemical reaction happened there was gases, but it went into the balloon, and so it added more mass to the system."

This difficulty with understanding the "mass conservation" at the macroscopic level was seen also in question 7 on the post-test (Figure 4.6). In that question students were given the total mass before a chemical reaction and were asked to choose what the mass would be after the reaction in an open system and what it would be if the reaction occurred in a closed system.

7. A student performs the same chemical reaction experiment twice — once in an open system, and again in a closed system. The mass before the chemical reaction is 13 grams. The chemical reaction produces a gas. What would you expect the mass to be after the chemical reaction in the open and closed systems?

a. 13 grams in the open system and 15 grams in the closed system
b. 13 grams in the open system and 11 grams in the closed system
c. 11 grams in the open system and 13 grams in the closed system
d. 11 grams in the open system and 15 grams in the closed system

(Correct answer: c)

Figure 4.6: Question 7 on the pre/post tests

This question was difficult for the students and revealed that they did not yet understand how the type of the system (open/closed) affects the total mass after a chemical reaction. Even on the post-test, after completing the unit's instruction, only 65% of the students answered the question correctly. Wrong responses were distributed almost equally among the other three alternatives (13%, 11%, and 11%) showing that students who answered incorrectly probably guessed. On the pre-test, students also answered this question incorrectly with only 30% choosing the correct answer while there was no dominant response.

This difficulty was also seen in questions 17 and 18 on the post-test (Figure 4.7 and Figure 4.8), which asked students what will happen to the total mass before and after the burning magnesium reaction and to choose the reason for the change, if any. These two questions are part of the burning magnesium scenario discussed earlier (in question 16, level 1).

17. Once the magnesium on side A has burned completely, towards which side will the scale tip?

a. The scale will remain balanced (see, Figure 1).
b. The scale will tip to side A (the side of the burned magnesium, see Figure 2)
c. The scale will tip to side B (the side of the un-burned magnesium, see Figure 3)

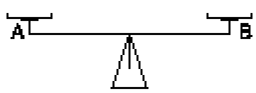


Figure 1

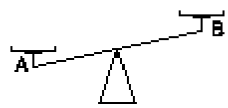


Figure 2

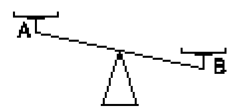


Figure 3

(Correct answer: b)

Figure 4.7: Question 17 on the pre/post tests

18. What is the cause of the weight difference, if any?

a. There is no weight difference.
b. Burning changed the magnesium into a heavier material.
c. Some of the burned magnesium disappeared.
d. Oxygen atoms combined with the magnesium.

(Correct answer: d)

Figure 4.8: Question 18 on the pre/post tests

Most of the students (72%) on question 17 on the post-test answered that the mass will decrease because gas escapes from the system. These students understood that because the system is an open the total mass change, but they assumed that burning is associated with the formation of gas. These students did not realize that solid products of the burning reaction (reaction with oxygen) have more mass than the mass of the starting solid. In question 18 of this scenario, students were supposed to choose the cause of the difference in weight. Slightly more than half of the students (60%) on the post-test and about half of the students (48%) on the pre-test chose that the mass changed because "some of the burned magnesium disappeared." By the end of the curriculum students should have known that atoms do not disappear. It is possible that students chose this option because that was the only one that referred to a reduction in the mass. If that is the case their understanding is consistent with their responses to question 17 in which most students thought that the scale would tip toward the unburned side.

Students were not asked to provide an explanation for their choice on question 17. Most of the students on the pre-test thought that as a result of the reaction, the mass will change. A few students (10 students, 16%) answered that the scale will remain balanced, while the rest of the responses were distributed evenly between the other two alternatives. Twenty-seven students (42%) thought that the scale will tip toward the burned side and the other 27 students (42%) thought that the scale will tip toward the un-burned side. Because responses were distributed evenly between tipping toward the two sides of the scale, it is possible that they just guessed.

On the post-test, the majority of the students also thought that the mass will change, but only twelve students (20%) thought that the scale will tip toward the burned side (correct answer). The dominant response was that the scale will tip toward the un-burned magnesium (41 students, 71%). Five students (9%) thought that the scale will remain balanced. One possible reason for this is that students were not familiar with the way the scale works (they are more familiar with digital scales), but this is very unlikely because their responses and explanations to the next question (question 19) of the scenario, in which they were asked what will happen to the number of atoms are consistent with their responses to this question (question 17). Twenty-seven of the group of students who chose that the scale will tip toward the unburned side also chose that there will be fewer atoms in the burned side, with the typical explanation being that atoms/molecules left. Thus, students probably had difficulties with the burning phenomena presented in the question and in understanding that a burning reaction results in an increase in mass. Understanding how scales works was not likely an issue.

Both questions 17 and 18 show that students struggled with the burning magnesium example in which mass was added to the system, and probably were not familiar with the idea that in a burning reaction the oxygen atoms from the air combined with the magnesium, resulting in a heavier product. This, in turn, causes the scale to tip toward the heavier side. Because the questions related to the burning of magnesium deal with an unfamiliar scenario, it is hard to conclude whether students had difficulties understanding “mass conservation” at the macroscopic level or just difficulties with understanding the specific example. Regardless, students tended to think of an open system as a system in which mass is lost rather than taking into consideration the possibility that mass can either be gained or lost.

It is possible that the difficulty understanding burning reactions results from students’ experience throughout the curriculum. They are more familiar with reactions in which gas is released and the mass of the remaining system is decreased. Although the students are taught that in open systems materials (atoms) can either enter or leave the system, they are more familiar with the case, in which material, for example, gas, leaves the system, and less familiar with the other option, in which gas is added to the system.

Thus, they do not realize that the magnesium combines with gas from the environment to form a heavier product. Although students were told in the class that in a burning reaction oxygen is involved, they do not necessarily associate it with an increase in mass, and do not realize that solid products of an oxidation reaction have more mass than the starting solid.

Level 3: In a chemical reaction molecules change, but the number and types of atoms depends on the type of the system (open or closed) (Time 3).

This section discusses student understanding of the third level of the "mass conservation" construct map after completing the unit's instruction.

The analysis of post-interviews and post-test questions that refer to "mass conservation" at the microscopic level shows that even after completing the unit instructions, students still had difficulties. Many students understood how the type of the system (open vs. closed) affects the total number and types of atoms before and after the chemical reaction, but many of them did not yet.

Difficulties with understanding that in a closed system the number and types of atoms do not change was seen, for example, in the vinegar – baking soda balloon inflation scenario (question 17 on the post-interviews) described earlier (in level 1). On this question students were asked to choose what caused the balloon to inflate from the following alternatives:

a. The atoms changed into other atoms that take up more space.
b. The number of atoms increased.
c. The molecules changed into other molecules that take up more space.
d. The mass in the system increased.

About one-third of the students answered incorrectly, demonstrating difficulties in understanding that in a closed system the number and types of atoms do not change (alternatives A or B, 4 out of 14 students) or that during a chemical reaction in a closed system, the mass remains the same (alternative D, 1 out of 14 students). About two-thirds of the students (9 out of 14) answered correctly, but some gaps in understanding were found in their explanations. Two students thought that in a closed system, the number of atoms and the number of molecules always stay the same, showing difficulties in distinguishing molecules from atoms and having difficulties in understanding that as a result of a chemical reaction molecules change, while atoms do not. One of them explained, for example, that "the molecules would also stay the same because they are all being trapped inside the balloon in the closed system." Other two students confirmed that they were not sure about the differences between atoms and molecules. One student thought that the number of atoms remained the same, but the types of atoms changed, saying that "the number of atoms does not change, but there are different types of atoms and those can rearrange to make different molecules."

The students were then asked what happened to the total number of atoms in the system after the balloon inflated in comparison to the number of atoms before. Almost all the students (14 out of 16) thought that the number of atoms will be the same, while two of them added that only after measuring the mass before and after to verify that the system is closed. Of the two students who thought that the number of atoms changed, one student thought that the number increased because "it was completely inflated so there are probably more atoms", and one student thought that the number of atoms decreased "because the atoms turned into a gas, breaking off from the liquid, and inflating the balloon."

However, not all the questions on student understanding of the "mass conservation" at the microscopic level were difficult. Question 2 on the post-test (Figure 4.9), for example, presented a chemical reaction at the symbolic level, using chemical formulas. Students were asked which of the given alternatives could be the product of the reaction between CO_2 and H_2O. In order to answer the question correctly, students had to be able to compare the number and the types of the atoms in the reactant and the product sides.

2. A chemical reaction occurs when a student mixes carbon dioxide (CO_2) and water (H_2O).

$$CO_2 + H_2O \rightarrow \ ?$$

Using the principle of conservation of mass, which of the following could be the product of the reaction?

a. $H_2O_2 + CO_2$
b. H_2CO_3
c. $H_2O + CO_2$
d. H_3CO_2

(Correct answer: b)

Figure 4.9: Question 2 on the pre/post tests

Most of the students answered the question correctly on the post-test (87%) with no dominant wrong answer.

Another difficulty found was the understanding that in an open system material can also enter the system, not only leave the system, which are the more familiar examples. In question 19 on the post-test (Figure 4.10), which is the last question of the burning magnesium scenario described earlier and a follow-up question to questions 16 through 18 discussed earlier, students were asked if the number of atoms of the burned magnesium will be same, less or more, than the number of atoms in the unburned magnesium. Most of the students answered incorrectly (only 16% answered correctly on the pre-test and 9% on the post-test).

19. Is the number of atoms of the burned magnesium the same, more, or less than the number of atoms in the unburned magnesium?

a. more
b. less
c. same

Explain your choice: ____

____

(Correct answer: a)

Figure 4.10: Question 19 on the pre/post tests

Student responses on the post-test distributed almost evenly between the two wrong alternatives, “less atoms” (44% in post-test) and “same atoms” (47% in post-test). Even high achiever students had difficulties with this question. One of the high achiever students explained, for example that: “the burned magnesium has less atoms the unburned magnesium because some of the magnesium escaped to combine with the oxygen to form oxygen magnesium.” This student knows that oxygen from outside reacts with the magnesium, but incorrectly thinks that the resulting product leaves the system. Another high achiever student explained that “the burned magnesium has as many magnesium atoms as the unburned magnesium. This is because according to the law of conservation of mass; no matter can be created or destroyed during a chemical reaction.” This explanation clearly shows that the student did not understand that mass is conserved only in a closed system. Other typical explanations involve matter leaving the system mostly as in the form of gas or smoke. As students stated, “when it burns some atoms go into the air” or “During the chemical reaction a gas occurred. In the end it was basically ash. It released atoms in the gas state.” Some students were also confused between burning and evaporation. Students indicated that “the molecules probably evaporated when it got put on fire” or “it only went through a phase change.”

In general, although the percentage of success on this question is lower than in the pre-test (five students succeeded in the post-test compared to ten students in pre-test) the explanations on the open-ended part of the question are much better on the post-test. On the pre-test, for example, only one out of ten students who answered the multiple-choice part correctly provided a relevant explanation. In contrast, on the post-test, one student (of the five students who answered the multiple-choice part correctly) provided a full explanation, three students provided a partial explanation, and only one student provided an irrelevant explanation. On the post-test student also elaborated more, and only a few of them provided no explanation or provided an irrelevant one, even if they answered the multiple-choice part incorrectly.

To summarize the question, only one student answered the multiple-choice part correctly and provided a complete explanation, saying that the mass was gained because oxygen atoms combined with the magnesium atoms to form a new substance with more atoms. Slightly more than half of the students (31 out of 57, 54%) provided no explanation or an irrelevant one, and the rest of the students (25 out of 57, 44%) provided a partial explanations. One student, for example, mentioned that a new substance was formed and it has more atoms, but he did not specify where the additional atoms came from.

Table 4.3: Student understanding of the "mass conservation" sub-construct at the three time points in the curriculum.

"mass conservation" Sub-levels	Time 1: Starting-point understanding	Time 2: Mid-point understanding	Time 3: End-point understanding
<u>Level 1</u>: A closed system and an open system are different	Most students were not yet familiar with open and closed systems, their meaning and were not able to distinguish the two types of systems.	X	Most students were able to choose the type of a given system (closed vs. open), but could explain the difference in only a limited manner. For example, some students referred only to the system set-up or the possibility of material (atoms) leaving/entering the system. Some did not take into account whether or not the mass has been changed.
<u>Level 2</u>: The total mass before and after a chemical reaction depends on the type of system (open or closed)	The majority of the students did not understand that at the macroscopic level mass is conserved during a chemical reaction or during phase change in a closed system. Students had difficulties understanding that material does not disappear.	X	Overall, most students understood that in a closed system mass is conserved during a chemical reaction while in an open system the mass changes, but many of them (about one-third) did not yet understand how the type of the system (open vs. closed) affects the total mass before and after the chemical reaction. Students tended to think of an open system as a system in which mass is lost (which are the more familiar examples) rather than taking into consideration the possibility that mass can either be gained or lost.

Level 3: In a chemical reaction molecules change, but the number and types of atoms depends on the type of the system (open or closed)	Most students did not yet understand that at the microscopic level the total number and type of atoms stays the same (in a closed system) or changed (in an open system) during a chemical reaction	X	Many students understood how the type of the system (open vs. closed) affects the total number and types of atoms before and after the chemical reaction, but many of them did not yet.

* X indicates that this sub-level was not dealt with

Having discussed the three sub-constructs separately, the “change of properties”, the “rearrangement of atoms”, and the “mass conservation”, I now will summarize student understanding of chemical reaction over time.

Section Four: Summary of Results

All the three sub-construct discussed above in sections one through three are related and contribute to the understanding of chemical reaction. The next section pulls together the results for each sub-construct to reveal student understanding of chemical reaction over time (Step 4.1 in Figure 4.1). Overall findings are summarized in the Table 4.4 at the end of this section. Here, I further discuss the findings in relation to the research questions followed by a summary Figure (Figure 4.11) presenting visualization trends of student understanding of chemical reaction over time.

The research questions.

This study characterizes students’ learning of a core idea in scientific literacy (the interactions of matter to form new substances), as they participate in a coherent curriculum. The specific research questions addressed in this study are:

1. What prior knowledge do 7th grade students have regarding chemical reactions? Particularly, what prior knowledge and difficulties do they have in relation to:
    a. Change of properties that occur as a result of a chemical reaction
    b. Rearrangement of atoms during a chemical reaction
    c. Mass conservation during a chemical reaction
2. How does 7th grade students' understanding of chemical reactions develop as they go through a coherent chemistry unit on chemical reactions? During this learning process, what do they understand? With what sub-ideas do students have difficulty? In particular, what are students able to learn and what difficulties do they face in understanding the following:
    a. Change of properties that occur as a result of a chemical reaction
    b. Rearrangement of atoms during a chemical reaction
    c. Mass conservation during a chemical reaction

The main findings as they relate to each research questions are presented next.

The first research question.

The first research question was what prior knowledge do 7th grade students have regarding chemical reactions. The analysis of pre-interviews and pre-test questions, which were used (Time 1) to answer that research question, shows that overall, prior to the curriculum experience or at the very beginning of the unit's instruction, students had not yet mastered any of the levels in any of the three construct maps. Students had limited knowledge regarding the "change of properties" sub-construct; had partial understanding of basis of the particulate nature of matter, which is part of the "rearrangement of atoms" sub-construct; and had the least familiarity with background knowledge associated with the "mass conservation" sub-construct.

More specifically, regarding the "change of properties" sub-construct, students initially used properties to describe substances, but in general they used everyday terms rather than scientific terminology and they had problems distinguishing properties from non-properties and understanding that properties are consistent and not determined by the amount of the substance. Students were not yet able to explain that properties could be used to distinguish one substance from another, and could not clarify that one property is not enough to distinguish one substance from another. This understanding is predictable since students are not expected to know any of this without instruction. Students also did not understand that a chemical reaction creates new or different substances with a different set of properties, and most students could not distinguish chemical reactions from mixtures and/or phase changes. This difficulty with differentiating chemical reactions from mixtures and phase changes is well documented in the literature (e.g., Ahtee & Varjola, 1998; Stavridou & Solomonidou, 1998; Eliks et al., 2007; Novak & Musonda, 1991) and is expected, especially prior to the unit's instruction.

In relation to the "rearrangement of atoms" sub-construct, students could describe what materials looked like, but they used everyday terms rather than scientific ideas. Some students, however, did have some background knowledge about the basis of the particulate nature of matter. Generally, understanding was mixed with respect to what constitutes matter, which is necessary for a solid understanding of the basis of the particulate nature of matter. All the students also had difficulties with understanding pure substances thinking that pure substances necessarily consist only of molecules of one type of atom. This understanding is expected prior to the unit's instruction. Among the students there was a mixed understanding in regard to phase changes and that heat must be added/removed to cause a change of state of matter. Many students were confused between phase change and mixtures as they suggested adding water in order to change sugar solid to liquid, and were confused between chemical reactions and phase changes at the microscopic level. None of the students had any background regarding the arrangement of atoms within a molecule and that during chemical reactions atoms are rearranged and create new combination/s of atoms. Students also were not yet familiar with scientific terminology such as state of matter, reactants, and products, which are necessary later on for a solid understanding of chemical reactions. This understanding is reasonable, particularly prior the unit's instruction.

In reference to the "mass conservation" sub-construct, most students were not yet familiar with any of the sub-levels of the construct map and had not yet made the connection between the macroscopic and the microscopic levels of understanding of the mass conservation law, to be specific, between the change (or not) with the mass and with the change (or not) with the number and type of atoms. This is expected, particularly prior the unit's instruction, but also after completing the unit's instruction, since linking macro and micro levels is one of the main challenges described in the chemistry education research literature (e.g., Eylon et al., 1987, Gable, 1998; Johnstone, 1991; Treagust et al., 2003).

The second research question.

The second research question was how does 7th grade students' understanding of chemical reactions develop as they go through a coherent chemistry unit on chemical reactions. The analysis of mid-interviews, post-interviews, and post-test questions, which were used (Time 2 and Time 3) to answer that research question, shows that overall, after completing the first part of the curriculum in which the students learned about substances and properties, but before they learned that substances interact to form new substances (i.e., chemical reaction) and conservation of mass (Time 2), most of the students seemed to have a general idea that a property is a characteristic of a substance. However, the data reveals some gaps in their understanding. Many students still had difficulties distinguishing between atoms and molecules and use the terms molecules and atoms interchangeably. There were no indications of learning and/or difficulties in reference to the "mass conservation" construct map. Mid-interviews did not deal with this sub-construct.

Overall, after completing the unit's instruction (Time 3), there was a noticeable increase in students' understanding of all three sub-constructs; however, there were still gaps in their understanding. Specifically, in relation to each of the three sub-constructs students had the following understanding presented by the time that the data was collected.

Regarding the "change of properties" sub-construct, at Time 2, most of the students could provide examples of properties (e.g., density) and could provide example/s of what is not a property (e.g., volume, mass). However, only about half of the students could use the change/no change in size/amount/shape to justify if an attribute is a property or not. Overall, after completing the unit's instruction (Time 3), there was a noticeable increase in students' understanding that properties changed as a result of chemical reactions. Even so, by the end of the unit's instruction, students still had some difficulties. Most of the students could distinguish properties from non-properties and seemed to understand that a property is a characteristic of a substance. But, about one-third of the students still struggled, considering volume and mass as properties. Most of the students also understood that comparing a single property is not enough to determine if two given samples are the same substance or different ones, but still thought that as a result of a chemical reaction every single property changes. Most of the student could state that properties change as a result of a chemical reaction, but could not elaborate why and most of the students could correlate specific phenomenon with its type, namely, chemical reactions, mixtures, or phase changes; however, an indication of difficulty with that idea among a few students was seen in the post-interviews.

Regarding the "rearrangement of atoms" sub-construct, at Time 2, students had difficulties in understanding that molecules of different substances are different and had difficulties in picturing atoms and molecules and estimating its size. Many students still had difficulties distinguishing between atoms and molecules and use the terms molecules and atoms interchangeably, and most of the students thought that chemical reactions occur only when there is more than one reactant. This difficulty is consistent with the literature in which student incorrectly think that chemical reactions require at least two reactants (Cavallo et al., 2003; Eliks et al., 2007; Hermann-Abell et al., 2009) and is expected, especially since at this point in the curriculum the students did not do yet the electrolysis lab, in which a chemical reaction occurs although there is only one reactant.

After completing the unit's instruction (Time 3), students overall seemed to understand that a substance is made of the same types of atoms throughout. Students still had difficulties understanding that a pure substance is made of one type of molecule that has a fixed composition of one or more different types of atoms and does not necessarily consist only of molecules of one type of atom.

Most of the students could differentiate between atoms and molecules at the microscopic level (model), but could not fully understand the symbolic level (chemical equation), which is also not expected at the middle-school level. These findings are consistent with other studies showing that such understanding is hard even for high-school students (e.g., Ben-Zvi et al., 1987).

Generally, most of the students understood that a chemical reaction results in a rearrangement of the atoms and the formation of new combinations. But, about one-fifth of the students still struggled with understanding that idea, choosing, for example, the products that are the same as the reactants, but in a different order or thinking that atoms become new atoms. Referring to a 3D balls and sticks model, most of the students (two-third) were able to demonstrate the differences between a chemical reaction and a mixture.

Regarding the "mass conservation" sub-construct, after completing the unit's instruction, most students were able to choose the type of a given system (closed vs. open), but could explain the difference in only a limited manner. Overall, at the macroscopic level, most students understood that in a closed system mass is conserved during a chemical reaction while in an open system the mass changes, but about one-third of the students did not yet understand how the type of the system (open vs. closed) affects the total mass before and after the chemical reaction. At the microscopic level, many students did not understand yet how the type of the system (open vs. closed) affects the total number and types of atoms before and after the chemical reaction. At both the macroscopic and microscopic levels, students had difficulty in understanding that in an open system material can also enter the system, not only leave the system (which are the more familiar examples) such as in the case of the burning phenomena. This finding is consistent with the literature. The literature shows that students often have difficulties with understanding the change of mass in a burning reaction, assuming that when something burns the mass decreases (e.g., BouJaoude, 1991; Kind, 2004). Perhaps this is just one of those difficult ideas that need coming back to during the instruction.

Table 4.4: Student understanding of chemical reaction over time.

Chemical reaction	Time 1: Starting-point understanding	Time 2: Mid-point understanding	Time 3: End-point understanding
"change of properties" sub-construct	Students used properties to describe substances, but used everyday terms and could not distinguish properties from non-properties. They were not able yet to explain that properties could be used to distinguish one substance from another and did not understand yet that properties change during a chemical reaction.	Most of the students could provide examples of properties and of what is not a property; however, only about half of the students could use the change/no change in size/amount/shape to justify if an attribute is a property or not.	Most of the students could distinguish properties from non-properties and seemed to understand that a property is a characteristic of a substance and most of them could correlate specific phenomenon with its type (chemical reaction/mixture/phase change).
"rearrangement of atoms" sub-construct	Students used everyday terms (not scientific ideas) to describe what materials looked like, had a mixed understanding about what constitutes matter,	Many students still had difficulties distinguishing between atoms. Most of the students think that chemical reactions	Overall, most of the students could differentiate between atoms and molecules at the microscopic level, but not at the symbolic level. Generally, most

	struggled with distinguishing the different types of particles, and struggled with understanding phase changes.	occur only when there is more than one reactant.	of the students understood that a chemical reaction results in a rearrangement of the atoms.
“mass conservation” sub-construct	Overall, students did not yet master any of the sub-levels of the “mass conservation” construct map.	X	Overall, most students (two-third) understood the mass conservation at the macroscopic level, but not yet at the microscopic level. Students also tended to think of an open system as a system in which mass is lost rather than that mass can either be gained or lost.

* X indicates that this sub-construct was not dealt with

Visualization trends of student understanding of chemical reaction over time. Figure 4.11 below attempts to visualize trends of how student understanding of chemical reaction developed over time. The trends demonstrated in the figure are not quantitative, but only reflect general trends of understanding over time. X indicates that this sub-level was not dealt with.

		Time 1: Starting-point understanding	Time 2: Mid-point understanding	Time 3: End-point understanding
Mass conservation	Level 3: In a chemical reaction molecules change, but the number and types of atoms depends on the type of the system (open or closed)		X	
	Level 2: The total mass before and after a chemical reaction depends on the type of system (open or closed)		X	
	Level 1: A closed system and an open system are different		X	
Rearrangement of atoms	Level 4: A chemical reaction can be distinguished from phase changes and/or mixtures (at the microscopic level)		X	
	Level 3: A chemical reaction results in new substances with a new arrangement of atoms			
	Level 2: Differentiating between different types of particles			
	Level 1: Basis of particulate nature of the matter			
Change of properties	Level 4: A chemical reaction can be distinguished from phase changes and/or mixtures (at the macroscopic level)		X	
	Level 3: A chemical reaction results in new substances with a new set of properties		X	
	Level 2: Different substances have different set of properties			
	Level 1: A property is a characteristic of a substance			

Figure 4.11: Visualization trend of student understanding of chemical reaction over time.

Having discussed the study results, I now turn my attention to the final chapter discussing the findings in relationship to the study contribution to the field, the study limitations, and the next steps.

Chapter 5

Discussion

In this chapter, I will comment on the main findings in relation to their contribution to the field. Next, I will discuss the study limitations, provide suggestions for further research, and propose future refinement of the construct maps.

Recent reports stress that students need to develop an integrated understanding of science throughout their education, particularly with a focus on big ideas or core concepts in science such as chemical reaction (Linn, 2007; NRC, 2006, 2007; Roth et al., 2006; Stern & Roseman, 2004). Although the arguments for a coherent science curriculum are clear, how students acquire key concepts within such a curriculum has not been elaborated. This study characterizes students' learning of a core idea in scientific literacy (chemical reaction), as they participate in a coherent curriculum. This study focuses on 7^{th} grade students' learning as they participate in the 7^{th} grade chemistry unit of the IQWST curriculum entitled "How Can I Make New Stuff From Old Stuff?" (Krajcik, McNeill, & Reiser, 2008; McNeill et al., 2004). This unit is part of the *Investigating and Questioning our World through Science and Technology (IQWST)* project (Krajcik, Reiser, Fortus, & Sutherland, 2008), a three-year middle school science curriculum, whose aim is to build students' ideas over time. The study explores the prior knowledge, new knowledge, challenges, and development of the middle school students' understanding of chemical reactions, which is one of the central concepts in chemistry and fundamental for learning other related chemical and scientific concepts.

In this study I used construct maps (a graphical representation of a consecutive continuum of the understanding of a specific construct) to guide the development and analysis of assessment items aimed at finding evidence for learning and monitoring student progress in learning of a specific idea at specific points in the curriculum. A solid grasp of the chemical reaction construct includes the understanding that as a result of a chemical reaction the properties of the substance change and that atoms rearrange while mass is conserved. The specific sub-constructs used in this study are:

- Change of substance properties as a result of a chemical reaction
- Rearrangement of atoms during a chemical reaction
- Conservation of mass during a chemical reaction

A separate construct map was developed for each of the above sub-constructs to demonstrate what students know or should know (Figure 3.1 through Figure 3.3). The maps were then used for developing and revising assessment items and subsequent analysis of those items. The specific construct maps are described in greater detail in the methods chapter. This study utilizes both quantitative and qualitative data from sources collected before, during and after the teaching instruction.

Although considerable research regarding students' learning of chemical reaction exists, studies have focused mainly on common student difficulties and at high school level at a certain stage of the learning, usually after completing study of the topic. Little has been done to analyze the acquisition process of these scientific ideas during the learning process for middle school students. Besides the difficulties in understanding, this work highlights what students are able to learn and at different stages of the learning process as opposed to what they are able to do at the end of the instruction process only. Furthermore, findings contribute to efforts to characterize students' understanding at different ages. Findings may also contribute to the larger efforts to enhance current efforts to create larger continuous coherent science curricula. In recent years there has been growing interest in researching learning over time. My study contributes to this line of inquiry by using construct maps to characterize learning of a core concept that is central to the field (NRC, 2007). The construct maps are used to identify student prior and existing understanding of the sub-ideas that are part of the understanding of the big idea. Identifying student prior and existing knowledge is important to adjust teaching accordingly and thus make teaching more effective (Taber, 2003). Through the use of the construct maps, I identify what student can do and then what they cannot do in each sub level rather than focusing only on difficulties. This kind of knowledge on what students can do is important and can be used to bring the research findings to practice suggesting specific instructional implications that are grounded on research and can be easily implemented in the classroom. *Ready Set Science* (Michaels et al., 2008), for example, put together a set of instructional experiences that is based on the National Research Council report *Taking Science to School* (NRC, 2007) and other latest studies and apply them to effective teaching practice to help K-8 students learn and understand science. Since chemical reaction is central and fundamental for the continuous learning in chemistry and other disciplines, knowing what students have learned and what they still struggle with is fundamental not only to teaching chemical reactions, but also for teaching future topics.

This study is an example of how an understanding of one sub-level contributes to the understanding at another sub-level. This study shows, for example, how students need to understand the particulate nature of matter in order to understand the rearrangement of atoms in chemical reactions. Although the particulate nature of matter has been extensively examined (e.g., de Vos & Verdonk, 1996; Gabel, et al., 1987; Harrison & Treagust, 2002; Johnson, 1998; Novick & Nussbaum 1978, 1981; Stavy, 1991), these studies have not looked at it from the perspective of how early learning contributed to later learning, which is fundamental to constructivism. Constructivist theory in its various forms is based on a generally agreed principle that learners actively construct meaning from their own experience and prior knowledge as they strive to reconcile present experiences with already existing knowledge (Bodner et al., 2001; NRC, 2000; Roth, 1993). In this regard, my study extends the existing work that normally focus on the separate sub-ideas such as the studies mentioned above that focus on the particulate nature of matter, and furthers our understanding of how the separate sub-ideas contribute to students' overall understanding of chemical reactions. For instance, the results show that students' ability to distinguish molecules from atoms affects their understanding of rearrangement of atoms and the formation of new combinations, and therefore contributed to students' overall understanding of chemical reactions.

Previous studies have investigates student understanding of chemical reactions and related understanding, but typically those studies did not look at growth but focused on student understanding at some time point (e.g., Andersson 1986, 1990; Athee & Varjola, 1998; Hesse & Anderson, 1992; Hinton & Nakhleh, 1999; Yarroch, 1985). This study is one of the first studies that look at student understanding of that core concept across time (unit's instruction duration). As can be seen in Figure 4.11 (visualization trend of student understanding of chemical reaction over time), overall, there was a noticeable increase in students' understanding that as a result of a chemical reaction the properties of the substance change and that atoms rearrange while mass is conserved. Students could distinguish, for example, open and closed systems, and understood that the products of a chemical reaction are not the same as the reactants. Besides the growth in specific understandings in each sub-construct, students also became more familiar with scientific terminology (rather than everyday language) such as phase changes, reactants, products, atoms, and molecules, and became more familiar with the macroscopic-microscopic-symbolic views, which are necessary for student growth and further understanding in subsequent learning.

This direction of studies on growth in understanding over time is one possible solution in an attempt to cope with the growing concern about the current science education in the United States in which students continue to languish in international comparisons of science achievement and that the situation becomes worse at higher grade levels (Linn, 2007) among other concerns such as the existence of science achievement gaps between various populations within the United States (NRC, 2007). Thus, studies on students' growth in understanding of core concepts are gaining popularity. For instance, very recently, Merritt (2010) tracked middle school students' understanding of the particle nature of matter, more specifically, how students move from a continuous view of matter to a particle view. This understanding is fundamental to gain a better understanding of the rearrangement of atoms, and therefore is essential to grasp a solid understanding of chemical reactions. Thus, my study extends Merritt's study wherein her study is the early learning that contributes to the later learning of chemical reactions, which is the focus of this study.

Smith and her colleagues (Smith et al., 2006) in their synthesis paper were the first to propose a learning progression for the matter and the atomic molecular theory supplemented with relevant assessment tasks. Their study also included discussion on "what changes and what stays the same when things are transformed", but they did not provide details on some aspects of chemical reactions that are included in the present study. For instance, Smith et al. did not address student understanding of mass conservation during chemical reactions, which is one of the focuses of the current dissertation. They did indicate that matter and mass are conserved across chemical and physical changes, but did not get into details of what students need to learn to grasp a solid understanding of that idea and did not provide many assessment items in reference to this understanding. Therefore, by basing my work on more nuanced construct maps, my study extends their work and more deeply explores what students are expected to learn to have a more sophisticated understanding of mass conservation.

It is important to note that the findings from this study are not independent; instead, they are related and together they contribute to the understanding of student understanding of the chemical reaction big idea. The findings support the notion of integrated understanding (Roseman, Linn, & Koppal, 2008). The ideas in this study are connected; student understanding in each of the three sub-constructs was related to their understanding and directly affected the understanding of the other sub-constructs. For instance, because of difficulties in distinguishing molecules from atoms ("rearrangement of atoms" sub-construct) students having difficulties in understanding that as a result of a chemical reaction molecules change, while atoms do not. This understanding influenced their ability to count the number and types of atoms in the reactants side and in the products side, which posed as an obstacle to understanding the mass conservation at the microscopic and symbolic levels ("mass conservation" sub-construct). Thus, the findings from this study must be viewed collectively since together they reveal students' understanding.

Stevens et al. (2010) offered a multi-dimensional hypothetical learning progression (HLP) that describes potential paths for students to develop understanding of two big ideas, atomic structure and the electrical forces. My work shows possible connections and provides empirical evidence that students do need to make these connections for understanding of the various sub-ideas. For instance, the results show that students who had difficulties in in understanding the change of properties as a result of chemical reaction ("change of properties" sub-construct), might have thought that the inflation of a balloon causes change of mass, even if the system is closed and the mass is conserved. Thus, difficulties in understanding the change of properties affected the understanding of mass conservation at the macroscopic level ("mass conservation" sub-construct). The *National Science Education standards* (NRC, 1996) and the *Benchmarks for science literacy* (AAAS, 1993) provide a detailed scope of topics, but while it suggests what subject matter should be taught at which grade, it does not try to further organize the concepts/topics in a helpful continuum. In their attempt to address the continuity issue the AAAS complemented their Benchmarks (AAAS, 1993) by publishing the two-volume *Atlas of Science Literacy* (AAAS, 2001, 2007). The Atlas contains strand maps and related commentary that organize and connect ideas and skills essential for constructing students' understanding of important science, mathematics, and technology topics from kindergarten through 12th grade in a logical manner. The strands maps show connection of ideas based on the logic of the discipline and on reported learning difficulties. Some of the connections in the map are based on empirical evidence, but some connections were not yet tested empirically. For example, they have not completed the formal path analysis for the atoms and molecules topic. They did find dependencies between student understanding of the mass conservation at the macroscopic and microscopic levels (Herrmann Abell, personal communication, 2010). In their recent assessment work of ideas related to chemical reactions and conservation of matter, DeBoer and colleagues from Project 2061 did a path analysis that showed some dependencies (DeBoer et al. 2009). For example, students use knowledge of properties to make decisions whether or not a chemical reaction has occurred. Like them, this study also found connections between those two sub-ideas of understanding. For instance, the results show that students who were confused between what is and what is not a property thought that during a chemical reaction properties would remain the same, which influenced their ability to determine whether or not a chemical reaction occurred. Also, similar to Project 2061 efforts (although on a smaller scale) my study aims to organize the ideas and provide empirical evidence how students' ideas in one sub-level (e.g., distinguishing atoms from molecules) can help or hinder their understanding of another ideas in another sub-level (e.g., mass and the number of atoms is conserved in a closed system). My study is, however, different from Project 2061 recent assessment work because it is situated in a coherent curriculum while their study is curriculum independent and as such they know very little about the instruction that occurred in the classrooms.

More specifically, the *Atlas of Science Literacy* (AAAS, 2001) provides four strand maps that are associated with the structure of matter: Atoms and Molecules (AM), Conservation of Matter (CM), State of Matter (SM), and Chemical Reactions (CR). However, the maps do not show connections between student understanding of atoms and molecules to their understanding of mass conservation discussed above. For instance, both the Chemical Reactions strand map (CR) and the Conservation of Matter (CM) strand are not connected to student ability to distinguish different types of particles. They do refer to the Atoms and Molecules (AM) strand map, but only in relation to the 4D/1 Benchmark that discusses that "all matter is made up of atoms, which are far too small to see directly through a microscope" (4D/1) and that "atoms may stick together in well-defined molecules, or may be packed together in large arrays. Different arrangements of atoms into groups compose all substances. …" (4D/1). In another example that is related to my findings, the Chemical Reactions strand map (CR) mention connections to the Conservation of Matter (CM) strand map only in relation to the same 4D/1 benchmark mentioned above. There is no connection in the strand maps between the understandings that during a chemical reaction in a closed system the mass is conserved. Thus, my work supplements their work, providing empirical evidence for additional connections between the ideas. This is consistent with the point made earlier that student understanding of the mass conservation was influenced by their ability to distinguish atoms and molecules.

The Chemical Reaction (CR) strand map does make a connection to the understanding of the "change of properties" sub-construct discussed in my study, referring to the understanding that "when substances interact to form new substances, the element composing them combine in new ways. In such recombination, the properties of the new combinations may be very different from those of the old." (AAAS, 1990, p. 47). They do not, however, make connections to the other sub-ideas that are part of the "change of properties" construct map such as what is a property and what is not a property and that different substances have different set of properties. This does not mean that the map should include greater detail, since this may lead to confusion. However, this detail would be valuable as a reference for teachers who teach this idea and want to establish more detailed connections among the sub-ideas. Thus, supplemental material for the Atlas including detail such as this should be made available. This supplemental material would enhance the value of the maps in the Atlas.

Contribution to the gap in the existing literature

The findings from this study show that the chemical reaction construct, although it is a core concept that is fundamental to the field, is a far more complex and difficult process than it might seem and this complexity is underexplored in the research literature. Students' understanding of chemical reactions has been the subject of substantial studies and there are a number of reviews of this work (Andersson 1986, 1990; Driver 1985; Driver et al. 1994, Garnett et al. 1995; Wandersee et al. 1994). However, many of the studies on chemical reactions have given emphasis to student understanding of the concept at the symbolic level and student difficulties with balancing equations (e.g., Ben-Zvi et al., 1987; Hesse and Anderson, 1992; Özmen and Ayas, 2003; Ramsden, 1997; Yarroch, 1985) or on student understanding of specific examples that are associated with the ideas of mass conservation, leaving other aspects of chemical reactions, especially at the macroscopic and microscopic levels, receiving little attention. Therefore, there is a gap in the existing research literature on student understanding of chemical reactions, which I will discuss next according to each sub-construct.

The literature is rich with studies on various aspects that are associated with student understanding of the “rearrangement of atoms” sub-construct, but not much on student understanding of the “mass conservation” sub-construct at the middle school level, and a thorough search of the literature revealed only a few studies on student understanding of the “change of properties” sub-construct. More specifically, in reference to student learning of properties, there appears to be only a few studies that are related to student understanding of that sub-construct. There are many studies of student understanding of what the specific properties means, for example, students understanding of density or solubility and its use in everyday life (e.g., Kennedy et al., 2006; Ebenezer & Erickson, 1996), but not much on student understanding of what is a property (or what is a non-property) and its relation to the understanding of chemical reactions. A few studies were found that are related to the understanding characteristic properties, but do not delve into further understanding beyond whether or not the students provide examples of observed phenomena to indicate that a chemical reaction has taken place such as bubbles, color change, and formation of a solid precipitate (e.g., Ahtee & Varjola, 1998; Hinton & Nakhleh 1999). Previous studies have suggested that this idea of characteristics properties that are changed during chemical reaction should be explored (Driver et al., 1994; Vogelezang, 1987), but only a few studies have actually been conducted; however, interest in this area is growing. My study does this work and builds upon those suggestions. On a larger scale (thousands of students, multiple curriculums), the AAAS Project 2061 explores students’ understanding of characteristics properties of substances as part of their assessment development project (DeBoer et al., 2007, 2008). In their recent study (DeBoer et al., 2009) they delve deeply into student learning of two key ideas that are relate to characteristic properties: (A) A pure substance has characteristic properties that are independent of the amount of the substance and can be used to identify it, and (B) Many substances react chemically in predictable ways with other substances to form new substances with different characteristic properties. Having Project 2061 identifying those two ideas as key ideas to be learned at the middle school level, strengthen the need for more empirical studies on this topic. Smith et al. (2006) also suggest that this understanding is important to student understanding of matter and the atomic molecular theory and provide relevant example of assessment items as part of their comprehensive descriptions of learning progression of the nature of matter for grades six through eight. My study supports Smith and colleagues (2006) recommendation that items focusing on properties be developed and narrowly explores student understanding of that idea, breaking down this understanding into the elements that contribute to this sub-construct. More specifically, at the macroscopic phenomena level, students learn that a chemical reaction is a process in which substances interact to form new ones with a different set of properties. To decide whether or not properties have changed, students first need to know what a property is (and what is not a property), and that different substances have different sets of properties, and that is why comparing a single property is not always enough to determine whether or not a substance is the different/same. At the highest level, students can synthesize their learning to distinguish between chemical reactions from phase changes and mixtures. Among others, the study results show that before instruction, students used properties to describe substances, but used everyday terms and could not distinguish properties from non-properties. After completing the first learning set, most of the students could provide examples of properties and of what is not a property, however, only about half of the students could use the change/no change in size/amount/shape to justify if an attribute is a property or not. Overall, after completing the unit's instruction, there was a noticeable increase in students' understanding that properties changed as a result of chemical reactions. Even so, by the end of the unit's instruction, students still had some difficulties. For instance, most of the student could state that properties change as a result of a chemical reaction, but could not elaborate why; i.e., could not make a connection to the formation of a new substance with a new set of properties.

In reference to the "rearrangement of atoms" sub-construct, previous work has investigated sub-ideas that are included in the construct map. For instance, studies on student learning of the particulate nature of matter, which is level 1 of the "rearrangement of atoms" construct map (e.g., de Vos & Verdonk, 1996; Gabel, et al., 1987; Harrison & Treagust, 2002; Johnson, 1998; Novick & Nussbaum 1978, 1981) and is a big idea by itself, or on student understanding of different types of particles, which is level 2 of the "rearrangement of atoms" construct map (e.g., Griffiths & Preston, 1992; Harrison & Treagust, 1996). However, most of these studies focused on separate ideas rather than how these ideas are relate to the larger understanding of a big idea. Thus, these studies do not demonstrate how students' understandings of early concepts relate to their understanding of later concepts. The present study differs from this previous work in that it looks at understanding of those separate sub-ideas in relationship to future understanding of related topics and its contribution to the understanding of a big idea (chemical reactions). For instance, my study explored student understanding of different types of particles in relation to the distinguishing between chemical reactions from mixtures and phase changes and later on also in relation to the understanding of the conservation of mass at the microscopic level in which as a result of a chemical reaction the total of number and types of the atoms do not change in a closed system while the total number and types of molecules change. Among others, results showed that two-thirds of the students (10 out of 15) could demonstrate (referring to a 3D balls and sticks model) that in contrast to a chemical reaction where molecules break apart and atoms re-arrange to form new molecules, in mixture, molecules remain unchanged and that student ability to differentiate atoms from molecules influenced their understanding of mass conservation at both the microscopic and the symbolic levels. A typical error was, for example, thinking that the atoms in C_3H_8 are: C_3 and H_8, which affected students' ability to determine whether or not the number and types of atoms has remained, thus, total mass stayed the same.

The study contribution in relation to the understanding of the rearrangement of atoms as a result of a chemical reaction is not only with the specific understanding of each sub-level in each construct map, but also with the contribution of these pieces of understandings to the understanding of a bigger idea, chemical reaction. It is valuable to construct a more sophisticated understanding of the discussed ideas over time (Corcoran et al., 2009; Wilson 2009) and corresponds with other recent studies that test how students' understanding of core scientific ideas grow and become more sophisticated over time as a result of instruction (e.g., Kennedy et al., 2006; Merritt 2010).

In reference to the "mass conservation" sub-construct, although this understanding is essential to understand chemical reactions and a prerequisite for the subsequent understanding of other topics in chemistry until now, a thorough search of the literature reveals little in the research literature at the middle school level. But, interest in this area is growing. Project 2061, for example, includes the understanding of mass conservation at both the macroscopic and microscopic levels in their new assessment development project and in their maps (DeBoer et al., 2007, 2008, 2009; Herrmann et al., 2009). There are few studies on student understanding of mass conservation at the middle school level, but in relation to mixtures and phase changes (e.g., Lee et al., 1993; Stavy, 1990). Even at the high school level, most of the studies (e.g., Barker & Millar, 1999; Hesse and Anderson, 1992; Özmen and Ayas, 2003; Ramsden, 1997) focus on the symbolic level (balancing equations, for example) and not much has been found on student understanding at the macroscopic and microscopic levels. My study adds to the existing literature and more narrowly focuses on student understanding of mass conservation at both the macroscopic and the microscopic levels of understanding.

There are, however, studies on student understanding of the role of gases such as oxygen in open systems and its effect on the total mass (e.g., BouJaoude, 1991; Driver, 1985), especially when the gas is involved as a reactant, (e.g., the formation of rust (oxidation), burning reactions (combustion)). This understanding is part of the understanding that my study looks at, but my study takes it further looking also at the distinguishing between open and closed systems and the use of this understanding to predict and explain the total mass of the system at both the macroscopic and the microscopic levels. The extant study differs from the studies above in that it looks at open systems in which matter leave the system in addition to the examples in which matter enter the system. Findings from this study indicate that it is easier for students to understand that matter can leave the system rather than understanding that matter can enter the system. Also, the existing studies (e.g., BouJaoude, 1991) typically do not look at growth but focusing on student understanding at some time point and my study looks at the understanding of the specific idea in relation to subsequent learning. For example, students may use their understanding of open vs. closed systems to explain and predict if, as a result of a chemical reaction, the total mass has been changed or preserved. More specifically, at the basic level, my study checks if students can distinguish a closed system from an open system in a process, understanding that in a closed system no material (atoms) can enter or leave the system, and in open system material (atoms) can enter (react/combine) or leave the system. Matter (atoms) is neither created nor destroyed in chemical reactions. Then, I delve into student understanding of mass conservation at the macroscopic phenomena level, checking student understanding that the total mass before a chemical reaction is equal to the total mass after a reaction in a closed system. The total mass of the system always remains the same no matter how substances interact with each other, or how they combine or break apart. Finally, I delve into student understanding of mass conservation at the microscopic level, checking student understanding that that the total number and type of atoms before a chemical reaction is equal to the total number and type of atoms after a reaction in a closed system. The number and type of atoms stays the same no matter how they are rearranged, thus, total mass stays the same. Among others, results showed that overall students developed an understanding of the mass conservation at the macroscopic level and some of them also could explain the mass conservation law at the microscopic level; whereas, many students still had gaps in their understanding. Students, for example, thought that the number of atoms and the number of molecules always stays the same because of the "mass conservation law", or as a result of difficulties distinguishing molecules from atoms had difficulties in understanding that as a result of a chemical reaction molecules change, while atoms do not. Many students also had difficulties in making the macroscopic-microscopic relationship. For instance, when students were asked what happened to the total mass of the system and to the total number of atoms in the system after the balloon inflated (in the vinegar – baking soda balloon inflation scenario described earlier), many students did not make the macroscopic-microscopic connection between the mass change and the change with the number of atoms, thinking that the mass changed (decreases or increases), but the number of atoms remained the same, or vice-versa, thinking that the mass did not change, but the number or types of atoms changed. A student explained, for example, that the mass increased because "when the chemical reaction happened there was gases, but it went into the balloon, and so it added more mass to the system", but thought that the number of atoms stayed the same "because no atoms can appear or disappear."

Thus, my study adds to the existing studies that focus only on one separate aspect of mass conservation (e.g., researching into student understanding of specific reactions in an open system in which oxygen enter the system) and extends their work with student learning of additional aspects of mass conservation and how the different ideas within that sub-construct are related to each other to gain a deeper understanding of the topic. Besides, some of those aspects that my study looks at were not yet elaborated much in the current literature, for example, the distinguishing between open and closed systems, especially not at the middle school level. In this regard, results showed that after completing the unit's instruction, most students were able to choose the type of a given system (closed vs. open), but could explain the difference in only a limited manner. For example, some students referred only to the system set-up or the possibility of material (atoms) leaving/entering the system. Students also tended to think of an open system as a system in which mass is lost (which are the more familiar examples) rather than taking into consideration the possibility that mass can either be gained or lost. Perhaps this is just one of those difficult ideas that need coming back to during the instruction. Further discussion in the class on this idea may also help students with understanding other difficulties reported in the literature such as believing that gases do not have mass even when students acknowledged the existence of gases (e.g., oxygen) as reactants (Driver et al., 1985).

Besides the contribution to the existing gap in the literature in each sub-construct, this study contributes to students' overall understanding of chemical reactions at the macroscopic and microscopic levels, which discussed less in the literature in comparison to the symbolic level. Constructing different representations (macroscopic, microscopic, and symbolic) of chemical reactions reported to be challenged for students (Kozma & Russell, 1997; Kozma et al., 2000; Hinton & Nakhleh, 1999; Gabel, 1998; Nakhleh, 2002). Previously studies report that even when students were able to interpret symbols and could balance chemical equations they did not necessary know how the equations are connected to the corresponded chemical phenomena they represent and did not necessary possess an understanding of those phenomena (Dori et al., 2003; Hinton & Nakhleh, 1999; Nakhleh, Lowrey, & Mitchell, 1996; Krajcik, 1991). Thus, concentrating on the macroscopic and microscopic levels, which is the focus of this study, is relevant not only for understanding the basic level in the current curriculum, but for future growth. If students can gain a better understanding of chemical reactions at the middle school level, this may facilitate their ability to establish better connections with the symbolic level of representation at a more advanced level of chemistry learning.

Contribution of the construct maps

The uses of construct maps suggested by Wilson (Wilson 2005, 2008, 2009) and implemented as the foundation for this study and have been used to guide the design and the analysis of the study to characterize what students know and what they still struggle with. This knowledge of student understanding is important so teachers and educators can adjust their unit's instruction accordingly. Thus, the proposed construct maps and the related findings may provide input for curriculum development and help instructors to break down the concept of chemical reactions into the elements that contribute to this big idea. Teachers can also use the suggested construct maps in conjunction with the curriculum to inform their lesson plans and to establish relevant connections among the sub-ideas that are taught. Furthermore, teachers can use construct maps to guide their assessment. For instance, the construct maps may assist with aligning the assessment items with the curriculum content, contribute to identifying what ideas need to be assessed, and in verify that the assessment items set cover the whole range of ideas that need to be covered. *Knowing What Students Know* (NRC, 2001) drew attention to many of the drawbacks of existing assessments. In their view, many assessments fail to track the growth in student understanding during instruction and are often not aligned with the curriculum. The construct maps, therefore, can be used as one possible way to overcome the limitation in current assessment brought up by the National Research Council (NRC, 2001). The construct maps may also be useful for upper grades instructors/educators who want to take into account what their student have learned prior to taking their class.

Limitations of the Study and Future Research

This study has some limitation, which need to be highlighted. The main limitation is that it is a preliminary exploration of the construct maps. Further research is needed to validate them. Another major limitation is that there is limited data on the middle points. Furthermore, the findings of this study should be considered only illustrative because they make use of data from 7^{th} grade students at a single middle school. Further, the school is not typical of most middle schools because it is an independent school, has small classes, and is staffed by experienced teachers who are knowledgeable of inquiry based teaching strategies. Nevertheless, the study does suggest what students are able to learn in that particular environment, with minimum interference from non-curriculum related issues such as inexperienced teachers and or big classes. Future research may include students from different kinds of middle schools. In addition, it may be informative to study other age groups, looking into how the big idea that has been investigated in this study (chemical reaction) develops in the continuous of learning process.

Further, my study focuses on how far students can learn when they are in a good instructional environment; the curriculum has been in place for several years, the teachers are experienced, knowledgeable about inquiry based materials, and care about their student learning, one of the teachers even has an ownership on the curriculum (she is part of the development team of the unit), the class size is small (64 students in five different classes), and the students seemed to be motivated students with few behavioral constraints. Thus, the study results are likely to represent what student can learn in the "best case scenario" and it is reasonable to assume that we should not expect middle-school students to go beyond the level of understanding that has been presented in the extant study. In relation to the difficulties that the student experience, it is likely to assume that other students who learn in a different environment with more restrictions such as inexperienced teachers and or big classes will struggle the same and even more.

Another limitation is that some of the assessment items used for this study (some of the pre/post-tests items) are pre-existing assessment items that were not developed for the purpose of this study. However, this limitation was addressed by adding more assessment items specifically created for the study. Also, the new assessment items created for the purpose of this study may be revised based on feedback from this study before they are used for future research.

Refinement of the construct maps

The current construct maps were based on, but not exclusively so on the IQWST curriculum. Further refinement of the construct maps could be undertaken. This refinement could include additional national, state and local standards such as those focusing on reaction rate. In this regard, the *Benchmarks for Science Literacy* (AAAS, 1993) provide the following benchmark: "The temperature and acidity of a solution influence reaction rates. Many substances dissolve in water, which may greatly facilitate reactions between them." 4D/M4. This benchmark can later serve as a foundation for student future learning of related advanced topics such as catalysts and cell function. More specifically, looking ahead to high-school, students are expected to learn, for example, that "Most cell function best within a narrow range of temperature and acidity. At very low temperatures, reaction rates are too slow. High temperatures and/or extremes of acidity can irreversibly change the structure of most protein molecules. Even small changes in acidity can alter the molecules and how they interact." 5C/7 (9-12 Benchmark).

In addition, in reference to the "mass conservation" construct map it is apparent from the data that items that are associated with the mass conservation at the macroscopic level were easier to students than items at the microscopic level. But, Project 2061 found that understanding the mass conservation at the substance level understanding was harder than at the atomic level understanding (Herrmann-Abell, 2010, personal communication) and that "students tended not to get the mass conservations items correct unless they got the atoms conservation items correct" (Roseman, 2010, personal communication). Their interpretation of the data is that students need a molecular model for thinking about conservation. However, in their path analysis (DeBoer et al., 2009) the microscopic level is still placed above the macroscopic level with a strong path coefficient between idea G (conservation of mass at the substance level) and idea H (conservation of mass at the atomic level) and there is no arrow in the other direction (from the atomic level to the substance level). Considering their results, a future research may consider focusing on those two sub-levels in an attempt to refine the relationship between the two levels of understanding. I predict that the relationship goes both ways, a molecular model for thinking about conservation help to understand the phenomena at the macroscopic level and a better understanding at the macroscopic level helps to interpret the phenomena at the microscopic level.

Summary of Major Findings

This study uses construct maps to characterize 7th grade students' learning of a core idea in scientific literacy (chemical reaction) as they participate in a coherent curriculum. The main findings show that prior to the curriculum experience, students had not yet mastered any of the levels in any of the three construct maps, which is also expected especially prior to the unit's instruction. Students, for example, used everyday terms (not scientific ideas) to describe what materials looked like, had a limited understanding about what constitutes matter, and struggled with distinguishing the different types of particles. After completing the first part of the curriculum in which the students learned about substances and properties, but before they learned that substances interact to form new substances and conservation of mass, most of the students seemed to have a general idea that a property is a characteristic of a substance. However, the data reveals some gaps in their understanding. Many students still had difficulties distinguishing between atoms and molecules and use the terms molecules and atoms interchangeably. After completing the unit's instruction, there was a noticeable increase in students' understanding of all three sub-constructs; however, there were still gaps in their understanding. Most of the students could distinguish properties from non-properties and seemed to understand that a property is a characteristic of a substance and most of them could correlate specific phenomenon with its type (chemical reaction/mixture/phase change). Most of the students could differentiate between atoms and molecules at the microscopic level, but not at the symbolic level and most of them understood that a chemical reaction results in a rearrangement of the atoms. Overall, most students understood the mass conservation at the macroscopic level, but not yet at the microscopic and symbolic levels. Students also tended to think of an open system as a system in which mass is lost rather than that mass can either be gained or lost.

Results also show that student understanding in each of the three sub-constructs was related to their understanding and directly affected the understanding of the other sub-constructs and together they contribute to the understanding of student understanding of the chemical reaction big idea. Dependencies were found, for example, between student understanding of the change of properties and their understanding of mass conservation, between student ability to differentiate atoms from molecules and their understanding of mass conservation, and between their understanding of what is and what is not a property and their ability to determine whether or not a chemical reaction occurred.

The findings from this study show that the chemical reaction construct, although it is a core concept that is fundamental to the field, is a far more complex and difficult process than it might seem and this complexity is underexplored in the research literature. My study contributes to this gap in the literature. More specifically, in reference to student learning of properties, there appears to be only a few studies (e.g., Project 2061) that are related to student understanding of that sub-construct. Previous studies have suggested that this idea of characteristics properties that are changed during chemical reaction should be explored (Driver et al., 1994; Smith et al. 2006; Vogelezang, 1987). My study does this work and builds upon those suggestions. In reference to student learning of rearrangement of atoms, previous work has investigated sub-ideas that are included in the construct map (e.g., the particulate nature of matter or student understanding of different types of particles), but focused on separate ideas rather than how these ideas are relate to the larger understanding of a big idea, which my study does. In reference to student understanding of the conservation of mass, a thorough search of the literature reveals little in the research literature at the middle school level. But, interest in this area is growing (e.g., Project 2061). There are a few studies on student understanding of mass conservation at the middle school level, but in relation to mixtures and phase changes (e.g., Stavy, 1990). Even at the high school level, most of the studies focus on the symbolic level (e.g., Özmen and Ayas, 2003) or on student understanding of specific reactions (e.g., burning reaction). My study adds to the existing literature and more narrowly focuses on middle-school student understanding of mass conservation at both the macroscopic and the microscopic levels of understanding.

This understanding is important because students at middle school are building their foundation for the understanding of big ideas in science. To ensure that students have this foundation it is important to know what students know and what they still struggle with. Such information can contribute to the development of curricula that promote the interconnection and interrelatedness of ideas in obtaining new knowledge. As a core concept, educators have to know what leads to students learning and where the difficulties arise so as to address them and establish a foundation for future science learning. Thus, this study contributes to the small, but growing body of literature on middle school students' understanding of chemical reactions.

Concluding Remarks

The main findings have shown that students' understanding of chemical reaction comprises of many components of understanding and that each component by itself is important for student growth and further developing understanding in his/her subsequent learning. Overall, after completing the curriculum, student understanding in each of the three sub-constructs was related to their understanding and directly affected the understanding of the other sub-constructs.

The construct maps have contributed to our understanding of how students learn chemical reaction, which appeared to be a far more complex and difficult process than it might seem, but is fundamental to an understanding of science. The construct maps lay out what students are expected to learn. In this study, they are also found to be useful for determining what students have learned. As such they can be instrumental for seeking evidence for learning and characterizing student understanding at other big ideas.

Appendices

Appendix A - Interview Protocol

1st set of interviews:

<u>Part 1 (Question 1)</u>: I'm going to begin by showing you some stuff and asking you some questions.

Take a look at this dish of stuff (Show a container with Sugar). Describe this stuff for me.

- Can you describe me what you see?

Possible Responses	Prompts
Does not describe, but tries to identify. (e.g. says that it is sugar)	• If someone didn't know it was sugar, how would you describe it to them?
Describes some observations, may or may not describe properties, may or may not mention state of matter.	• Prompt for more descriptions. • What **<u>tests</u>** could you do in science class to identify this stuff? Or to find out more about this stuff?
Mentions terms such as mass, volume, texture, solubility, melting point, density in response.	• When you say_____, what do you mean? • If I take only one teaspoon of sugar, will it still has the same _______

<u>Part 2 (Question 2)</u>: show a container with salt; ask again to describe it and to compare it to the sugar description in part 1.

<u>Comment</u>: This part (part 2) I will do at the end of the interview, if time allowed. I put it here because the content fits here.

- Can you describe me what you see?
- Then, ask to compare between the two stuffs - is it the same stuff as the one before (the sugar)? Why? Why not? What <u>tests</u> could you do in science class to figure out if they are the same or different? How would those <u>tests help</u> you to figure out whether they are the same or different?
- What *property* means in science? What are some examples of properties of these two things?
- Are there ways to describe these two things that are not properties? What ways? Why are they not properties?

Reference to the construct maps:

Through the above two parts (part 1 and part 2) of the interview I try to learn where the students at in the "change of properties" construct map (Figure 2). This part of the interview refers to the first two bottom levels (levels 1, and 2), in which students should master the understanding that a property is a characteristic of a substance and it is consistent and not determined by the amount of a substance, and that each substance presents a unique set of properties.

Both parts 1 and 2 are related to students understanding at the macroscopic level.

Part 3 (Question 3): If we had a magnified pair of glasses that are very powerful and can magnify (enlarge) millions of times - what will you see? What makes up this table spoon of sugar?

Possible Responses	Prompts
Does not know OR gives no response	• Try to think of what the matter is made up from? Have you ever discussed it in the class?
Particles	• What do you mean by particles? • What kind of particles? • Try to prompt the students to get to the molecule term, if not ask - have you ever heard of molecules? And then go to the related prompts for the "molecule" response
Molecules	• What do you mean by molecule • How many sugar molecules? • Does the molecule of solid sugar and liquid sugar looks the same or different? Why?
Atoms	• What do you mean by atoms • Try to prompt the students to get to the molecule term, if not ask - have you ever heard of molecules? And then go to the related prompts for the "molecule" response
Any other response rather than particles/molecules/atoms	• Do you know the scientific name/term for that? • Try to prompt the students to get to the molecule term, if not ask - have you ever heard of molecules? And then go to the related prompts for the "molecule" response

<u>Part 4 (Question 4)</u>: I show a molecular structure (and a 3D model consisting balls and sticks) of a sugar molecule to the student and ask:

- Can you describe the sugar molecule to me? Can you tell me something about the sugar molecule?

Possible Responses	Prompts
Does not know OR gives no response	• Have you heard of molecules before? • What can you tell me about the molecule presented in the model?
Made of atoms	• What do you mean by atoms? • What's the difference between an atom and a molecule? • How many atoms? • How many types of atoms • Do all sugar molecules will have the same number and type of atoms? • What is in between the atoms?
Other response rather than atoms	• Do you know the scientific name/term for that? • Try to prompt the students to get to the atom term, if not ask - have you ever heard of atoms? And then go to the related prompts for the "atom" response

<u>Reference to the construct maps</u>:

Through the above two parts (part 3 and part 4) of the interview I try to learn where the students at in the "rearrangement of atoms" construct map (Figure 3). This part of the interview refers to the first two bottom levels (levels 1, and 2), in which students should master the understanding that matter is made of particles, made of molecules, made of many molecules, that molecules is made of atoms, and distinguish between molecules and atoms.

Both parts 3 and 4 are related to students understanding at the microscopic level.

Part 5 (Question 5): In the first part of the interview (description part), you mentioned that the sugar is in a solid state (or if not, ask what the state of matter is), and then ask:

- What shell we do to change the solid sugar to liquid?

Possible Responses	Prompts
Does not know OR gives no response	• Do you have an example of other substance that can change from solid to liquid? Students might give a specific example such as melting ice to water, then ask what did we do in that particular example.
Heat it	I take a candle and melt the sugar • Ask what happened • If say, "melted", what does it mean? • What has been change, what is the difference between the sugar before and after heating it, • Can draw the particles before and after heating it representing each sugar molecule as a simple circle (o)? • If we had a scale and we were weight it before and after heating it, would the mass stay the same or change? Why? • Can we get it back to sugar solid? How?
Put in water (or any other liquid)	I add a spoonful of solid sugar in water (dissolve it) • Ask what happened. If the sugar sank in the bottom, stir it (until all sugar dissolve) and then ask again what happen. • Where is the sugar now? Can we see it? What happened to the sugar? How can we check it? • If students mentioned "dissolved" ask - tell me more about what it means for something to dissolve. • What dissolved? Why did it dissolve? What evidence do you have that dissolving happened? • Can we get it back to sugar solid? How? • Is dissolving the sugar in water change it to liquid? --- students need to get at this point that to change it to liquid they need to do something else, if say "burn"/"heat" – go to prompts for those responses respectively
Burn it	I burn the sugar in the table spoon • Ask what happened • What is the difference between the sugar before and after burning it? • If we were weight it before and after heating it, would the mass change? Why? • After burning the sugar, can we get it back to the sugar solid? Why? Why not? How? • Is burning the sugar change it to liquid? --- students need to get at this point that to change it to liquid they need to do something else, if say "put in water"/"heat" – go to prompts for those responses respectively

Part 5 is related to both students understanding at the macroscopic level and the microscopic level and the connection between the two levels of understanding. This part refers to the first level in the “rearrangement of atoms” construct map, where students are expected to learn the three states of matter, and also refers to the fourth level of that construct map and the “change of properties” construct map where students are expected to distinguish between phase change, mixtures, and chemical reaction. A wrong response, such as (burn it, put in water) will reveal difficulties in distinguishing between the different phenomena.

The prompt question, in which I ask if the mass stay the same or change, refers to the second level of the “mass conservation” construct map. At this point students are not expected yet to know that the mass is conserved.

Comments:

Some of the prompt questions that are presented here referred to upper level understanding that the students are supposed to learn only in the continuous of the unit or even only at the end, such as the understanding whether or not the mass is conserved in each of those processes.

Part 6 (Question 6): Below is a table of substances with each of their melting and boiling points.

	Melting point (°C)	Boiling point (°C)
A	1,535	3,000
B	-220	-183
C	-100	-35
D	0	100
E	-259	-253
F	808	1,465
H	-23	77

Which of the above substances is a solid at room temperature (25°C)?

Which of the above substances is a liquid at room temperature (25°C)?

Which of the above substances is a gas at room temperature (25°C)?

Explain:

What can I learn from this question?

Students use the melting point as an example for a property. They do not expect however to have a deep understanding of the meaning of melting point, but are only expected to use melting point data to determine if the property has been changed or not. This question going beyond those expectations, checking if students understand what melting point (and boiling point) means and its role in everyday life phenomena. This question is beyond the curriculum expectations but can reflect on students understanding of the three states of matter. This is an example where I expect large diversity in students' responses, in which I expect high achievement students to answer the question correctly, while low achievement students may not be able to answer it correctly.

2nd set of interviews:

<u>Part 1 (Question 7):</u>

I have two expensive rings that look the same. I would like to know whether or not they are made of the same materials (without damaging the rings).

To check whether or not the two rings are made of the same material, I put each of the rings in a graduated cylinder that has 20 ml of water in it and measure the displacement of the water (volume before and after). Is this enough to see if the materials are the same or not?

<table>
<tr><th>Possible Responses</th><th>Prompts</th><th>Reference to construct maps</th></tr>
<tr><td>Yes</td><td>- How sure are you of your answer? Why do you think that it is enough?
- What can displacement tell you about the ring? Prompt the student to get to the understanding that displacement tell us about the volume. …, does volume stay the same regardless of the amount of a substance? Is volume a property?</td><td rowspan="2">This part of the interview refers to the first two levels (levels 1 and level 2) in the “change of properties” construct map, in which students should have mastered the understanding that a property is a characteristic of a substance and is consistent regardless of the amount of a substance. Students also should have mastered that a different set of properties means different substances and different substances have different set of properties.

From the students responses I can learn if students understand that adding the ring to the water is done to check the volume of the ring and volume by itself is not a property. They need to know that they have to also measure its mass and then find the relationship between the mass and the volume in order to figure out the density, which is a property.

I can also learn if students understand that comparing one property only is not always enough to know if the materials are the same or not. If the single property is the same, more tests need to be done.</td></tr>
<tr><td>No</td><td>- How sure are you of your answer? Why do you think that it is not enough?
- What would you do differently?
- Expected answer is measure it’s mass to find out the density (the relationship between the mass and the volume), which is a property.
- You measure the mass and calculate the density. What next?

Students are expected to know that:
- If the densities of the two rings are the same, it is only one property, which is not enough by itself and more measurements are needed to determine other properties. Students are not expected however to know what other tests could be done without damaging the rings (such as shininess, magnetism, conductivity, etc.).
- If the densities of the two rings are different, we can conclude that the two rings are made of different materials.</td></tr>
</table>

Reference to the construct map and what can I learn from this?

This part of the interview refers to the first two levels (levels 1 and level 2) in the "change of properties" construct map, in which students should have mastered the understanding that a property is a characteristic of a substance and is consistent regardless of the amount of a substance. Students also should have mastered that a different set of properties means different substances and different substances have different set of properties.

From the students responses I can learn if students understand that adding the ring to the water is done to check the volume of the ring and volume by itself is not a property. They need to know that they have to also measure its mass and then find the relationship between the mass and the volume in order to figure out the density, which is a property.

I can also learn if students understand that one property only is not enough to know if the materials are the same or not, and more tests need to be done.

Part 2 (Question 8):

A student believes that he has measured a new property that he did not learn about in class. He calls his new property "Crad". Here is a table of Crad measurements for different objects:

Object	**Crad (cr)**
Copper kettle	14 cr
Copper wire	31 cr
Aluminum pen	89 cr
Nickel wire	31 cr

Based on his results, do you think "Crad" is a property?

Prompt questions:

- What info did you use to make your choice?
- How sure are you of your answer? Did you guess? If yes, what led you to this particular guess?
- Tell me more what you meant by __
- What does *property* means in science? What are some other examples of properties?
- Did you find any aspects of the question confusing? In which parts were you confident?

Reference to the construct maps:

This part of the interview refers to the first level (levels 1) in the "change of properties" construct map, in which students should have mastered the understanding that a property is a characteristic of a substance and is consistent regardless of the amount of a substance.

From the students' responses I can learn if they understand that if "Crad" is a property, copper wire and copper spoon are supposed to have the same values (in "cr" units).

If students explain that "Crad" is a property because the copper spoon and the wooden spoon have the same values, I can learn that students have difficulties understanding that the property refers to the material that the spoon is made of and not to what it is used for.

Comment: This question has been modified from another question from the post tests on which the students did poorly (in previous years). I use similar question in the interviews, making some changes, such as replacing the "Yepop" word with a different word, "crad" that also has no meaning in the language but sounds less like a “nonsense” word. I also changed the list of objects and the measurement results. I did not use the exact same question so students will not be biased when taking the post tests. Through the interviews I hope to delve into the extent of students understanding of properties. By this, I also hope to get feedback on the post-test question, whether or not it was just a bad question or the idea of consistency of properties regardless of their use or amount is hard to understand.

Part 3 (Question 9):

A student has two test tubes with 10 ml of colorless liquid in each of them. He wants to figure out if the two liquids are the same or different substances. Which of the following is the best method to use?

A. Measure the mass and temperature of each liquid and compare
B. Mix the two liquids together and see if the liquids separated into two layers
C. Pour the two liquids together and then test the properties
D. Compare the density, freezing point, and boiling point of each liquid

Prompt questions**:**

What info did you use to make your choice?

Did you guess? How sure are you of your answer?

Reference to the construct maps:

This part of the interview refers to the second level (level 2) in the “change of properties” construct map (Figure 2), in which students should have mastered the understanding that different substances have different set of properties.

Option A is not the correct answer since mass by itself is not a property. We need also to know the volume in order to find out the density, which is the relationship between the mass and the volume.

Option B is not the correct answer since by mixing the liquids and seeing if they are separate to two layers students can figure out if the two liquids have different densities or not, but this is only one property.

Option C is not the correct answer since pouring the two liquids together might result a reaction and then the properties would change.

Option D is the only option that includes a set of properties, and not only one property.

<u>Part 4 (Question 10):</u>

Below is a table of "specific heat" measurements for different objects:

Objects	**Specific heat (cal/g° C)**
Nickel door handle	0.106
Aluminum pen	0.217
Copper wire	0.093
Nickel wire	0.106

Based on the data in the table above, do you think "specific heat" is a property?

<u>Prompt questions:</u>

- What info did you use to make your choice?
- Tell me more what you meant by __
- What does *property* means in science? What are some other examples of properties?
- Did you guess? If yes, what led you to this particular guess?

<u>Reference to the construct maps:</u>

This part of the interview refers to the first level (level 1) in the "change of properties" construct map (Figure 2), in which students should have mastered the understanding that a property is a characteristic of a substance and is consistent, regardless of the amount of a substance or its use. To justify that specific heat is a property students need to refer to the specific heat measurements of nickel wire and nickel door handle that are the same because they are made of the same substance, nickel, and are different from the specific heat measurements of objects that are made of different substances. Students also may refer to the measurements of the two wires, copper wire and nickel wire that despite their similar functionality, they have different measurements because they are made of different substances.

<u>Comment:</u> specific heat is a property that is most likely not familiar to 7^{th} grade students. An unfamiliar property was chosen on purpose, so students will not base their answer on prior knowledge but only on the given data.

Part 5 (Question 11):

A balloon filled with helium gas is set free and starts to move upward.

Why does helium balloon move upward?

Following up questions:

- What do you mean by density? How can you measure the density of the helium in the balloon?
- A bigger balloon filled with helium. What will happen?
- If you were wearing very powerful glasses, allowing you to see individual particles of the helium and air. If I ask you to draw the model of helium particles and air particles, how would you explain the density difference at the particles level?

Reference to the construct map and what can I learn from this question?

This question checks if students understand "relative density". The helium balloon moves upward because the density of helium is less than the density of the air in the surrounding environment. When students asked what will happen to the bigger balloon, they are expected to know that the density is a property and independent on the size (level 1, "change of properties" construct map). By asking the students to explain the density differences using the particles model, I refer also to the first level of the "rearrangement of atoms" construct map.

Comment:

This question is based on a multiple choice question given in TIMSS exam, in which students were asked which of the following best explains why the helium balloon moves upward?

a. The density of helium is less than the density of air.
b. The air resistance lifts the balloon up.
c. There is no gravity acting on helium balloons.
d. The wind blows the balloon upward.
Correct response: A

Part 6 (Question 12):

Which of the following is the smallest?

1. An atom
2. A bacteria
3. The width of air
4. A cell in your body

This question was taken from the 2061 assessment project (presented by professor DeBoer in the AAAS Project 2061 Science Assessment Seminar in Ann Arbor, February, 2009). The question refers to basis of particulate nature of the matter (level 1, “rearrangement of atoms” construct map) in which students are expected to estimate the size of atoms in compared to other “objects” from everyday life. This is not a main learning goal in that unit, but it would be nice o get students’ perspective of how they picture atoms in their mind. It would be also nice to compare how the students participated in this study perform compared to the performance of the students that are participated in Project 2061 testing study.

3rd set of interviews:

<u>Part 1 (Question 13):</u>

<u>Step 1</u>: A science teacher mixes 50 ml of colorless water with 50 ml of colorless alcohol and gets a mixture of water & alcohol.

Prompt questions	Possible responses/comments
- What do you think the volume of the water-alcohol mixture will be? Why?	Possible answers: 100ml (which is the sum of the volume of its component), less than 100ml or more than 100ml

<u>Step 2</u>: The teacher measures the volume of the mixture and the resultant mixture is only 96 ml (not 100 which is what students would have expected).

Prompt questions	Possible responses/comments
- Why is the volume of the mixture less than the sum of the volumes of its parts? -	At this point, students may suspect that some liquid has been lost in the transfer. If students suspect loss of liquid in the transfer, ask what test you can do to check if liquid has lost. If needed, give a hint that you (the student) allow to start over the experiments. Students may suggest that in order to check if some liquid has been lost, we can start over the experiment measure the mass before and after mixing the water and the alcohol.
- What do you think the mass of the mixture will be? Why?	Students are expected to know that if no liquid has been lost the mass should be equal to the total mass of its parts.

<u>Step 3:</u> The teacher measures the mass of the mixture and its mass is equal to the total mass of its parts. (In doing this, the teacher rules out the possibility that some liquid has been lost in the transfer.)

Prompt questions	Possible responses/comments
- Is this an open system or a closed system? Why? What information supports your decision? - Why is the mass of the mixture equal to the mass of its parts?	
- Going back to the change in volume	

(volume decreased), do you suspect that some liquid has been lost in the transfer? Why? Why not? What information in the described scenario did you use to support your decision?	
- Why is the volume of the mixture less than the sum of the volumes of its parts?	

Step 4: Here is a model (I show a model of the water and alcohol molecules, consisting of balls and sticks) of few molecules of water (H2O) and a few molecules of ethanol (ethyl alcohol, CH3CH2OH).

Ethanol molecules:

Water molecules:

Prompt questions	Possible responses/comments
- How many types of atoms do we have? Show me the atoms. - How many atoms do we have? - How many types of molecules do we have? Show me the molecules. - How many molecules do we have?	

Step 5: I then ask the students to use the models to demonstrate the formation of the water-alcohol mixture as described in the phenomena above.

Prompt questions	Possible responses/comments
- What happened to the molecules? - Does the number of molecules stay the same?	If students break the molecules apart, ask them to explain what they did and why. If students just move molecules around, mixing the 2 types of molecules, ask them to explain what they did and why.

- What happened to the atoms? - Does the number of atoms stay the same? - Do the types of the atoms stay the same? - When the volume decreased, do you think that the atoms became smaller/stayed the same or become larger? Why?	
- Using the models, how can you explain that mass has been conserved? How can you explain that the volume decreased?	
- Using the model, show me what a mixture of the two would look like? - Using the models, show me what needs to be done in order to have a chemical reaction between the water and the alcohol? What are the possible products?	Students that can distinguish chemical reactions from mixtures are expected to show that molecules do not remain unchanged but must break apart and the atoms need to rearrange, forming new molecules.

<u>Reference to the construct map and what did I learn from this</u>?

"One plus one" does not always equal two. One case is the phenomenon of mixing two equals volumes of water and alcohol, 50ml of each for example, the resultant mixture of water and alcohol is only about 96ml, not 100 ml, which is what would have expected by many students.

This is an example in which students need to explain how the volume of something can change when its mass or weight has been conserved. In this case, when alcohol and water mix the resulting volume of the two solutions is less than the total of the individual volumes, while its total mass has been conserved. The reason is that there are a lot of spaces between the alcohol molecules, like little pockets for the water molecules to fit in, thus mixing a cup of water molecules with a cup of alcohol molecules does not result two cups of liquids. A more advanced explanation (that is beyond the expectations from 7^{th} graders) for this decrease in volume can be attributed to the hydrogen bonds between the alcohol molecules and the water molecules. This hydrogen bond pulls the molecules really close to each other and the small water molecules will fit in the spaces between the alcohol molecules. 7^{th} grade students are not expected and are not familiar yet with intermolecular forces such as hydrogen bonds and are not expected to use it in their reasoning.

To develop initial understanding of the phenomena at the microscopic level, students are expected to understand that no matter was lost and the mass has been conserved; in other words, the number and types of atoms did not change before or after mixing the water with the alcohol.

The discussion about the mass conservation throughout the whole scenario refers to all the levels in the "mass conservation" construct map, where in the first level (level 1) students are expected to distinguish between a closed system and an open system. The discussion then refers to level 2, where students are expected to understand at the macroscopic phenomena level that the total mass before and after mixing the two liquids remains the same. The discussion then focuses on the third level, where students are expected to understand mass conservation at the microscopic level, understanding that the total number and type of atoms remains the same.

The "mass conservation" construct map used for this study refers to the mass conservation during a chemical reaction, but students were taught that it is true also for mixtures and phase changes, and are expected to apply this understanding for the mixture phenomena described in the discussed scenario.

Using the models, I will check if at this point students can distinguish between molecules and atoms. This refers to level 3 in the "rearrangement of atoms" construct map, where students are expected to differentiate between atom and molecules.

In addition, using the models, I will check if students understand that in contrast to a chemical reaction where molecules break apart and atoms re-arrange to form new molecules, in the mixture, molecules remain unchanged. This refers to level 4 of the "rearrangement of atoms" construct map, where students are expected to distinguish chemical reaction from mixture at the microscopic level.

Also, by asking the students to demonstrate the phenomena using the models I will check the connection between the macroscopic view of the phenomena (mass is conserved while volume change) and the microscopic view.

Step 6: I show a model of few molecules of ethanol (CH_3CH_2OH) and tell the students that the molecules are now in the liquid state, and ask:

Prompt questions	Possible responses/comments
- What will happen in the gas state?	
- What will happen in the solid state?	

Part 2 (Question 14):

I show students a molecule of propane C_3H_8.

Comment: To make a connection to everyday life, I tell the students shortly about propane. Propane is used as fuel in cooking on many barbecues, portable stoves and in motor vehicles. It is normally a gas, but compressible to a transportable liquid.

Step 1: One possible reaction of propane is:

$$C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$$

Comment: In class students discussed a similar reaction: $CH_4+2O_2 \rightarrow CO_2+2H_2O$. The reaction I am asking about here is similar but the total number of molecules is not the same before and after the reaction.

In addition, I ask students same prompt questions about a different reaction that is different from the one that has been discussed in class: $Zn + 2HCl \rightarrow ZnCl_2 + H_2$

Referring to the chemical reaction formula and ask the students:

Prompt questions	Possible responses/comments
- How many types of molecules did we start with? - How many types of molecules did we end with? - How many types of atoms did we start with? - How many types of atoms did we end with? - How many molecules did we start with? - How many molecules did we end with? - How many atoms did we start with? - How many atoms did we end with?	Ask the students to write their responses down in a table given to them (see below).
- How many molecules are there in reality? How big they are?	

Tables given to students to fill out:

Part 2, for the reaction: $C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$	Before reaction (start with)	After reaction (end with)
# of types of molecules, write down the molecules		
# of molecules (how many molecules)		
# of types of atoms, write down the atoms.		
# of atoms (how many atoms)		

Part 2, for the reaction: $Zn + 2HCl \rightarrow ZnCl_2 + H_2$	Before reaction (start with)	After reaction (end with)
# of types of molecules, write down the molecules		
# of molecules (how many molecules)		
# of types of atoms, write down the atoms.		
# of atoms (how many atoms)		

Reference to the construct map and what can I learn from this?

By asking what will happen in the solid state and in the gas state I refer to the first level in the “rearrangement of atoms” construct map, checking if students explain that when matter change the state of matter (from solid to liquid to gas to liquid to solid), in which molecules moves faster/slower, spread further/closer and move from orderly (in solid) to disorderly (in gas) arrangement.

By asking the students to count the number and types of atoms/molecules I refer to the 2nd level in the “rearrangement of atoms” construct map looking for evidence of learning, such as counting of the number of atoms, counting of the types of atoms, listing of different atoms, counting of the number of molecules, and counting of the types of molecules. In the first part (Part 1, Step 3) I as the students about the number and types of molecules and atoms showed in the model (model of water and alcohol molecules using balls and sticks), which refer to students understanding at the microscopic level. In the next part (Part 2), I add also the symbolic level, asking the students to count atoms and molecules in the written chemical equation. IQWST curriculum introduces the students to symbolic representation, but do not delve into stoichiometry and balancing equations. Understanding of chemical reaction at the symbolic level is expected only in advanced grades. This is one of the questions where I therefore expect variation with students’ responses, probably only high achiever students will be able to correctly count the atoms and molecules before and after the chemical reaction.

Part 3 (Question 15):

When water changes into ice, does the mass change? Why?
Does the density change? Why? Does the volume change? Why?
Do the properties change?

Reference to the construct map and what did I learn from this?

In the first interview, students were asked if the mass of the melted sugar will be the same or different from the mass of the solid sugar.

The purpose of asking a similar question again, is to check if at this point, after learning the mass conservation law students can apply it into a familiar everyday phenomenon.

Part 4 (Question 16):

Wood is placed on a scale (on fireproof containers), set on fire and burns. A pile of powder is left. The powder weighs less than the wood prior to burning.

1. Would you describe this scenario as occurring in an open or closed system? a. Open system b. Closed system c. There is not enough information to decide Explain your answer:_______________________ What information did you use to support your decision?	Q1 refers to level 1 of the "mass conservation" construct map – whether or not students' responses indicate that they can distinguish between an open and a closed system. Through students explanations I also hope to identify students' misconceptions about this matter. This Q is similar to Q1 in part 3 of the pre/post-tests, but in this case mass left the system rather than being added to the system as in the case of the pre/post-tests Q. Through students explanations I hope to check whether or not the students understand the meaning of open/closed systems. Choosing the correct answer by itself without a reasonable explanation does not reflect understanding but only the knowledge of terminology or successful guessing.
2. What best describes the cause of the weight difference? a. Some of the atoms in the wood burned out and disappeared b. The atoms in the wood changed and became smaller. c. Some of the atoms in the wood reacted with oxygen and formed gas that went into the air. d. The wood reacted. Why? Why not the other choices?	This part delves into the next level in the construct map, level 2 where students need to understand at the macroscopic level, the reason for the change in mass.
3. Are the number of atoms of the powder the same, less or more than the number of atoms in the wood? d. More e. Less f. Same Why? Why not the other choices?	This part delves into the next level, level 3 in the construct map (microscopic level), where students make the connection between the mass change and the change with the number of atoms.
4. Are the properties of the system before and after burning the wood the same/different? Why?	This part refers to the third level in the "change of properties" construct map, in which students are expected to know that a chemical reaction results in new substances with a new set of properties

Part 5 (Question 17):

Question 17 (3rd set of interviews):

A test tube is half filled with vinegar. Baking soda is placed in a balloon. The opening of the balloon is wrapped around the opening of the test tube, while making sure that the balloon contents are not released into the test tube (see Figure below labeled "before"). The contents are then released into the test tube. The balloon inflates (see Figure below labeled "after").

Before After

Specific questions asked on the above scenario	Reference to the construct maps
1. Would you describe this scenario as occurring in an open or closed system? a. Open system b. Closed system c. There is not enough information to decide Why? 2. What caused the balloon to inflate? a. The atoms changed into other atoms that take up more space. b. The number of atoms increased. c. The molecules changed into other molecules that take up more space. d. The mass in the system increased. Explain your choice: 3. Is the number of atoms in the system after the balloon inflated the same, less or more than the number of atoms before? a. More b. Less c. Same d. There is not enough information to decide Why? Why not the other choices?	In order to answer the question correctly, students should master all three levels of the "mass conservation" construct map. Students should know that the reaction is taking place in a closed system (level 1 in the construct map) because nothing can get in or out, assuming of course that the balloon is airtight and nothing can get in or out. They also need to know that the mass doesn't change (level 2 in the construct map) and the number and type of atoms do not change (level 3). Q2: Students who choose options "a" or "b" do not understand that in a closed system the number and type of atoms do not change. Students that choose option "d" have difficulties to understand that during a chemical reaction in a closed system, the mass remains the same. The question on purpose doesn't explicitly say whether or not mass has been changed. At the highest level I expect students to say that the system is seemed to be closed but we can't know for sure unless we get mass measurements before and after verifying that the mass of the system did not change. Students at that level will indicate that there is not enough information to decide (in both Qs 1&3) and will support their choice reasoning that we are missing information whether or not mass has been changed. Through the explanations I hope to learn also to learn more about possible misconceptions.
4. Are the properties of the system before and after the balloon inflated the same/different? Why?	This part refers to the third level in the "change of properties" construct map, in which students are expected to know that a chemical reaction results in new substances with a new set of properties.

Appendix B- Pre/Post Test

Part 1 - Multiple Choice Questions (pre-existing items)

1. To determine if a chemical reaction occurred, you should measure and compare which of the following?

   volume of the materials
   A. shape of the products
   B. properties of the substances
   C. mass of the reactants

2. A chemical reaction occurs when a student mixes carbon dioxide (CO2) and water (H2O).

   $$CO_2 + H_2O \rightarrow \ ?$$

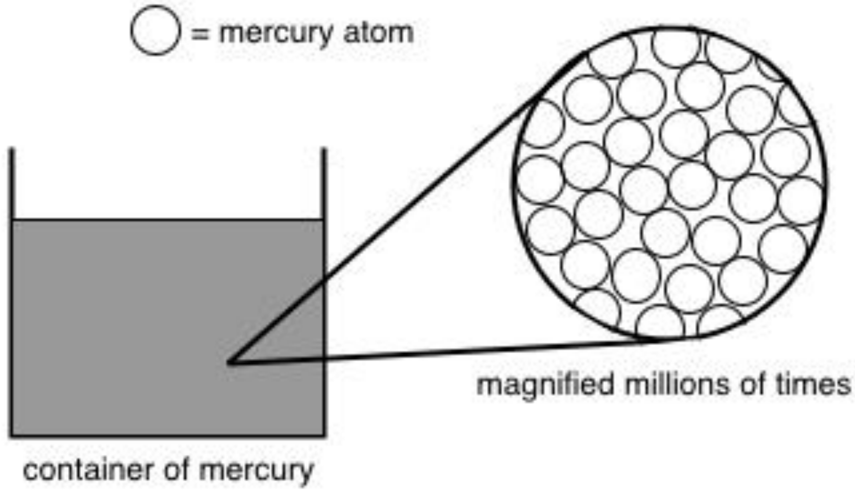
   Using the principle of conservation of mass, which of the following could be the product of the reaction?

   A. $H_2O_2 + CO_2$
   B. H_2CO_3
   C. $H_2O + CO_2$
   D. H_3CO_2

3. A student found 2 green powders that look the same. He wants to figure out if the 2 powders are the same or different substances. Which of the following is the best method to use?

   A. Measure the mass, volume, and temperature of each powder and compare.
   B. Combine both green powders and see if there is a chemical reaction.
   C. Mix the 2 green powders together and then test the properties.
   D. Determine the density, solubility, and melting point of each powder and compare

4.



The model above represents which of the following?

A. a phase change
B. a substance
C. a chemical reaction
D. a mixture

5. Which of the following is an example of a chemical reaction?

A. mixing lemonade powder with water
B. burning marshmallows over a fire
C. melting butter in a pan
D. boiling water on a stove

6. A piece of copper is a substance because it

A. is made of the same type of atom throughout.
B. consists of many different types of atoms.
C. can be made into something different.
D. reacts with other substances.

7. A student performs the same chemical reaction experiment twice — once in an open system, and again in a closed system. The mass before the chemical reaction is 13 grams. The chemical reaction produces a gas. What would you expect the mass to be after the chemical reaction in the open and closed systems?

   A. 13 grams in the open system and 15 grams in the closed system
   B. 13 grams in the open system and 11 grams in the closed system
   C. 11 grams in the open system and 13 grams in the closed system
   D. 11 grams in the open system and 15 grams in the closed system

8. A student believes that she has measured a new property that she did not learn about in class. She calls her new property "Yepop". Here is a table of Yepop measurements for different objects:

Object	**Yepop (yp)**
Copper wire	132 yp
Copper spoon	240 yp
Glass jar	89 yp
Wooden spoon	240 yp

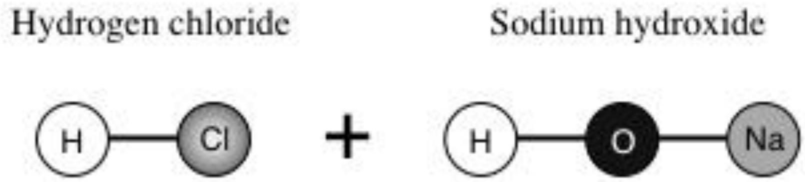
   Based on her results, do you think "Yepop" is a property?

   A. No, because the copper objects have different measurements.
   B. No, because the same substances have the same measurements.
   C. Yes, because the spoons have the same measurements.
   D. Yes, because the different substances have different measurements.

9. A chemical reaction occurs when substances interact and their atoms

   A. disappear.
   B. change their size.
   C. become new atoms.
   D. recombine.

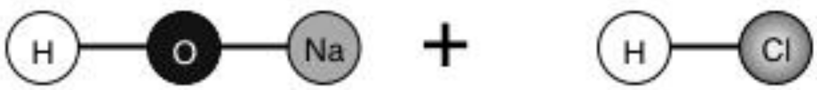
10. The following are models of two substances:



A chemical reaction occurs when hydrogen chloride and sodium hydroxide are mixed together. Which of the following are the products of the chemical reaction?

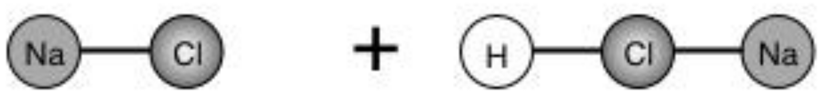
A.

B.



C.

D.



11. Which statement is always true about conservation of mass?

A. The total mass of the reactants is equal to the total mass of the products.
B. The mass of one reactant is equal to the mass of one product.
C. The total mass of a system changes in a chemical reaction.
D. The mass changes in a phase change, but not in a chemical reaction.

12. A property is

A. determined by the amount of a substance.
B. made of one type of substance.
C. a process to make a new substance.
D. a characteristic of a substance.

13. Which of the following is a possible chemical reaction?

A. $O_2 + CO_2 \rightarrow CO_2 + O_2$
B. $CuSO_4 \rightarrow CuSO_4$
C. $NaOH + HCl \rightarrow NaCl + H_2O$
D. $O_2 \rightarrow H_2$

14. Water (H2O) cannot be turned into salt (NaCl) through a chemical reaction because

A. salt is a mixture of atoms.
B. salt and water are made of different atoms.
C. water is made of three atoms.
D. water contains liquid atoms and salt contains solid atoms.

15. The total mass of two liquids is 32 grams. When a student combines the liquids in an open beaker, she observes bubbles. Then she finds that the mass of the combined liquids is 29 grams. This could be because molecules

A. became smaller.
B. escaped the beaker.
C. were destroyed.
D. packed closer together.

Part 3 – self developed items

Questions 16-19 refer to the following scenario:

Two pieces of magnesium are placed on opposite sides of a scale (on fireproof containers). The scale is balanced (see Figure 1), indicating that the weight of both pieces is identical. The magnesium on side A is set on fire and burns completely.

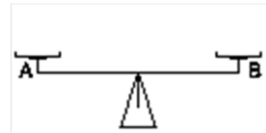


Figure 1

16. Would you describe this scenario as occurring in an open or closed system?
    a. Open system
    b. Closed system
    c. There is not enough information to decide

Explain your choice:

___

___

___

17. Once the magnesium on side A has burned completely, towards which side will the scale tip?
    a. The scale will remain balanced.
    b. The scale will tip to side A (the side of the burned magnesium, see Figure 2)
    c. The scale will tip to side B (the side of the un-burned magnesium, see Figure 3)

Figure 2

18. What is the cause of the weight difference, if any?
    a. There is no weight difference.
    b. Burning changed the magnesium into a heavier material.
    c. Some of the burned magnesium disappeared.
    d. Oxygen atoms combined with the magnesium.

Figure 3

19. Is the number of atoms of the burned magnesium the same, more, or less than the number of atoms in the unburned magnesium?
    a. more
    b. less
    c. same

Explain your choice:

___

___

___

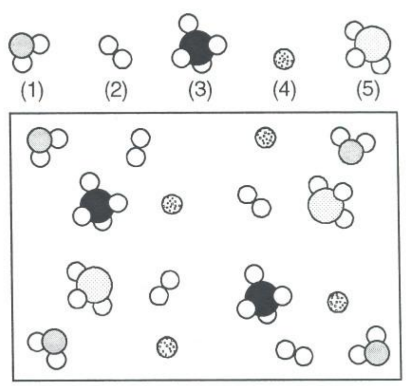
20. An electric current is passed through water. Bubbles appear. These bubbles are:
    a. Air
    b. Heat
    c. Oxygen and hydrogen gases
    d. Water vapors

21. What happens to water left outside in the sun in an open cup over time?
    a. The water is converted to vapors and goes into the air
    b. The water disappears and does not exist anymore
    c. The water goes through a chemical reaction breaking it down into oxygen and hydrogen gases
    d. Nothing happens

22. Which is an example of a chemical reaction?
    a. The melting of ice
    b. The grinding of salt crystals into a powder
    c. The burning of wood
    d. The evaporation of water from a puddle

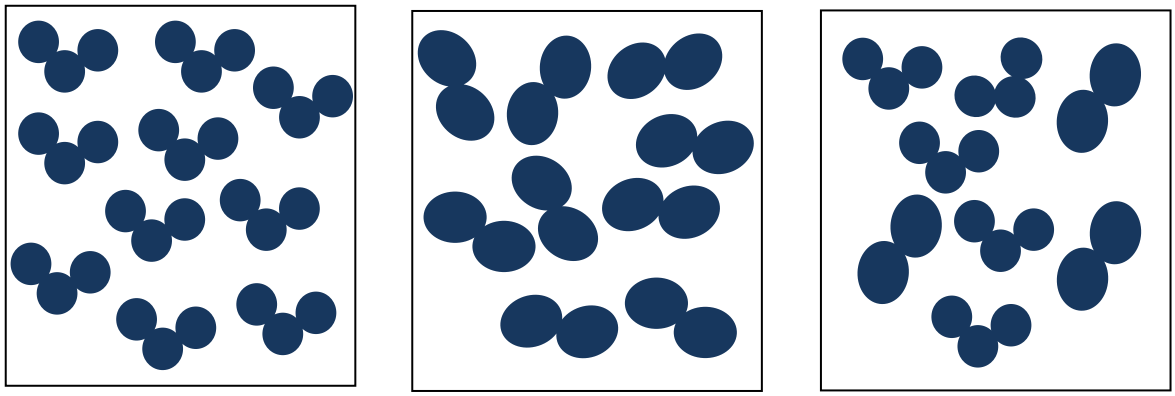
23. When sulfuric acid, H_2SO_4, is broken down into separate atoms, how many different atoms are there?
    a. Two
    b. Three
    c. Six
    d. Seven

24. The diagram below represents a mixture of gases.



Which of the following represent **ALL** of the examples of molecules in the diagram?
    a. 2,4
    b. 3,4,5
    c. 1,3,5
    d. 1,2,3,5

25. The diagrams below represent either pure substances or mixtures.



(1) (2) (3)

Which of the diagrams represents a pure substance?

a. 1 and 2
b. 1 and 3
c. 1 only
d. 2 only

Appendix C - Additional Findings beyond the Construct Maps Levels

In addition to the quantitative and qualitative data related to the sub-constructs, additional interesting findings emerged, although not directly related to any of the specific sub-levels of the construct maps. These additional findings are still worthy of discussion.

Time 1 (Additional findings): Before or at the very beginning of the unit's instruction.

1) Very often students used examples of properties in their explanations such as melting point, but there was a mixed understanding of what that property means and its use in everyday life. This was seen in question 6 on the pre-interviews when students were given a table of substances with each of their melting and boiling points, and were asked which of the substances will be a solid/liquid/gas at room temperature (25°C). Students' responses can be categorized into three main groups. About one-third of the students answered completely correctly (7/7 correct substances), another one-third of the students got none of the substances right and another one-third of the students got some right. Students who were completely correct also knew how to provide clear and logical description. For example, "because 25 is below the melting point, so it would be a solid, it hasn't melted." "H is liquid because it's above the melting point, but before the boiling point." One student even came with a general scheme: "A substance is a gas if the temperature is ≥ BP, A substance is a liquid if the temperature is m.p - b.p, A substance is a solid if the temperature is < m.p."

2) A common struggle was the confusion between Celsius and Fahrenheit degrees. Many students repeatedly compared the data that was given in Celsius degrees to the melting point and boiling point of water in Fahrenheit degrees. A student explained

for example that substance D (M.P. 0°C; B.P. 100°C) is a liquid at room temperature (correct answer) because "it boils at 100 which is lower than the boiling point of water, which is like 250." She described substance A (M.P. 1,535°C; B.P. 3,000°C) as a solid (also correct answer) because "the temperatures are high for like the melting and the boiling. Water's boiling point is like 250 or something and this is much higher." Although the student answered the multiple-choice part of both questions correctly, she did not appear to understand Celsius and repeatedly returned to the water example using Fahrenheit rather than Celsius. In all of her explanations, the student never referred to 25°C and whether this is below or above the given melting point or boiling point. She only compared the data to what she knows about water, and used only Fahrenheit.

3) Another difficulty was with understanding that each substance has a unique melting and boiling points. A student who was completely wrong in identifying the liquid, solid or gas phases of all substances (in question 6 on the pre-interviews mentioned above) thought for example: "because the temperatures are rarely normal as a solid would be." This student does not understand that the melting point is unique to each substance and that there are no normal melting point values. She is probably familiar with the water example and assumed that other substances have similar melting points.

4) Most students do not make a connection between the macroscopic and the microscopic level of understanding of the mass conservation law; in other words, they do not correlate the change of the mass with the change with the number of atoms. In the pre-test, for example, students were asked if as a result of a burning magnesium reaction the mass will change and toward which direction the scale will tip to (question 17). In a related question on the same scenario (question 19), the students were asked if the

number of atoms of the burned magnesium will be the same, more, or less than the number of atoms before the reaction. There was inconsistency in the students' responses to those two questions. Specifically, only half of the students (5 of the 10) who thought that the scale will remain balanced chose later on in question 19 that the number of atoms will stay the same, which is the expected answer if the student were making the connection between mass and number of atoms. Of the 27 students who chose the correct answer that the scale will tip toward the burned magnesium (meaning that burned magnesium weighs more) and only two chose in the follow-up question of the scenario (Q 19) that there will be more atoms in the burned side, which is the expected answer if they make the connection between more mass and more atoms. Sixteen students said that there will be fewer atoms and 9 students said that the number of atoms will stay the same. Of the 27 students who chose that the scale will tip toward the un-burned magnesium (meaning that burned magnesium weighs less), only about half of the students (15 out of 27) said that there will be fewer atoms, which is the expected answer if the student make the connection between less mass and less atoms, 3 students said that the there will be more atoms in the burned side, and 9 students said the number of atoms will not change. Interestingly, the distribution among the three alternatives (more, less, same number of atoms) is very similar in both groups of students, those who chose that the scale will tip toward the burned magnesium and those who chose that the scale will tip toward the un-burned magnesium. The inconsistency in the students' responses to questions 17 and 19, and the similar distributions show that the students have not yet made the connection between change with the mass and change with the number of atoms.

Time 2 (Additional findings): During the unit's instruction.

In addition to the pieces of evidence for learning in each sub-level of the construct map, students' responses to the mid-interviews revealed other difficulties worthy of discussion.

5) The use of unfamiliar language is hard for students.

An unfamiliar property (specific heat, "crad") was chosen, so that students would not base their answers on prior knowledge, but only on the given data. The use of unfamiliar language, whether "crad" or "specific heat", confuses students. Specific heat is a property that is most likely not familiar to 7th grade students. "Crad" is a word that was made up and has no meaning. A student said, for example, "it's kind of hard to explain it when I don't know what crad necessarily is." Two other students eventually answered the question that used the new word "crad" correctly, but were very confused at first and did not really respond directly to the question. They just said that they cannot really tell because "well I don't really know what those numbers are", or because they need to know how it was measured. After prompting the students to use the given data in the table they both answered it correctly. In a written test without the prompting that occurred during an interview, I assume that both students would just guess the answer (in case of multiple-choice question). In another question students were given a list of objects and their "specific heat" values and were asked if "specific heat" is a property or not. About one-third of the students (6 out of 16) gave irrelevant explanations trying, for example, to interpret what "specific heat" means rather than looking solely at the data. A student asked, for example, "so specific heat is the melting point or… ." In addition, three students eventually, after prompting, looked at the given data and provided relevant explanations. Thus, overall only half of the students looked directly at the data and provided relevant explanations, while the other half of the students were distracted by the new terminology and some of them ended up not giving a relevant explanation at all.

Time 3 (Additional findings): After completing the unit's instruction

This section examines student understanding of additional findings emerged that are beyond the construct maps levels, after completing the unit's instruction.

6) Difficulties in making the macroscopic-microscopic relationship:

In the vinegar – baking soda balloon inflation scenario (question 17 on the post-test) described earlier, students were also asked what happened to the total mass of the system after the balloon inflated, and if the number of atoms in the system after the balloon inflated the same, less or more than the number of atoms before. One-quarter of the students (4 out of 16) did not make the macroscopic-microscopic connection between the mass change and the change with the number of atoms, thinking that the mass changed (decreases or increases), but the number of atoms remained the same, or vice-versa, thinking that the mass did not change, but the number or types of atoms changed. Some students, for example, explained that the mass increased because "when the chemical reaction happened there was gases, but it went into the balloon, and so it added more mass to the system", but thought that the number of atoms stayed the same "because no atoms can appear or disappear."

In addition to that group of students, difficulties with the macroscopic-microscopic connection were found also among the group of students who chose that both the mass and the number of atoms did not change. As part of question 17 on the post-interviews, students were asked to choose what caused the balloon to inflate and to explain why they did not choose the other alternatives. Alternatives B ("the number of atoms increased") and D ("The mass in the system increased") referred to an open system situation where mass/atoms are added to the system. At least two students could not see that the two alternatives are associated with each other, but on a different level, where alternative B refers to the macroscopic level (the mass can change) and alternative D refers to the microscopic level (the number of atoms can change). One student, for instance, was explicitly asked for similarities and differences in the meanings of the two alternatives B and D and could not find any relationship between the two "because atoms and mass are different" and added that "they both ask for something that is increased, but then one is about mass, one is about atoms."

Difficulties with making the connection between the macroscopic and the microscopic view of the mass conservation law was seen also on questions 17 and 19 (burning magnesium scenario) of the pre-test, though student understanding improved by the post-test. Question 17 asks students which side (burned vs. unburned) has more mass and on the follow-up question (question 19) students were asked which side (burned vs. unburned) has greater number of atoms. Only half of the students on the pre-test who thought that the scale will remain balanced (5 out of 10), chose later on in the follow-up question that the number of atoms will stay the same. This is the expected answer if the student has made the connection between mass and the number of atoms. Among students who chose the correct answer (that the scale will tip toward the burned magnesium) only a few (2 out of 27) chose also on the follow-up question that there will be more atoms on the burned side. The rest of the students concluded that there will be fewer atoms (16 out of 27) or that the number of atoms will remain the same (7 out of

27). Of the group students who chose that the scale will tip toward the un-burned magnesium, only about half (15 out of 27) thought that there will be more atoms on the un-burned side. The connection between the change of the mass and the change with the number of atoms improved on the post-test. Most of the students who chose that the scale will tip toward the unburned side also chose that there will be fewer atoms on the burned side, where the typical explanations were that atoms/molecules left.

7) The analysis of students' responses to both the pre-test and the post-test has shown a discrepancy between the multiple-choice part of the question and the students' explanations for their choices. In some questions on the post-test (for example, two out of the four questions of the burned magnesium scenario, questions 16 and 19), students were also asked to provide an explanation for their choice. In some cases, students answered the multiple-choice part correctly, but could not support their choices and in other cases, students provided explanations that demonstrated some understanding, despite choosing the wrong answer on the multiple-choice part. For example, on the pre-test, only one student correctly answered all four multiple-choice questions on the burned magnesium scenario, but that student did not provide any explanation at all. The student wrote "I do not know" in both explanation parts. She probably made a good guess. In contrast to her success on the multiple-choice part of the pre-test, on the post-test, the student correctly answered only one out of the four questions.

Analysis of the students' explanations on question 19 supports the conclusion that the multiple-choice part by itself was not enough to learn about students' understanding. On the pre-test, only one of ten students who answered the multiple-choice part correctly provided a relevant explanation: "oxygen atoms were added to the system." The rest of the students wrote that they have just guessed or that they do not know, or provided an irrelevant explanation such as “because the burnt atoms weigh more.” This explanation does not provide any reasoning for why the burned substance weighs more; the student just re-stated what is given in the multiple-choice question.

On the other hand, almost half of the students (25 out of the 54) who answered the multiple-choice part incorrectly got partial credit for their explanations. Thirty five students, for example, chose that there will be fewer atoms. Those students received no credit for the multiple-choice part alone. But, looking at their explanations, many of them provided good reasons such as that the atoms went into the air. Those students probably are not familiar with the specific example of a burning reaction in which mass is gained, but they do have some understanding that particles can leave the system as a result of a chemical reaction, which is the more familiar case of open systems. Also, burning is associated in students’ mind with smoke and therefore many of them thought that gas was created and left the system. Many students among this latter group of students who correctly answered the multiple-choice part of the question provided an irrelevant explanation, such as, “More because once heated the molecules will move faster.”

A Discrepancy between the multiple-choice part and the open-ended parts of the question was also seen on the post-test. The multiple-choice part by itself was not enough to learn about students understanding. Out of the five students (9%) that correctly answered the multiple-choice part, only two students provided a good and relevant explanation. One student wrote that he just guessed, another student’s explanation showed a contradiction in his understanding saying that “more, because the burned magnesium lost atoms", and one student thought that "the burned magnesium created a new substance out of the magnesium and fire."

8) A lack of familiarity with burning reactions. Together, questions 17 through 19 show that students did not succeed in the scenario of the burning magnesium, which is an example of an open system where mass is added to the system as a result of reaction with oxygen from the surrounding environment. Students may have heard that in a burning reaction oxygen reacts, but most of them thought that it will cause the magnesium to leave the system and react with the oxygen, which is the case of more familiar reactions in which gas is released, for example, resulting loss of mass.

The Literature shows that students often have difficulties with understanding the change of mass in a burning reaction, assuming that when something burns the mass decreases. In BouJaoude' research (1991), for example, all the students questioned about burning wood concluded that wood lost weight during burning, since the products of burning looked smaller and thus weighed less. Even when oxygen was known to be involved, students did not necessarily associate this with an increase in mass (Kind, 2004).

It is possible that the difficulty understanding burning reactions results from students' experience throughout the curriculum. They are more familiar with reactions in which gas is released and the mass of the remaining system is decreased. Although the students are taught that in open systems materials (atoms) can either enter or leave the system, they are more familiar with the case, in which material, for example, gas, leaves the system, and less familiar with the other option, in which gas is added to the system. Thus, they do not realize that the magnesium combines with gas from the environment to form a heavier product. Although students were told in the class that in burning reactions oxygen is involved, they do not necessarily associate it with an increase in mass, and do not realize that solid products of an oxidation reaction have more mass than the starting solid. In other research it was reported that some students do not think that gases have mass. When students were asked about the reaction of iron and oxygen, one explained that "The iron had only reacted with the oxygen of the air which does not weigh anything." (Driver et al, 1985 p. 163).

Appendix D - A Full Transcription of Sample Interview Questions

Students' responses to question 16:

Student C-29, Fri, April 24 (PM)   4

Q16	**I:** Ok now we are in scenario 4. I put wood and burn it. And then I get ash. And then I measure the mass before and after and the ash weighs less than the wood before I burn it, of course. So then I ask, do you think it's an open system or closed system?
	S: Open system.
	I: Why?
	S: Because it changed mass because mass got away and mass wouldn't get away in a closed system. The mass would always stay the same in a closed system, pretty much.
	I: So you say that the mass of what?
	S: The mass of the wood.
	I: Now what best describes the weight difference? I have 4 options.
	S: C. The best answer is C but D is also right; the wood reacted and then something got out, but C is the answer.
	I: Why C is better than B?
	S: B, it doesn't say that a gas was emitted but C it does say that a gas was emitted, and that is how it changed the mass.
	I: Now do you think something happened to the atoms, like they became smaller or…?
	S: No, they're the same but they went to different places.
	I: And then why not A?
	S: Because atoms don't get destroyed, pretty much.
	I: Are the number of the atoms of the ash the same, less or more than the number of atoms in the wood?
	S: There are less atoms in the ash than the wood because some of the atoms turned into a gas.

Student C-30, Wed, May 27 (AM) & Thu, May 28 (AM)   11

Q16	**I:** Ok now I have 2 more questions and I believe we are out of time. So the first question is, I have wood, I put it on fire and burn it, and I weigh the mass before and after I burn it. After I burn it, I have leftover powder. I measure the weight and the weight after I burn it is less than before. So what do you think, is it an open system or closed system?
	S: Open system.
	I: Ok why?
	S: Because the smoke escaped and the smoke is part of the wood.
	I: Ok. Now what indication do you use from what I told you that the smoke escaped? How do you know it?
	S: It's an open system and nothing was covering it to stop it from going

	away.
	I: Yeah but I'm asking you if it's open, I'm not telling you. Like from what I said, what indication do you have that the smoke escaped? I didn't say smoke escaped, I said I burned the wood.
	Time: 20:04
	S: Because it's an open system.
	I: Because what?
	S: Because you said it's in an open system.
	I: No I asked if it's open or closed. I will tell you the information again and then what from this information can you use to say that smoke escaped or it's an open system? I take wood, I put it on fire, I have leftover powder, and the weight of the powder is less than the weight of the wood. So what from this information can you use to assume that there was some smoke?
	S: Because whenever you burn something there is smoke, and then if you kept the smoke the mass would have stayed the same but since the mass is less, the smoke escaped and so it's an open system.
	I: Ok. Now do you think the number of the atoms of the powder will be the same or different?
	S: Different, because some of the atoms escaped with the smoke. The smoke is made of atoms, and the atoms were part of the wood, so yeah, it escaped.
	I: So the number of the atoms of the powder will be more or less than the number of atoms of the wood?
	S: Less.
properties	**I:** Less, ok. Now what will happen to the properties?
	S: Be different.
	I: Why?
	S: Because it's been through some sort of change.
	I: What kind of change?
	S: Phase change.
	I: Why do you think it's a phase change?
	S: No, chemical reaction.
	I: Why?
	S: Because the fire and the wood became dust and the density probably changed, the mass and volume and stuff.
	I: Ok so mass you think it's a property?
	S: No. Yes, no. No, no, no.
	I: Ok why isn't mass a property?
	S: Because it can change when you add stuff to it because it's like weight.
	I: Ok so now what best describes the cause of the weight difference? Just read the 4 options.
	S: Um, G.
	I: Ok why G?
	S: Because they reacted together and they formed a gas, yeah, and they went in the air.

	I: Ok and then why not E?
	S: Because it is not a lot of smoke or anything.
	I: Because what?
	S: It didn't talk about the smoke.
	I: What do you mean it didn't talk about the smoke?
	S: Because it said it just disappeared and then it disappeared through smoke.
	I: Ok now why not F?
	S: Because it didn't talk about smoke either.
	I: Because what?
	S: Because it didn't talk about anything else.
	I: Just read F aloud.
	S: The atoms in the wood changed to become smaller.
	I: Ok so what is wrong with F?
	S: Atoms stay the same.
	I: Ok so just one more thing, why not H?
	S: Because no fire, no smoke.
	I: Ok now we have just one more question *???*
	Time: 23:37
	******************************END OF RECORDING*************************
	*********************Interview continues in additional recording***************
	discussing stuff with people, unrelated to the interview

<u>Student C-36, Thu, May 28 (AM) +-day 21</u>

Q16	**I:** question 4: I have wood, and I burn it, and then after I burn it I have leftover powder, and the mass of the powder is less than the mass of the wood, ok? Do you think it's an open system or closed system?
	S: Open.
	I: Open, why?
	S: Because when it burns, the wood has changes to ash and then the air and some smoke can get out of the ash, changing the mass.
	I: Did I mention anything about smoke here, or just because you are familiar with burning?
	S: Just because I'm familiar with it.
	I: So what is the scenario that I said the indication for open system?
	S: Say that again.
	I: From the information I gave you at the beginning, and I can repeat it, just from this, what is the indication for the open system? So the scenario is like this: I have wood, I burn it, I get leftover powder, and the mass of the powder is less than the mass of the wood. So what from this is the indication for open and closed system?
	S: When you say that it's less than what it was before.
	I: What does that mean?
	S: When the wood burns you said it's less dense, or what did you say?

	I: It weighs less.
	S: So the mass is less, and so that indicates that something was let out of wood.
	I: What do you think will happen to the number of atoms in the wood and in the powder? Will it be the same or different?
	S: They would probably change, oh wait, the atoms?
	I: Yeah, the number of atoms in the wood and the powder.
	S: It stays the same.
	I: Stays the same?
	S: Except it's like the same substance except it's just in a different form.
	I: What do you mean by in a different form?
	S: Like wood, anytime you burn it, it turns into ash. That's how it is.
	I: So you think the atoms will stay the same?
	S: Yeah.
properties	**I:** What happens to the properties?
	S: They change.
	I: Why?
	S: Because the color might stay the same but probably not. And then the mass changed and the other properties changed also because it changed to ash not from wood.
	I: Ok you think there was a chemical reaction?
	S: No.
	I: No? Why?
	S: Because it's just a phase change from wood to ash, it's not a new substance, it's still wood, it's just burned.
	I: Ok now I have here, what best describes the cause of the weight difference, and there are 4 options, so just read it.
	S: I think it's the first one. *mumbling*
	I: Why not S?
	S: Oh I think it's that one.
	I: Which one?
	S: G.
	I: G, why G?
	S: Because it says some of the atoms in the wood reacted with the oxygen to form a gas that went into the air, because that represents how it phase changed in the open system because when the air was let out, the mass went down because it lost some of its weight.
	I: So why not E?
	S: Because, well it could be E or G.
	I: So what is the difference between E and G? What gives you to decide E over G or the opposite?
	S: Well it could be either one of those because E, some of the atoms burned out, because when the smoke went out it may have taken atoms with it. And then it's not S because the atoms wouldn't change because it's the same substance and it's not H because it's not a chemical reaction and it might be

	G because the open system.
	Time: 15:05
	I: If you need to decide between E and G, which one would you pick?
	S: Probably G.
	I: why G over E?
	S: Just because of the open system it's a better explanation of why it changed.

Student C-37, Fri, May 1st (AM) & Wed May 27 (AM) 27

Q16	**I:** Ok. *mumbling* So I have wood, I put it on fire, and then I weigh the mass of the wood before and after. After the fire was completed there was leftover powder, ok? And this powder weighed less than the original wood. So, now from this scenario that I told you, do you think it's an open system or a closed system?
	S: It's open.
	I: Why open?
	S: Because there is nothing around it. There is nothing around it making it closed.
	I: And what information in this story that I told you can you use to support if it's open or closed?
	S: Um, if it weighs less than some escaped.
	I: What do you think will happen to the number of atoms before and after the burning?
	S: If they would stay the same.
	I: Why?
	S: In a closed system they would stay the same, but in an open system there would be a less amount after.
	I: In this case it would be less or the same?
	S: Less.
	I: Why would there be less?
	S: Because some escaped.
	I: What do you think will be the best explanation for the cause of the weight difference, just read for yourself the four options.
	S: Um, I guess A.
	I: you mean E, probably.
	S: I mean E, sorry.
	I: Why do you think it's E?
	S: Because the atoms would burn and then in an open system go away. They wouldn't disappear so I don't really know.
	I: You think it's E or not?
	S: Well I don't think it's any of the other ones.
	I: Well let's just go through why you don't think it's S?
	S: Because the atoms I don't think change their size.
	I: Why not G?
	S: Because, I don't really know. It might be G.

	I: Let's wait until the end to decide. Why not H?
	S: Because the wood is… I don't know.
	I: What is the difference between H and G?
	S: What?
	I: What is the difference between H and G? If you had to decide between the two, so…
	S: I would pick G because the gas…it's G, because it doesn't say that they disappeared; it says that they went somewhere with the molecules, or the atoms, went somewhere instead of *???*
	I: So what's your last pick, E or G?
	S: G.
	I: G. now why not E?
	S: Because the atoms don't disappear.
properties	**I:** now what do you think happens to the properties, do they change or stay the same?
	S: No they changed.
	I: Why?
	S: Because burning is a chemical reaction.
	I: what kind of property could be changed, for example?
	Time: 5:00
	S: The color.

<u>Student C-39, Thu, April 23 (PM) 36</u>

Q16	**I:** Now we are in part 4, I told you part 3 was quick. In part 4, we place a wood on a scale and we burn it completely. And then the leftover is ash. We measure the wood before we burn it and the ash after, and then the ash weighed less than the wood. My first question is: do you think it's an open system or closed system?
	Time: 40:13
	S: Open system because there was nothing preventing wood or fire from escaping.
	I: now what evidence do you use from the information I gave you, is there any scientific, this is the scenario: the wood was weighed, converted to ash, the ash weighed less. So what information do you use to explain that it's an open or closed system?
	S: It's an open system because you, well, there's not enough information to decide because they didn't tell you if there was something covering the wood or not. They didn't tell you what condition the wood was in, if it was completely dry
	I: Why is it important to know if it was completely dry or not? They tell you that it was burned completely.
	S: Oh, no, it's not important but there is not really that much information because you don't know…fireproof containers, you don't know if those fireproof containers were closed or open. I guess you could assume they were open but you don't know.
	I: Do you think there is not enough information because they didn't provide if the container was closed or not?
	S: Yeah.

	I: now if you need to choose what caused the weight difference, so can you choose between these 4 options? What best describes the cause of the weight difference?
	S: I'd say C *???*
	I: now why didn't you choose A?
	S: Because fire needs oxygen to survive, really.
	I: But why not A? A says that some of the atoms in the wood burned out and disappeared. So what…
	S: Because…
	I: Burned out can also mean they go to oxygen. What is incorrect in A?
	S: They didn't react; they disappeared and didn't go into the air. In this one, when you put a fire, the sme has to go somewhere.
	I: So what is the main difference between A and C?
	S: Well A says disappear, which means vanished. And C says went into the air.
	I: now what about B?
	S: B, wood, the gas didn't go back into the wood and compact itself into a smaller space. It went up into the air.
	I: I lost you, what do you mean by this?
	S: Um, the atoms in the wood left, they didn't change.
	I: Yeah but here they say maybe the weight difference is because the atoms became smaller. Is it possible?
	S: It's possible but I think you have more evidence for C.
	I: and then why not D?
	S: Because D is too vague.
	I: so are the atoms of the ash the same, less or more than the number of atoms of the wood?
	Time: 45:03
	S: I'd say less because some of the atoms, like we said in C, some of the atoms left.

Student B-15, Fri, May 15 (PM) 46

Q16	**I:** I have wood, I burn the wood, and I weighed the wood before I burn it and the powder that is left after I burn it. The powder weighs less than the wood.
	S: that would be an open system.
	I: why?
	S: A way you could do it closed system is maybe take a bit of wood, put it maybe on….hmm…maybe have a fire but in a closed area. So put the wood, light it and burn it, and make sure all the gas stays in there. That would be a closed system.
	I: So in this case, what do you say, open or closed?
	S: It's open.
	I: why?
	S: Because the gas can go wherever. It doesn't stay with the wood.
	I: Now how do you know that gas went wherever?
	S: Because when you burn it, you see that it's white and everything and kind of

	smaller. Some of the wood, it soaks off, and becomes sme and comes out. It works with fire.
	I: now do you think the number of the atoms in the wood and the leftover powder is the same or different? Like if I compare the wood and the powder that's leftover after the burning. Will the number and types of atoms be the same or different?
	S: The log will probably have more atoms because it's atoms.
	I: Which one will have more?
	S: The log. It's bigger and needs more atoms.
	I: and from information I gave you at the beginning, so can you know from this whether the number of atoms is the same, less or more?
	Time: 40:05
	S: What?
	I: What information do you use in order to decide if the number of atoms is the same, less or more?
	S: You can't really tell. You need a really strong microscope to tell that. But usually by the size of it, if it's big and if you burn it and it shrinks, you can tell that some of it has gone away. You can tell it has less atoms.
	I: you think there is less atoms just because it takes less space?
	S: Yeah. It's smaller.
	I: now what do you think caused the difference in weight? Why does the powder weigh less than the wood?
	S: Because the wood, like a powder it's a solid but very small, so it's lighter. It's not densely packed. And then the log, it's still pretty dense, so it weighs the same. And then the powder which is sugar weighs not that much. It's just not heavy.
	I: with the sugar and powder sugar, you think it's made up from the same atoms or molecules or not?
	S: No, sugar comes from sugar canes and the it's processed or whatever. And I believe they add something to powdered sugar to make it powdery, I'm not quite sure what that is.
	I: now I have here 4 options for you to choose what best describes what caused the weight difference. So if you could just pick the one you think.
	S: C.
	I: why C?
	S: Because that's how the chemical reaction reacts with the fire. It burns, the oxygen gets in and makes a gas that lets the wood go out.
	I: Now why not A?
	S: Because if the atoms disappear, does that mean they're gone or what? You can't destroy atoms, they don't just disappear.
	I: and why not B?
	S: It's good, it would work, but I thought C gave more depth to it. And it gave you more information about it.
	I: and why not D?
	S: Because the wood reacted. It doesn't give you any depth at all.
	I: So if we go back to B, what do you mean that's it good and it works but C gave more information?

	S: It says the atoms in the wood changed and became smaller. It's kind of summarizing what C says, but C gives more description to what it is. The atoms in the wood changed, so that's pretty much saying that the wood reacted and the atoms became gas.
	I: So you still think B could work but C is more detailed?
	S: Yeah.

Student B-16, Thu, May 28 (PM)   57

Q16	**I:** *???* Now we two more questions. First, I have wood and I burn it. And I have leftover powder. And then I weighed the wood and the powder before the burning and after, and I found out that the powder weighed less than the wood. Do you think it's an open system or closed system?
	S: Open system.
	I: Why?
	S: Because it'll burn all the oxygen, well not really all the oxygen, but some of the oxygen out. And so it'll make it smaller and yeah.
	I: what with the story I told you is an indication you have that it's an open system? I will tell you the story again and tell me which part of the story indicates that it's an open or closed system. I have wood, I burn it, it becomes leftover powder, and the weight of the powder is less than the weight of the wood.
	S: The weight, pretty much.
	I: The weight? What does the weight tell you?
	S: It told me that, you said it was the same substance? Or was it?
	I: It's a wood that I burn and it becomes ash. So I don't know if it's the same substance or not. I ask you.
	S: Well, I don't know that one.
	I: So what does the weight tell you?
	S: It told me that it's…I don't know.
	I: So do you think it's the same substance or not?
	S: Yeah, only it's just burned off a little bit. Some of the oxygen and stuff escaped into the air.
	I: So if I lo at the number of atoms in the wood and the number of atoms of the powder, will it be the same number of atoms or different number?
	S: Different.
	I: Why?
	S: Because some of the atoms burned off from the fire. But in the wood, it really hasn't.
	I: and what do you mean by some of the atoms burned off?
	S: Yeah, when it burns some of the oxygen just goes into the air.
	I: So where does the oxygen come from?
	S: From the wood.
	I: now what happens to, so you say the number of atoms will be less or more in the powder?
	S: Less.

	I: Now what describes the cause of the weight difference? You have 4 options. What one do you think is the correct one?
	S: G.
	I: why G?
	S: Because some of the atoms in the wood would react with the oxygen, and they would escape into the air.
	I: why not E?
	S: Because they don't disappear, they are still there, the atoms are.
	I: why not F?
	S: Because the atoms don't change, and they really don't become smaller atoms.
	I: why not H?
	S: Because wood doesn't just react; it's the molecules and stuff that react.
properties	**I:** now what do you think about the properties? Do the properties change or not?
	S: Yeah.
	I: Yeah, why?
	Time: 25:00
	S: I don't know.
	I: You don't know. What kind of property, for example, could change?
	S: Just like the mass and density and stuff.
	I: Mass, density and stuff? *???*
	S: Mass, volume, density…
	I: this kind of property that could change?
	S: Yeah.

Student B-18, Thu, May 28 (PM) 65

Q16	**I:** That was quick one. Now to question 4. I have wood and I burn it. Now the leftover powder, after burning it weighed less than the wood in the beginning. So now the question is, is this an open system or closed system?
	S: I think it's an open system.
	I: Why?
	S: Because you lost mass and that can only happen in an open system where you allow things to escape.
	I: What about the number of the atoms in the wood and the powder? Are they the same or different?
	S: Well I mean if you allow all the atoms to escape, then they would be different. But in a closed system, they would be the same.
	I: Yeah but in this system.
	S: They would change.
	I: And the number of atoms of the powder will be less or more?
	S: It would be less.
	I: why?
	S: Because you're losing atoms because it's an open system.
properties	**I:** what about the properties of the wood and powder?

	S: They would be the same because it's the same substance you just burned it.
	I: what kind of properties do you think the wood has?
	S: Wood? It has a specific density, which is a property.
	I: So you think it will stay the same?
	S: Yeah.
	I: was there a chemical reaction here?
	S: Yeah, I think, because burning is a chemical reaction.
	I: and in a chemical reaction-
	S: It changes. So the properties would change, my bad.
	I: just think about a property of wood that may change for the powder?
	S: Hardness.
	I: the hardness of the wood is different than the hardness of the powder. Now do you think that when we say the mass changed, is the mass a property or not?
	S: It's not a property.
	I: Why not?
	S: Because it changes. I mean, in this piece it changes, but if we had it in a closed system it would stay the same, and properties, you know..
	I: So how do you know if it's a property or not?
	S: Can I just start over with that?
	I: Sure.
	S: mass, you can have a really small chunk of it or a really big one, and the mass would be different. But in order for it to be a property, they would have to be the same no matter how much you have, what the shape is, blah blah blah.

Student B-19, Fri, May 1st (PM) 72

Q16	**I:** great, now we are in scenario 3. In scenario 3, I burn wood, I put wood on a scale and then I burn it and I have leftover powder, ? And then I measure the mass and I see that the mass of the wood is more than the mass of the powder. The mass of the powder is less than what was originally the mass of the wood. So that's the scenario. Now do you think it's an open system, closed system and why?
	S: I think it was an open system because the oxygen, through the fire, was combined with the wood, so that would be a chemical reaction that led to the powder. But according to the law of conservation of mass, the mass would stay the same during the burning if it was in a closed system because the mass couldn't disappear, so the oxygen and the wood, so it would be the combined mass of the oxygen and the wood, and-
	I: The oxygen and the wood?
	S: The oxygen and the wood, the oxygen that reacted with the wood.
	I: Ah, the oxygen that reacted with the wood.
	S: And since I'm pretty sure that oxygen doesn't have a negative mass, then some of the mass must have escaped.
	I: Now what best describes the difference with the mass? Here there are 4 options.

	S: I think some of the atoms in the wood reacted with the oxygen and formed gas that went into the air.
	I: now why not A?
	S: Because the atoms can't just disappear.
	I: why not B?
	S: The atoms wouldn't change, just the molecules would change because the atoms in the reactants and the products have to be the same.
	I: now the atoms can become smaller?
	S: No, if they are the same atoms they can't become smaller.
	I: now what do you think will happen to the number of the atoms? Will it be less, more or the same in the powder?
	S: The number of the atoms…well-
	I: If you compare the number of the atoms of the powder with the wood.
	S: You mean that's not escaped? Including the ones that escaped or not?
	I: Just the ones in the powder.
	S: I think it would be less because some of the atoms that were in the wood and the oxygen escaped into the air through the sme and gas, so I think it would have less because some of them flew out.
	I: And just to conclude, so-
	S: And because it has less mass so it has less matter in it.

<u>Student B-24, Wed, May 27 (PM)   78</u>

Q16	**I:** now we are in question 4. I have wood and I burn it. And I have leftover powder after it was burned. The weight of the powder is less than the weight of the wood. Now the first question, do you think it's an open or closed system?
	S: Open.
	I: Why?
	S: Because it weighs less.
	I: So that means that…?
	S: That means it's open because then everything would escape.
	I: Not everything.
	S: Yeah. Some things.
	I: Part of it. Now do you expect the number of atoms of the powder and the wood to be the same or different?
	S: The number of atoms, if it was an open system, then if it was an open system it would probably be different because some of the atoms would escape.
	I: it would be less or more? Will the number of atoms in the powder be less?
	S: Less.
	I: why less?
	S: Because it's an open system all the other molecules would escape in atoms.
properties	**I:** what about the properties? Do they change or not?

	S: I think they change because the state of matter changed.
	I: Both of them *???*
	S: Yeah, stayed solid. Because there is probably going to be less powder than there was wood-
	I: What kind of properties could be different?
	S: Color could be different because you added fire, so the ashes or powder is probably like black-ish and the tree or wood is probably brown-ish.
	I: now what best describes the cause of the weight difference? There are 4 options here.
	S: *mumbling* G.
	I: why G?
	S: Because they're all true but G is the most detailed *???*
	I: why not E? You said they are all true. So why not E?
	S: Because it could be an answer because the atoms did burn out, or no, they didn't disappear because atoms can't disappear, they just went away.
	I: now what about F?
	S: The atoms usually stay the same size because they are already microscopic.
	I: they can become smaller?
	S: Yeah, or no they can't.
	I: why not H?
	S: Because it doesn't really explain what happened or what went on, it just says that the wood reacted. It's just kind of a statement.

<u>Student D-47, Wed, May 27 (PM)   85</u>

Q16	**I:** now we are in question 4. I have wood and I burn it. I have leftover powder. The mass of the powder is less than the mass of the wood. So far that is the data. The question is: is it an open or closed system?
	S: Open.
	I: Why?
	S: Because when you burn things it oxidizes them, and it creates a gas which would make it lighter.
	I: what indication do you have that the gas was created? I didn't say gas escaped, I just said I have wood, I burned it, I make powder, and the mass of the powder is less than the mass of the wood.
	S: Just assuming it is open because the mass can't change unless something is getting out of the system.
properties	**I:** now what will happen to the properties before and after?
	S: They will change.
	I: what kind of properties do you think of that could change?
	S: All of them.
	I: Just give me an example.
	S: The density, boiling point, melting point.
	I: So basically we have a totally new substance.
	S: Yes.

	I: that was a chemical reaction?
---------	**S:** Yes.
	I: now what about the number of the atoms of the wood and the powder?
	S: It will stay the same but some of the atoms might not still be with the powder, but they will be in a gas.
	I: So if I just compare the number of atoms of the wood and the powder.
	S: Then the powder will have less atoms.
	I: now what do you think caused the weight difference? There are four options here.
	S: I think it's G.
	I: why?
	S: Because you can't change the amount of atoms you have, and you can't change the size of the atoms. They're always there, so…
	I: that eliminates F, right? And why not E?
	S: Because you can't destroy an atom.
	I: and why not H?
	S: Technically H is also correct. But it's not as good as G.
	I: G has more…
	S: G is more detailed.

<u>Student B-26, Tue, April 21 (AM) & Wed, April 22 (AM) 90</u>

Q16	**I:** Now I'm in part 4. Wood is placed on a scale, set on fire and burns. A pile of ash is left. The ash weighs less than the wood prior to boiling. So we have wood and we burn it and it became ash, and the ash weighed less. So now the question is, would you describe this scenario as an open or closed system?
	S: An open, because when you burn it the gas is able to escape and you should have the same mass before and after if you have a closed system and gas is created. So it's an open system.
	I: So the indication for the open system is what information here that tells you it's an open system?
	Time: 5:02
	S: Because it burned completely and a pile of ashes was left, but the mass is not the same.
	I: So the mass is not the same. now what do you think best described the cause of the weight difference so you already said it but just repeat it. The cause for the weight difference was…?
	S: Because the gas escaped.
	I: do you think the number of atoms in the ash would be the same, more, or less than the number of atoms of the wood?
	S: It's the same.
	I: The same? Why?
	S: Because we burn it, that's a chemical reaction, so it has the same number of atoms before and after.
	I: So now I'm comparing the number of atoms, you say it would be the same? , now can you explain it again why it'd be the same?

	S: Well maybe it would be less because some of the gas was able to escape and that has some of the atoms.

Student D-40, Fri, May 29 (AM)   104

Q16	**I:** We are on question 4. 2 more short questions. I have wood, and I burn it. I weighed before and after I burn it. After I burn it I get leftover powder, and the weight of the powder is less than the weight of the wood before I burn it.
	S: You must have lost atoms while burning it.
	I: Oh. So that's one of my questions. Do you think the number of the atoms before and after would be the same or different?
	S: Different, it would be less.
	I: Why?
	S: Because they burn the fire.
	I: and what information in the scenario indicates to you that we lost atoms? I said there is wood, burn, it becomes powder, and the weight of the powder is less than the weight of the wood. So what from this indicates that you lost some atoms?
	S: When you said there is wood and it being burned, you set it on fire and it burns completely.
	I: so yeah but I didn't say that atoms were lost.
	S: No but you still said that and that pretty much means that atoms were lost because if you set the whole building on fire, obviously atoms are going to be lost.
	I: Yeah but there is something here that I did say that indicates that atoms were lost, which is what?
	S: That the powder weighs less than the wood.
	Time: 20:06
	I: The weight?
	S: Yes.
	I: so do you think it's an open system or closed system?
	S: Open system, because atoms were lost. And if it was a closed system, they would have to be trapped inside.
properties	**I:** good. And what about the properties, did they change or not?
	S: They changed.
	I: what example do you think that was changed?
	S: Well it went from… actually they didn't change, because even though you burned it, it still is a solid unless it turned to a gas. Or some of it's a solid and some of it's a gas.
	I: So what kind of properties do you have in mind that you could check if it changed or not? Just give me an example of a property.
	S: Um, density.
	I: Density, , do you think the density changed or not?
	S: The density changed if they lost atoms, that means the mass must have changed, they lost atoms because you said it weighs less. And that means

	that it changed.
properties	**I:** the properties changed or not?
	S: Yes, some did.
	I: now mass is a property?
	S: No, mass is not a property.
	I: Why?
	S: Because…I don't know.
	I: How do we know that something is a property or not?
	S: I don't know.
	I: You don't know.
	S: We learned this but I forgot it.
	I: You just remember that mass is not a property.
	S: Mass is not a property, I know that for sure.
	I: But you don't remember why.
	S: No, we learned about it but I just forgot.
	I: what about volume?
	S: Volume is not a property, either.
	I: And color?
	S: Color is a property.
	I: so you don't remember why you just remember that it's not a property?
	S: Yes, I'm sorry.
	I: now I have here a short question. What best describes the cause of the weight difference? There are 4 options if you could read it.
	S: Read out loud?
	I: Just read it for yourself.
	S: I pick F.
	I: why F?
	S: Because it explains that the atoms in the wood changed, and became smaller. No I choose A, actually.
	I: E.
	S: E, yes. Some of the atoms burned in the wood and disappeared and it was an open system.
	I: so why not F?
	S: Because that explains that they just became smaller, which wouldn't change it because they're still there.
	I: so I didn't get it. Can you explain a little bit more why not F?
	S: Because they just became smaller, they still are there, but they just changed.
	I: atoms can become smaller or not?
	S: Yes they can, but they change, I lost my train of thought.
	I: The atoms can become smaller?
	S: Yes, they can.
	I: So why not here?
	S: Why not?
	I: You said it's not F, so why don't you think this is it?

	S: Because the atoms becoming smaller wouldn't cause the wood to change because the atoms are still there.
	I: they can become smaller but the weight will stay, it will just be more condensed or something.
	S: Yeah.
	I: why not G?
	S: Because that doesn't make sense.
	I: Why doesn't it make sense?
	S: I don't know, it just doesn't make sense to me. It says that some of the atoms reacted with oxygen to form a gas. I mean it could work, too, but yeah, I just don't…it just says they reacted and turned to a gas.
	I: why not H?
	S: Because that just says the wood reacted. It doesn't tell you what happened with the atoms.

Student D-41, M, June 8 (AM) 113

Q16	**I:** Water, Now we are in the next question, question 4: I have wood, and I burn it, and I have leftover powder, it burned completely, and the mass of the powder is less than the mass of the wood. So that is the scenario. Now the question. Do you think it's an open system, closed system, or not enough information?
	S: An open system.
	I: An open system, why?
	S: Because the…wait, what was the scenario again?
	I: I have wood and I burn it completely.
	S: What did you say about the powder?
	I: The powder weighs less than the wood.
	S: So the mass has changed, so that indicates that it's an open system because a chemical reaction happened.
	I: Now so what caused the mass to change?
	Time: 5:03
	S: Mostly because it changed to a new substance, so because it burned and burning is always a chemical reaction. And during that time, if the mass changed, and mass is not a property, so that's why it changed. I guess what caused this is because it's an open system, I don't know. Now I am getting all confused.
	I: now do you think the number of the atoms in the wood and in the powder will be the same or different?
	S: The number of atoms?
	I: Yes.
	S: It would be the same. In a chemical reaction, no atoms are lost, they can just be rearranged and can make new molecules. And the number of molecules could change but the number of atoms are always the same kind of atoms and the types of atoms are the same. Atoms are always there.
	I: but the number of molecules could change?

	S: Because atoms can rearrange.
properties	**I:** now what about the properties of the wood and the powder?
	S: Properties, what do you mean?
	I: If they change or not?
	S: Oh the properties, properties are a characteristic of a substance that can't change if something is added on or taken off. A property is like solubility and melting point, so it wouldn't change.
	I: It would or wouldn't?
	S: Wouldn't.
	I: Wouldn't. They are not changing? Or yes? Think about the property for wood. Like what kind of property do you think of?
	S: Solubility.
	I: What about the color, does the color change?
	S: What?
	I: Color is a property?
	S: Color, yeah, it would change. yeah.
	I: what other properties do you know for sure that would change?
	S: Melting point. Density.
	I: we are not sure about these but for example, hardness, wood is hard but powder not so hard?
------------	**S:** Yeah.
	I: properties will change. now there is multiple choice question here. What describes the cause of the weight difference, pick one and explain.
	S: Either E or G, they seem to be representing the same thing. Some of the atoms in the wood burned and disappeared, but burning is the atoms reacting with oxygen, that's what burning is. So basically it's the same thing, and *???* so I guess G.
	I: G, .
	S: It best describes.
	I: why not E?
	S: Because it's an open system, that's how the mass escaped because the atoms that moved faster by heat wouldn't burn, escaped into the air and what was left was just powder and that's why it weighs less.
	I: why not E?
	S: Because G gives more description, just like burned oxygen and atoms mixing, and then gas went into the air instead of disappeared. It's more descriptive. And it says gas and it's just better.
	I: now why not F?
	S: That's just atoms and the wood changed and became smaller, because the atoms in the wood don't change, and they don't become smaller. The substance becomes smaller. It's not right.
	I: now atoms can get smaller or not?
	S: They can get smaller but in this case the gas escaped and that's why the mass changed, so that's not the reason.
	I: Why not H?

	S: H, the wood reacted, because that gives no description whatsoever and it doesn't tell why.

Student D-42, Tue, June 2 (AM) 119

Q16	**I:** now we are in question 4. *talking about time left*. I have wood and I burn it. Then I have leftover powder, ash. And then the weight of the ash is less than the weight of the wood. So that's the scenario. Do you think it's an open or closed system?
	S: I'd say it's open system.
	I: Why?
	S: Because in an open system, the ash would end up weighing less than the wood, because in a closed system it would end up catching all the gas that is released from the wood, which weighs something. But in an open system, it would end up losing some of the gas, making it weigh less.
	I: now what about the number of the atoms?
	S: In the wood it would be dense, a lot of atoms, millions, moving back and forth in a neat pattern without quite touching. In the ashes, it would be about the same, depending on the *???*
	I: So the number of the atoms will be less, the same or more in the ashes?
	S: I think the atoms would be less.
	I: Why?
	S: Because of the gases released from the wood.
	I: ? Like the gas released, so?
	S: It would end up weighing less.
properties	**I:** now what about the properties of the wood and powder? Would they be the same or different?
	S: Very different.
	I: Why?
	S: Different colors, different density, different mass.
	Time: 25:05
	I: why?
	S: Because it was a chemical reaction because when it's not a chemical reaction you can do something but you can separate it and have it to where *???* done. But with the mixture, that's how it would work. But a chemical reaction, once it's done it can't really be undone.
	I: Now I have here a multiple choice question.
	S: *mumbling* I'd say E.
	I: why?
	S: Because atoms can't really become smaller. Actually no I'd say G because some of the atoms in the wood reacted with oxygen and formed a gas that went into the air.
	I: So why not E?
	S: I'm not sure *???* they are about the same but not exactly, because molecules don't just disappear, they just go into the air and they're just not there anymore.

	I: you think it's G.
	S: Yeah. Some of the atoms in the wood reacted with oxygen and formed a gas that went into the air. I'd say it's that because it doesn't just disappear, it does go into the air but it's just not there with the wood.
	I: why not H?
	S: Because it doesn't say enough about it. Of course the wood reacted, but it doesn't say how it reacted.

Student D-48, Wed, May 13 (PM) 128

Q16	**I:** Now we are in the 4th part. We have a wood, and I place it on a scale, and I burn it.
	S: You burn it?
	I: Yes.
	S: .
	I: And then I have leftover some powder.
	Time: 30:03
	S: Yeah.
	I: and the powder weighed less than the wood before I burned it. So now the question is the same, is it an open or closed system?
	S: Open.
	I: Why?
	S: Because it's not in a controlled environment.
	I: What do you mean by controlled?
	S: There is nothing surrounding it to prevent anything from leaving.
	I: and what evidence do you use from the story to support this?
	S: The mass changes.
	I: So in this case, what happened? The mass was less than the beginning so what does it mean?
	S: It lost mass.
	I: So here I have what caused the weight difference? What do you think? There are 4 options.
	S: I'm going to guess.
	I: Why do you need to guess?
	S: I think it's C.
	I: why C?
	S: Because if something in the wood did react with the oxygen, and it formed a gas, then it would escape because it's an open system and so it would have less mass.
	I: why not A?
	S: Because they can't disappear.
	I: Why not B?
	S: Because they can't become smaller.
	I: and why not D?
	S: Because that doesn't tell you much.
	I: now in the last question I ask if you think the number of atoms in the powder

	and the wood are the same, less or more?
	S: Same.
	I: Same, why?
	S: No atoms are lost so the numbers stay the same.
	I: just explain more.
	S: The number of atoms, none are lost, so the number of atoms in the powder stays the same but the number of molecules did change because it's a chemical reaction, the atoms joined together to form different types of molecules. And so the number of molecules did change, and the atoms didn't.
	I: So we have the wood and then it reacted with what?
	S: The fire, or burning.
	I: With…?
	S: I don't know.
	I: You don't know. Like you said, with the fire , and then we got the powder. So I just want to summarize to clear up what you said. So you say why the number of molecules did change and the number of atoms didn't change?
	S: Yeah.
	I: So what do you mean exactly?
	S: The number…like when you changed to the powder, none of the atoms were lost. They were all still there, but they formed different types of molecules, since it was a chemical reaction.
	I: And then why is the mass less?
	S: The mass is less because they are closer together.

Students' responses to question 17:

Student C-29, Fri, April 24 (PM) 4

Q17	**I:** Now we are in the last scenario, almost done. You did a similar experiment in the class. We have a test tube filled up half with vinegar and a balloon filled with baking soda. I connect the balloon with the tube very well and pour it the baking soda into the tube. Do you think this is an open system or closed system?
	S: Closed system, because the balloon makes it a closed system by making it airtight, keeping in the molecules that get turned into a gas.
	I: Now if we want to make sure it's a closed system, what do we need to do?
	S: Make sure the balloon is over it before the reaction starts, or make it a closed system before the reaction.
	I: And how can you measure if it's closed? Is there a way to test?
	S: Mass.
	I: So what do you need to do with the mass?
	S: You need to measure the before and after, and if it changes then it wasn't a closed system. It might have been a closed system but it wasn't a closed system fast enough.
	I: And then the number of the atoms in the system has been changed or not?
	Time: 30:02
	S: In a closed system it wouldn't be changed.

	I: So just say it again.
	S: In a closed system the atoms would be the same.
	I: So in order to make sure it's a closed system we need to…?
	S: Measure the mass.
	Time: 32:08

Student C-30, Wed, May 27 (AM) & Th, May 28 (AM) 11

Q17	**I:** the last question is, I have a test tube that is filled up with vinegar. And baking soda in a balloon, and I connect everything together and turn it up and the balloon inflates. So is this an open system or a closed system or not enough information?
	S: Closed system.
	I: why?
	S: Because nothing has escaped.
	I: how do you know that nothing has escaped?
	S: Because if you measure the mass before and measure it afterwards, it should be the same.
	I: Did we measure the mass here?
	S: I don't think so.
	I: No. , so you still think it's a closed system?
	S: Yes.
	I: now what will be the number of atoms before and after?
	S: The same.
	I: The same?
	S: Yeah.
	I: Why?
	S: Because nothing escaped.
properties	**I:** now what about the properties before and after?
	S: They are different because a chemical reaction happened with the vinegar and the baking soda.
	I: So do we have any indication that the chemical reaction happened?
	S: Yes.
	I: What is the indication?
	S: It changed so there's not just vinegar and baking soda now.
	I: How do you know this?
	S: Because *???* if you opened it up.
	I: Yeah but from what we said, how do you know there is not only baking soda and vinegar?
	S: Because baking soda or vinegar wouldn't cause the balloon to inflate *???* would.
	I: So you know it from the inflation of the balloon. what happens during this chemical reaction, like can you describe me what sign you have that a reaction happened?
	Time: 3:00
	S: Two or more substances were combined and they reacted to create

	something new.
	I: what is new now?
	S: Inflated balloon.
	I: now so what kind of properties, for example, could be changed?
	S: The mass, no, the density.
	I: density. So density is a property?
	S: Mmm.
	I: what about the mass?
	S: No.
	I: No, why not?
	S: Because it changes.
Sub q2	**I:** now in this question, what caused the balloon to inflate, there are 4 options. So if you could just read it.
	S: C.
	I: Why C?
	S: Because the molecules for the baking soda and the vinegar change into different molecules, and yeah.
	I: why not A?
	S: Because I can't remember what atoms are.
	I: You don't remember what atoms are. and why not B?
	S: Yeah, same thing, I can't remember what atoms are.
	I: but here when I ask you if the number of atoms will be different you said they will stay the same, right?
	S: Yes.
	I: So what is the difference between this and B?
	S: Oh yeah, there is no difference.
	I: There is no difference. So why not B?
	S: Because I said they would stay the same.
	I: So why not D?
	S: Because mass is not a property, it's a changing property.
	I: can you explain a little bit more about D?
	S: The mass would stay the same because nothing escaped.
	I: what's the difference between B and D?
	S: I don't know.
	I: Does it say the same thing in different words or not?
	S: No because atoms and mass are different.
	I: now what is similar between B and D? What is the difference?
	S: They both ask for something that is increased, but then one is about mass, one is about atoms.
	I: And you say both of them are not correct? , so now I think we're done. Thank you very much. Try to catch Kelsey and send her in.
	Time: 6:34

Student C-36, Thu, May 28 (AM) +-day 21

Q17	**I:** now we will have the last question, I hope we finish it up. We can finish it up. So the last question, a test tube filled halfway with vinegar and baking soda in a balloon and I connect everything together, and I put up the balloon and the balloon inflates. So my first question is, so you have here the picture before and after, ? Now do you think it's an open system, closed system, or not enough information to decide?
	S: It's a closed system.
	I: Why?
	S: Because when putting the balloon over it, it keeps all the air inside and all the chemicals that you put in, and so that's what made the balloon inflate because of the closed system.
	I: What do you mean by it makes the balloon inflate because it's a closed system?
	S: Well because when the baking soda and the vinegar, when they reacted it made a chemical reaction, which made the balloon inflate. It makes air, I guess.
	I: What do you think will be the number of atoms before and after, the same or different?
	S: They would probably be different just because before the balloon wasn't inflated at all.
	I: And after?
	S: It was completely inflated so there are probably more atoms.
Properties diss	**I:** and what about the properties?
	S: The properties would probably change because it's a chemical reaction between the vinegar and baking soda.
	I: now do you have any new substance here that was formed?
	S: Uh, yeah, you got some sort of air too, like carbon dioxide or just oxygen.
	I: how do you know this?
---------	**S:** Because otherwise the balloon wouldn't have inflated at all.
Sub q2	**I:** now what caused the balloon to inflate? There are 4 options, that's our last thing for today.
	S: The number of atoms increased.
	I: why not A?
	S: Because, oh wait no it would be A. I didn't read them right. It would be A because during the chemical reaction some of the atoms were added and changed.
	I: so why not B?
	S: Because even though the atoms probably increased because of the air, it's not like the same atoms as before.
	I: Why not C?

	S: I'm not sure why.
	I: What is the difference between A and C?
	S: The A is atoms and C is molecules.
	I: which one do you think is the better choice?
	S: The atoms.
	I: The atoms, why?
	S: Because, I actually don't know.
	I: You know the difference between atoms and molecules?
	S: Not specifically.
	I: So the question I still need to do with you that I forgot the model is about atoms and molecules. That will take like 5 minutes next time, why not D?
	S: Because the mass probably did increase but the atoms changing into other atoms is a better explanation because it takes up more space, which inflates the balloon.
	I: Just one quick more question. I'm not in charge of writing the curriculum, but I am *???* so what do you think of the curriculum, was it good, too long, too short?
	S: Wait what liquid?
	Time: 20:47

<u>Student C-37, Fri, May 1st (AM) & Wed May 27 (AM)   27</u>

Q17	**I:** Now we are in the last question. It's very similar. I have a test tube filled up with vinegar and I have some baking soda in the balloon and I attach the balloon and put it over and the balloon inflates, that is the scenario. Do you think this is an open system or a closed system?
	S: A closed system.
	I: Why closed system?
	S: Because the balloon is not allowing the molecules to escape.
	I: now you have any way to make sure if it's a closed or open system?
	S: Huh?
	I: What test can you do or what can you measure to make sure that it's really a closed system?
	S: You could measure the mass.
	I: and then what?
	S: See how much it weighs before and after the vinegar and baking soda.
	I: and then what?
	S: See how much it weighs in an open system, and see how much it weighs in a closed system.
	I: So what would be the difference?
	S: In an open system, it would change after. In a closed system it would be.
	I: Now what do you think will happen to the atoms before and after?
	S: They would be the same.
	I: why?

	S: Because it's the same number of atoms just in different formations.
Properties diss	**I:** now what is the property?
	S: The properties would have changed.
	I: why?
	S: Because it was a chemical reaction.
	I: how do you know there was a chemical reaction?
	S: Because I think so, that baking soda and vinegar is a chemical reaction.
	I: There is any indication? What can you lo for?
	S: Well it doesn't say but um…
	I: Like what from the observation you can tell that there was a chemical reaction?
	S: You can't. So if there was a chemical reaction from that.
	I: Oh, I think you can tell. Just think. What happened here?
	S: The color might be different. It might lo different.
	I: we don't know what the color before and after is, right? But what do we know?
	S: It might have…I don't know. I don't really remember what properties were.
	I: What happens in a chemical reaction?
	S: The molecules rearrange to form a new substance?
	I: Do we have a new substance here?
-------------	**S:** Um, I don't know. It doesn't say.
	I: now what caused the balloon to inflate? There are 4 options here.
	S: A.
	I: A, why?
	S: Because the atoms would have-
	I: You can talk louder.
	S: Because the atoms would have become other atoms that might have *???*
	I: now why not B?
	S: Because the number doesn't increase.
	I: what is the number of the atoms?
	S: What is the number of the atoms?
	I: Like if it stays the same or what happened to this?
	S: It would stay the same because…I don't know.
	I: now why not C?
	S: Because it's the same as A but with molecules and atoms.
	I: what is the difference between A and C?
	Time: 10:00
	S: Um, A uses atoms and C uses molecules.
	I: which one do you think is right? So you said you think the right answer is A, so just explain why you chose A over C.
	S: Because atoms are smaller and the atoms make up a molecule, and they…well I don't really know how to describe it. But there are different

	types of atoms and those can rearrange to make different molecules.
	I: we'll go back to this one in a second. Why not D?
	S: Because mass didn't change. Because…I don't know. Because the mass didn't change.
	I: why don't you expect the mass to change?
	S: Because the amount of atoms or molecules doesn't change.
	I: So now that's the last thing we do. Just and if you can clarify your decision of A and C.
	S: Because the molecules are made up of different kinds of atoms that could rearrange into other molecules and in the molecules that doesn't make sense.
	I: so you think it's A.
	S: I guess if there are 3 carbon atoms, and 3 Hydrogen atoms in a molecule, you could rearrange them into 2 carbon atoms and a hydrogen atom. And that would be a different molecule than before.
	I: in the chemical reaction will you get different molecules?
	S: Yes.
	I: what is changing here, the atoms or the molecules?
	S: The atoms, the molecules, I'm changing, I think.
	I: it will be A or C?
	S: C.
	I: What about the atoms, they don't change?
	S: The atoms don't change.
	I: So now what about the properties? We already talked about the properties, right? , now I think we're done, so thank you, go eat lunch.

Student C-39, Thu, April 23 (PM) 36

Q17	**I:** now we are in the last part. So we have a test tube that is filled with vinegar half-way, and then I have baking soda in a balloon, and I place the baking soda, making sure nothing will get poured into the test tube, and then I connect it so it will be connected, and then after I make sure the balloon is not dropped to the test tube, now that I pour the content of the balloon into the test tube and the balloon inflates. So that is the scenario. What caused the balloon to inflate?
	S: The molecules reacted to form a new product that *???*. Because they created a gas that wanted to escape, but the balloon made it stay, and that gas is called helium, I believe. That's what makes the balloon inflate, I believe.
	I: now do you think it's an open system or closed system?
	S: Closed because they had to go into the balloon and they couldn't go into the air and escape.
	I: Do you think the number of atoms that are now in the system are the same or different?
	S: The same because you added nothing, but you added the baking soda *???*
	I: What do you mean?
	S: The baking soda was in the balloon and then that reacted *???* but that doesn't count for…

	I: now so the mass will change or not?
	S: No.

Student B-15, Fri, May 15 (PM) 46

Q17	**I:** Now in the last question, I have a similar situation to something you did in class. I have a test tube filled up halfway with vinegar and a balloon with baking powder. And then I tie the balloon and I move the powder into the vinegar, and then the balloon inflates. Do you think it's a closed or open system?
	S: It's a closed.
	I: why?
	S: Because the balloon is covering the top, trying to catch whatever will come out from the vinegar and baking soda reaction. So…
	I: now if you want to double check if it's really closed or maybe the balloon is not tightly on, what test do you need to do to check if it's closed or open system? How can you test it?
	S: You don't test it to see if it is a closed system. It's a closed system or open system based on the way you test it.
	I: Ah , but what indication do you have that it was a really closed one?
	S: Maybe test it several times or you can feel with baking soda and vinegar, usually in volcanoes or whatever, and so they add color and it makes lava lo. And so you could feel for when you open it up and put the vinegar in for the gas that will come out. You can put your finger around where the balloon is.
	Time: 45:13
	I: If I feel any gas.
	S: Yeah if you feel anything.
	I: And if I want something to measure, is there a way for me to measure if it's really tightly closed or not?
	S: No, just that *???* by your finger.
	I: Now do you think that the number of the atoms in the system before and after will be the same or different?
	S: I don't know. The vinegar and baking soda go together and make *???* so when it happens they both combine and *???* instead of doing that, it foams up. So instead of staying that way, they combined and poof.
	I: what will happen to the number of the atoms?
	S: It should stay the same because they're not escaping as far as you know. And then you didn't add anything else so…
	I: Now what happened to the types of molecules, did they stay the same or are they different?
	S: The molecules are different because they combined to make the foam, but then the atoms are still the same.
	I: now there is one last question: what caused the balloon to inflate? So there are 4 options, choose one.
	S: C.
	I: why C?
	S: It kind of worked the best. See, the molecules changed into other molecules,

	which can happen when the atoms react to each other and move around to other molecules to take up more space, like what would happen with vinegar and baking soda.
	I: now why not A?
	S: So the atoms changed into other atoms that take up more space. The atoms can't change into other atoms, because they are that atom, but they can rearrange.
	I: now why not B?
	S: Because you didn't put any more atoms in and they can't just be created like that.
	I: why not D?
	S: Because it doesn't make sense. The mass increased? , it would increase because of that *???*
	I: you think if the inflation happened, the mass was supposed to decrease, not increase? Or not? What do you think will happen to the mass?
	S: I think the mass would actually go down because the gas formed by it is lighter so it would probably weigh less after that.
	I: now you said at the beginning that it's a closed system, and then you said in the second part the number of atoms stayed the same?
	S: The number of atoms stayed the same.
	I: And you say the mass is going down because…
	S: It's a gas.
	I: It's a gas and it's lighter. thank you, we're done.

Student B-16, Th, May 28 (PM) 57

Q17	**I:** now the last question is, I have a test tube with vinegar. I have baking soda in a balloon and then I connect the balloon and turn it on the test tube and then the balloon inflates. You did something similar in class, right? So do you think it's an open system or closed system?
	S: Closed system.
	I: why?
	S: Because there is no way the oxygen can get out so it blows up the balloon.
	I: why do you think there is no way?
	S: Just because it blows up the balloon, because if there was a hole and it was an open system and stuff, it wouldn't blow up the balloon. It would just go into the air.
	I: what is the best way to check if it's really tightly and nothing can escape? Just a minute. *talks to someone else* So what scientific measurement can you do to check if it was a closed system or not?
	S: You can do…I forget what it's called.
	I: So, what can you measure?
	S: You can measure the, well what we did in class is to see whether it was open or closed system, we first tested it.
	I: how did you test it?
	S: We did the whole thing, the whole experiment and then if it didn't work

	we help support it with more things around it.
	I: how did you know if it works or not?
	S: You tested it, you tried it once before.
	I: now do you think the number of atoms before and after would be the same or different?
	S: The same.
	I: Why?
	S: Because they never left, hold on one second I have a call.
	I: we have about two more minutes. So why will it be the same?
	S: Because none of the atoms escaped into the air.
Properties diss	**I:** now what about the properties? They will change or not?
	S: They won't change.
	I: Why?
-----	**S:** Because it's all the same stuff in it.
	I: now the last question is what caused the balloon to inflate? There are 4 options, so just read it.
	S: None of them.
	I: let's go one by one. Why not A?
	S: Because none of the atoms really changed. Well I guess it could be A because they kind of do change because it was a chemical reaction. So I guess it could be A.
	I: what about B? Why not B?
	S: Because the atoms don't increase.
	I: The number of the atoms?
	S: Yeah.
	I: why not C?
	S: Because molecules don't just change to take up more space. They would have to interact with other molecules, just transform into a different molecule.
	I: what about D?
	S: Mass didn't change because it's all the same stuff in the bottle.
	Time: 30:05
	I: you think it's A?
	S: Yeah.

<u>Student B-18, Thu, May 28 (PM)   65</u>

Q17	**I:** great. So we are on the last question. I have a test tube filled up halfway with vinegar, and I have a balloon with baking soda. And then I attach the balloon to the test tube and move the contents of the balloon up, hold it up above the test tube and the balloon inflates. So that is the scenario. Do you think it's an open system or closed system or we don't have enough information to decide?
	45:04
	S: Wait, so you have vinegar in a test tube and you pour baking soda and

	then you quickly over it?
	I: No I first put the baking soda here, in the balloon before, then I connect it well. After it's connected I put the contents of the balloon above the test tube.
	S: It's a closed system.
	I: why?
	S: Because there is no room for anything to escape.
	I: is there a way you can make sure if it's closed or not?
	S: You can weigh the mass before and after, and if they're the same it'll be a closed system.
	I: And if they are different?
	S: It's an open system.
	I: in this case, you know if it's open or closed?
	S: Well I'm pretty sure it's closed but I can't be sure without the mass.
	I: So what about the number of atoms before and after?
	S: The same.
	I: why?
	S: Because if it's a closed system you can't really lose atoms.
	I: in order to be sure if it's closed or not, what do you need to do?
	S: The same mass before and after.
	I: The same number of atoms or the same mass, so…
	S: So what you do is you have this, right? *???* You wait for the entire thing. Then you do the experiment and then you weigh this.
	I: and then what?
	S: And if the masses are the same then it's a closed system.
	I: And the number of atoms will be…?
	S: The same.
Properties	**I:** What about the properties, do they change or not?
	S: They would change because it's a chemical reaction.
	I: what kind of properties, for example, changed?
	S: Density, for example.
	I: how do you know the density changed?
	S: Well it's a chemical reaction, and in chemical reactions properties change. I mean, we could take this substance at the bottom, we could find the density before we put it in.
	I: What do you know for sure, for example, that changed? And from this can you figure out the density?
	S: What do you mean?
	I: In order to find out the density, what do you need to do?
	S: You need to find the mass and volume.
	I: for example, in this case-
	S: Oh yeah, you could just find the mass of the whole thing and then find the volume of the whole thing.
	I: you are not sure if the mass changed or not? What do you think, did the mass change or not?

	S: I don't think it changed.
	I: But the volume?
	S: It probably changed because *???*
	I: It inflates, so you know for sure the volume changed because it inflates. So the density will…
-----	**S:** Change.
	I: now the last question, what do you think caused the balloon to inflate? And there are 4 options here.
	S: I'd say C.
	I: why C?
	S: Well, I mean with this one, I already told you why I think B and D are wrong.
	I: let's just go one by one. What is the difference between B and D?
	S: D talks about the mass and B talks about the atoms.
	I: basically they indicate the same things or different things?
	S: They indicate different things but I mean, well I guess you could say they represent the same thing because if the number of atoms increased, then the mass would increase, assuming they are the same atoms.
	I: just for you to know, this is what you see, and this is what the model is. So , you think it's not increased so it's not B and D?
	S: Yes.
	I: How do you decide between A and C? What is the difference?
	S: Well, when I lo at A, you can't really change the atoms in the middle of the experiment; it just doesn't happen.
	I: -
	S: But you can make new molecules and for example, a gas molecule takes up more space than a liquid molecule, and I think that's what happened here.
	I: Ah you think it's C, can you explain a little bit more why it's not A?
	Time: 50:05
	S: Well, if you have a certain substance in a container, and no matter what, the atoms are still going to be there because, yeah.

<u>Student B-19, Fri, May 1st (PM)   72</u>

Q17	**I:** Now we are in the last scenario. Here I have something you did similar in class but with different materials. I have a test tube filled half with vinegar, and a balloon I put baking soda and then I connect everything well and then I pour in this and the balloon inflates. ? So now what I'm asking is whether you'd describe this as an open system or closed system?
	S: This is a closed system because the mass would be the same because the balloon filled up. So if you weighed the contents of the test tube before and after, then there would be the same mass, so none of it can escape from the balloon.
	I: Now just based on the scenario here, how sure are you that it's closed?
	S: I'm pretty sure that it's closed because unless there was some gap in the area between the neck of the balloon and the test tube, then none of the matter can

	escape.
	I: Now what do you need to do in order to be sure?
	S: You have to mass the balloon, the test tube, the baking soda, and the vinegar before the reaction, and then the system, the test tube, the baking soda-vinegar product, and the balloon, before and after.
	I: now did we do that in this scenario here or did we measure the mass or not?
	S: In this? It doesn't say that we measured the mass.
	I: So you're pretty sure it's a closed system. Like you assume there are no holes or something.
	S: Yeah.
	I: But in order to be 100% sure, what do you need to do?
	S: Before and after, measure the mass.
	I: Now what is best to describe the…, here, what caused the balloon to inflate?
	S: The molecules, they reacted and changed into other molecules and the gas to up more volume.
	I: what option will that be?
	S: It will be option C.
	I: why not option A?
	S: Because the atoms can't change into other atoms because new atoms can't form.
	I: and why not B?
	S: Because new atoms can't appear out of nowhere.
	I: why not D?
	S: Because in a closed system, according to the law of conservation of mass, the number and type of molecules can't change and the mass will be the same. So if this is a closed system, then it can't be D.
	I: now what do you think will happen to the number of the atoms?
	S: The number of atoms, it stays the same because in a closed system none of the matter can escape.
	I: I think we are done. Let's see the time. You went fast. Thank you very much.

<u>Student B-24, Wed, May 27 (PM)   78</u>

Q17 (Connor)/ <u>Brandon</u>	**I:** Now we are in the last question. In the last question I have a test tube filled up halfway with vinegar and a balloon with baking powder. And then I attach the balloon to the test tube and then I shift the balloon and it inflates. So do you think it's an open system or closed system?
	Time: 20:04
	S: It's a closed system because the balloon and the test tube are connected and they don't have, unless they have holes in them, it would be a closed.
	I: is there a way you could know if there is like a hole or something?
	S: Yeah I guess you could pre-blow the balloon up to see if there wasn't any holes.
	I: what scientific test could you do to measure if it's an open or closed system?
	S: You could test, scientific test…

	I: Like what could you do to measure, to check if it's open or closed system?
	S: Make sure there aren't any holes. Make sure there is no way for it to leak and reinforce…
	I: How can you make sure? You said it's a closed system right? If you want to make sure it's a closed system, what do you need to measure?
	S: I don't know.
	I: What did you measure in class to see if the system was closed or open?
	S: The total mass at the end.
	I: and…at the beginning.
	S: Yeah at the beginning you test the mass.
	I: you can be sure it's a closed system or not?
	S: If you did the experiment and the mass is the same at the beginning and after the experiment, then it would be the same, it would be a closed system.
	I: And if the mass was different?
	S: If the mass was different it would be an open system.
	I: Do you think the number of the atoms before and after would be the same or different?
	S: They'd be the same if it was an open system.
	I: If it was…
	S: An open system.
	I: Closed system.
	S: Oh yeah, closed system. Oops.
	I: So you think it will be the same?
	S: Yes.
	I: The number of atoms. What about the type of atoms?
	S: The type of atoms…would be the same.
	I: now what do you think caused the balloon to inflate?
	S: There was a chemical reaction and some of the liquid turned to gas and rose up into the balloon and it inflated.
Properties	**I:** So what happened to the properties?
	S: The properties, I mean, I think they would stay the same.
	I: Stay the same?
	S: Yeah I think so.
	I: Why?
	S: Because…it was a closed system, and nothing really got out so the mass, well I mean if some of the liquid turned to gas then I guess it would be different but only some properties would. Like the density of the water would stay the same. *???*
	I: So you say some properties would change and some would not?
	S: Yeah.
	I: So what example do you think could change?
	S: Like the volume of the vinegar could have changed because some of

	it turned to gas.
	I: So you think volume is a property.
-----	**S:** Yes.
	I: The last question just choose the correct answer here: what caused the balloon to inflate? There are 4 options.
	S: C.
	I: why C?
	S: Because molecules can change and it just seems like the most logical out of all of them.
	I: now in this case, what molecules do you think change? What indication do you have that molecules changed?
	S: Just that the balloon inflated, I'm not sure.
	I: There is something here that wasn't here?
	S: Yeah there is gas, more gas.
	I: Why not, so that's something new?
	S: Yeah.
	I: now why is it not A?
	Time: 25:00
	S: Because atoms can't change into other atoms.
	I: What about B?
	S: Since it was a closed system no atoms could be added or escape.
	I: why not D?
	S: Because it doesn't seem logical, or the mass in the system increased. I mean, it could be possible, I don't know.
	I: What do you think about D?
	S: Out of A, B and D, I think I would choose D. But C just seemed like a better answer for the whole system, question.
Properties continues	**I:** now we just go back to, just 30 seconds. We'll just go back to the properties. We said the volume changed, so you think the volume is a property or not?
	S: As a property, yeah.
	I: why?
	S: Because it affects the density and density is a property and you can tell if the mass is the same, let's say the mass for water and alcohol is the same, the volume could be different to make depending on the density.

<u>Student D-47, Wed, May 27 (PM) 85</u>

Q17	**I:** now we are in the last question. I have a test tube filled halfway with vinegar and I have a balloon with baking soda. I connect it together and I pull it over and the balloon inflates. Is it open or closed system?
	S: Closed.
	I: Why?
	S: Because technically you don't have the data to figure that out yet.
	I: why, what data am I missing?

	S: Well you don't know what the mass is before and after, so you wouldn't be able to tell if it was open or closed.
	I: if you had to choose between the 3 options, you would choose G?
	S: Yeah. I know it's closed but from this data, you cannot say *???*
	I: now if you had the data for the mass, so what kind of information are you looking for in order to figure out if it's open or closed?
	S: If it's lighter or heavier because if it weighs the same before and after, then you know you didn't lose any of the stuff.
	Time: 40:06
	I: Now what about the number of the atoms?
	S: It would be the same.
	I: So before and after it will be the same?
	S: Yes, assuming it's closed.
	I: If you don't know the mass?
	S: H.
	I: What caused the balloon to inflate?
	S: When the baking soda and vinegar reacted, it created a gas which inflated the balloon.
	I: just choose here from the 4 options.
	S: C.
	I: Why not A?
	S: Not A because atoms can't change into other atoms, they can only regroup into different molecules.
	I: why not B?
	S: Because you can't create matter.
	I: why not D?
	S: Because if you have the same amount of matter, the mass won't change.
	I: what is the difference between B and D?
	S: Well you wouldn't necessarily know if they're the same because with B, D could be caused by B could happen, but D could also be the atoms getting bigger, which can't happen either, or the atoms getting heavier, which can't happen either.
	I: Atoms can become bigger or heavier?
	S: No.
	I: Basically, B and D are the same just *???*
	S: Well B could cause D, but D could be caused by other things.
	I: Yeah this is like what you see, the mass, the microscopic and this is like what is in the molecular level.
	S: Yeah.
Properties	**I:** What will happen to the properties before and after?
	S: Um, well it will create several new substances and they will all have different properties.
	I: now it's possible that some of the properties will be-
	S: Some of the properties may remain the same, but the substances will have at least a couple of changed properties.

	I: Great. So what is the indication for the new substance, just an example?
-------	**S:** Well the balloon inflating is an example that there is a gas being created.

Student B-26, Tue, April 21 (AM) & Wed, April 22 (AM)   90

Q17	**I:** Now I have a test tube and I fill it up with vinegar, and baking soda was added. I have a test tube that is filled with vinegar, ? And then I take a balloon and put baking soda in the balloon, ? Now I put the balloon around a test tube and then just after I close it I let the baking soda go into the vinegar, ? And now I drop it in the test tube and the balloon inflates, ? So the question is: what do you think caused the balloon to inflate?
	S: Well the vinegar and the baking soda create a chemical reaction and it created gas, so this would be a closed system because the balloon is over it, covering the test tube when the gas is created it caused the balloon to inflate because the gas cannot escape.
	I: So do you think in this case it would be open or closed?
	S: Closed system.
	I: Closed system. So do you expect, assuming it's a real closed system and nothing can escape, do you expect the mass before and after to stay the same or different?
	S: The same.

Student D-40, Fri, May 29 (AM)   104

Q17	**I:** We are in our last question and hopefully we'll finish it. The last question is: I have a test tube filled up halfway with vinegar, and I have a balloon with baking soda, I connect everything well and then after it's connected well I put up the balloon on top of the test tube and then the balloon inflates. So that's the picture before and after. Do you think it's an open system or closed system?
	Time: 25:06
	S: It's a closed system because oxygen or any other substances can't get out.
	I: Is there anything in this story that indicates that nothing got out or not?
	S: You said you tied it around and there is something on top to keep it from going out, so yeah.
	I: what do you think will be the number of the atoms before and after, the same or more?
	S: The same because all you did was inflate a balloon. They are still trapped in that little bottle.
Properties	**I:** What about the properties?
	S: The properties stay the same because it's still going to be the same density, because, oh no, it says in a gas, so the properties will change.
	I: What example of properties changed?
	S: Density will change because it's losing, no it won't actually. Actually, properties won't change even though because it's still all in there because

	when you change states, it doesn't change mass, so yeah.
	I: What about the volume, for example?
	S: The volume is not a property.
	I: So what do you think, was there a chemical reaction here?
	S: There was, no there wasn't. No there wasn't a chemical reaction.
	I: Why?
	S: There was a state change which is not a chemical reaction.
	I: so you think the property doesn't change and there was no chemical reaction?
	S: Yes.
Sub q2	**I:** Just state change. what do you think caused the balloon to inflate? There are 4 options here to choose and that's the real last question.
	S: The number of atoms increased, B.
	I: B, . But before you said that the numbers didn't change because it was a closed system.
	S: Oh. C.
	I: C, why C?
	S: Because when they change into a gas they take up more space.
	I: why not A? What is the difference between A and C?
	S: Atoms and molecules.
	I: So which one is the one that you think changed?
	S: Atoms, A. Actually I pick A.
	I: A? So you think the atoms changed.
	S: Yes I do.

<u>Student D-41, M, June 8 (AM) 113</u>

Q17	**I:** Now we are in question 5. I have a test tube filled up halfway with vinegar, and the baking soda in the balloon, and I connect it well, and then after it's connected I turn over the balloon so basically the baking soda falls down to the vinegar and then the balloon inflates. Now do you think this is an open system, closed system, or not enough information?
	S: Closed system.
	I: Closed system. Why?
	Time: 10:00
	S: Because nothing is escaping, air cannot escape, it's going into the balloon. It's just filling up the balloon because when it created gas when vinegar mixes, it's neutralizing, and when it does that it makes gas, so the gas can't escape so it's blowing up the balloon.
	I: now do you think the mass will change or stay the same?
	S: Stay the same.
	I: Stay the same.
	S: Because it's in a closed system and no gas can escape.
	I: now what about the number of the atoms?
	S: The number of atoms will stay the same because atoms won't change. They are always the same, just rearranged in different ways.

	I: And the number of molecules?
	S: The number of molecules can possibly change.
Properties	**I:** Can possibly change. Now what about the properties?
	S: The properties, this is a little, uh…the properties will change.
	I: What example of property do you know for sure will change?
	S: The hardness, I think, I don't know. The solubility, the color, I don't know.
	I: Like you see it here. It's very simple. It's not something difficult.
	S: The density.
	I: The density, . Why?
	S: Because, I don't know, it won't change. Because basically it's just since more gas is formed and so since the gas is blowing up the balloon, that creates more volume, it's taking up more space as *???* take up more space, that's a change of volume and then mass changes and stuff so yeah.
	I: So mass changes?
	S: Yeah.
	I: You said before that mass doesn't change.
	S: Yeah that's what I meant. Mass doesn't change but the volume does. So that means the density has to change.
-------	**I:** Good, great. So now there is again a multiple choice question, what causes the balloon to inflate?
	S: . C. *???* changed into other molecules that take up more space.
	I: why not A?
	S: Because atoms can't change. They stay the same.
	I: why not B?
	S: The number of atoms increased because atoms stay the same and they don't change the number of atoms.
	I: and why not D?
	S: Mass *???* because that wouldn't explain anything that mattered. Just because the mass, and the mass doesn't increase, it would stay the same.
	I: now I have a general question. What is the difference between B and D?
	S: They say the mass increased, which is how much the mass increased, the mass in the system increased and then the number of atoms increased. Atoms and mass are different.
	I: They are different.
	S: Yeah.
	I: In what way are they different?
	S: Well mass is not a property. I don't understand how you can explain they're different. They are like, mass is a measurement, and atoms are a thing.

<u>Student D-42, Tue, June 2 (AM) 119</u>

Q17	**I:** we are in the last question, I have a test tube filled halfway with vinegar, and I have a baking soda in the balloon and I connect everything together and then after it's tightened I tip over the balloon and it inflates.

	Now the question: is this an open or closed system?
	S: It's a closed system
	I: Why?
	S: *???* the gases are being released because if the gases were being released the balloon wouldn't expand, it would stay shrunken.
Properties	**I:** now what do you think happened to the properties? Did they change or stay the same?
	S: They changed.
	I: what example?
	S: Because when you put baking soda and vinegar together, it bubbles. It changes color, I think. The density would change.
	I: How do you know the density changed?
	S: You'd have to weigh it before and after.
---------	**I:** And what about the number of atoms before and after?
	S: There would be less atoms.
	I: why?
	S: *???* turning a liquid to a gas, and the reason you can tell it's a gas is because the balloon is inflating.
	I: why is it less atoms?
	S: Because the atoms turned into a gas, breaking off from the liquid, and inflating the balloon.
	I: What about the number of molecules?
	S: The number of molecules would also go down.
	I: why?
	S: Because, wait, for the molecules and atoms do you still say it counts if it's in the balloon?
	I: Yes, it still counts. *???*
	S: *???*
	I: So both of them will stay the same?
	S: They both stay the same.
	I: why?
	S: Because nothing is lost in the closed system, the balloon *???* confused about that for a second.
	I: So you say that the number of atoms will stay the same?
	S: I said it would stay about the same.
	I: And what about the number of the molecules?
	S: They would also stay the same because they are all being trapped inside the balloon in the closed system.
	I: now the last thing is this multiple question: what caused the balloon to inflate?
	S: *mumbling* C, the molecules changed into other molecules *???* because the vinegar and baking soda atoms and molecules combined and they would take up more room, which is making the balloon inflate?
	I: So why not A?
	Time: 30:01

	S: I'm not exactly sure if that would happen. I'm pretty sure it wouldn't because molecules *???* atoms don't really change.
	I: why not B and D?
	S: The number of atoms increased, because it couldn't increase or decrease because atoms and the mass can't increase because it's a closed system, so therefore nothing can really happen.
	I: So what is the difference between B and D?
	S: I'd actually like to say that it's B because molecules don't change, molecules are the actual substance itself. But atoms are what they are connected to.
	I: Yeah but you said that both B and D indicate that it's increased, so what is the difference in terms of understanding, like B and D they are the same or different?
	S: B and D are different because it couldn't increase or decrease because it's in a closed system.

Student D-48, Wed, May 13 (PM) 128

Q17	**I:** now is the last question, I have a similar scenario. I have a test tube and I fill it up halfway with vinegar, then I put some baking soda in a balloon and I connect it well, really tight, and then I pour the contents of the balloon, I drop it, and the balloon inflates. So you did something similar in class.
	S: That is exactly what we did.
	I: So do you think it's an open or closed system?
	S: Closed.
	I: Why?
	Time: 35:00
	S: Because everything is happening in one place. None of the stuff in there is being exposed so it can leave.
	I: do you have any evidence in the scenario if it's a closed or open system?
	S: Because the balloon is secured on top of the tube, so anything that leaves the tube will go into the balloon.
	I: Now if I ask what caused the balloon to inflate, could you just…
	S: The mass of the system increased.
	I: You think it's D? The mass of the system increased. Why not A? First of all, why do you think it's D?
	S: I think it's D because the mass did increase because between the baking soda and vinegar, a chemical reaction happened and so when the chemical reaction happened there was gases but it went into the balloon, and so it added more mass to the system.
	I: Why not A?
	S: Because atoms can't change into other atoms.
	I: Why not B?
	S: Because the number of atoms can't appear. More atoms can't appear from somewhere else.
	I: Why?

	S: Because they can't appear.
	I: Why not C?
	S: I don't know why not C, I just chose D.
	I: So if we go back to D, so you say that the mass of the system increased because the balloon was inflated. So and then in the first question you said that it's a closed system. So in a closed system what happens?
	S: In a closed system all the gases or anything that are trying to escape the…they are trapped and can't leave.
	I: now you think that the number of the atoms of the system before and after, it's similar?
	S: It's the same.
	I: why?
	S: Because no atoms can appear or disappear.

Appendix E - Percentage of Success in the Multiple-Choice Questions on the Tests

Table E.1: Percentage of success in the multiple-choice questions on the tests

Q #	Key answer	Construct maps & sub-levels*	% "A" pre	% "B" pre	% "C" pre	% "D" pre	% "correct" pre	% "A" post	% "B" post	% "C" post	% "D" post	% "correct" post
1	C	CP-3	10%	5%	57%	29%	57%	0%	2%	97%	2%	97%
2	B	MC-3 & RA-3	5%	61%	28%	6%	61%	5%	87%	5%	3%	87%
3	D	CP-2	11%	16%	8%	66%	66%	5%	0%	2%	94%	94%
4	B	RA-1	16%	73%	5%	6%	73%	3%	92%	3%	2%	92%
5	B	CP-4	62%	13%	10%	16%	13%	6%	87%	3%	3%	87%
6	A	RA-1	58%	25%	9%	8%	58%	90%	6%	2%	2%	90%
7	C	MC-1	14%	30%	30%	27%	30%	13%	11%	65%	11%	65%
8	A	CP-2	50%	14%	5%	31%	50%	76%	11%	3%	10%	76%
9	D	RA-3	3%	11%	30%	56%	56%	0%	0%	18%	82%	82%
10	C	RA-3	16%	28%	52%	5%	52%	5%	10%	80%	5%	80%
11	A	MC-2	30%	20%	23%	27%	30%	87%	5%	8%	0%	87%
12	D	CP-1	13%	22%	8%	58%	58%	2%	2%	3%	94%	94%
13	C	RA-3	8%	6%	72%	14%	72%	3%	2%	94%	2%	94%
14	B	RA-3	17%	36%	11%	36%	36%	10%	82%	0%	8%	82%
15	B	MC-1	9%	55%	8%	28%	55%	2%	94%	2%	3%	94%
16	A	MC-1	28%	31%	41%		28%	76%	7%	17%		76%
17	B	MC-2	16%	42%	42%		42%	9%	19%	72%		19%
18	D	MC-3	11%	24%	48%	17%	17%	7%	3%	60%	29%	29%
19	A	MC-2	16%	55%	30%		16%	9%	44%	47%		9%
20	C	CP-4	27%	16%	40%	17%	40%	5%	5%	81%	9%	81%
21	A	CP-4	75%	11%	10%	5%	75%	90%	3%	2%	5%	90%
22	C	CP-4	24%	16%	48%	13%	48%	3%	3%	90%	3%	90%
23	B	RA-2	10%	19%	27%	44%	19%	3%	16%	21%	60%	16%
24	D	RA-2	14%	29%	27%	30%	30%	10%	19%	14%	57%	57%
25	A	RA-1	21%	19%	19%	41%	21%	45%	10%	5%	40%	45%

*CP = Change of Property construct map; RA=Rearrangement of Atoms construct map; MC=Mass Conservation construct map; the numbers are the sub-levels of the construct maps

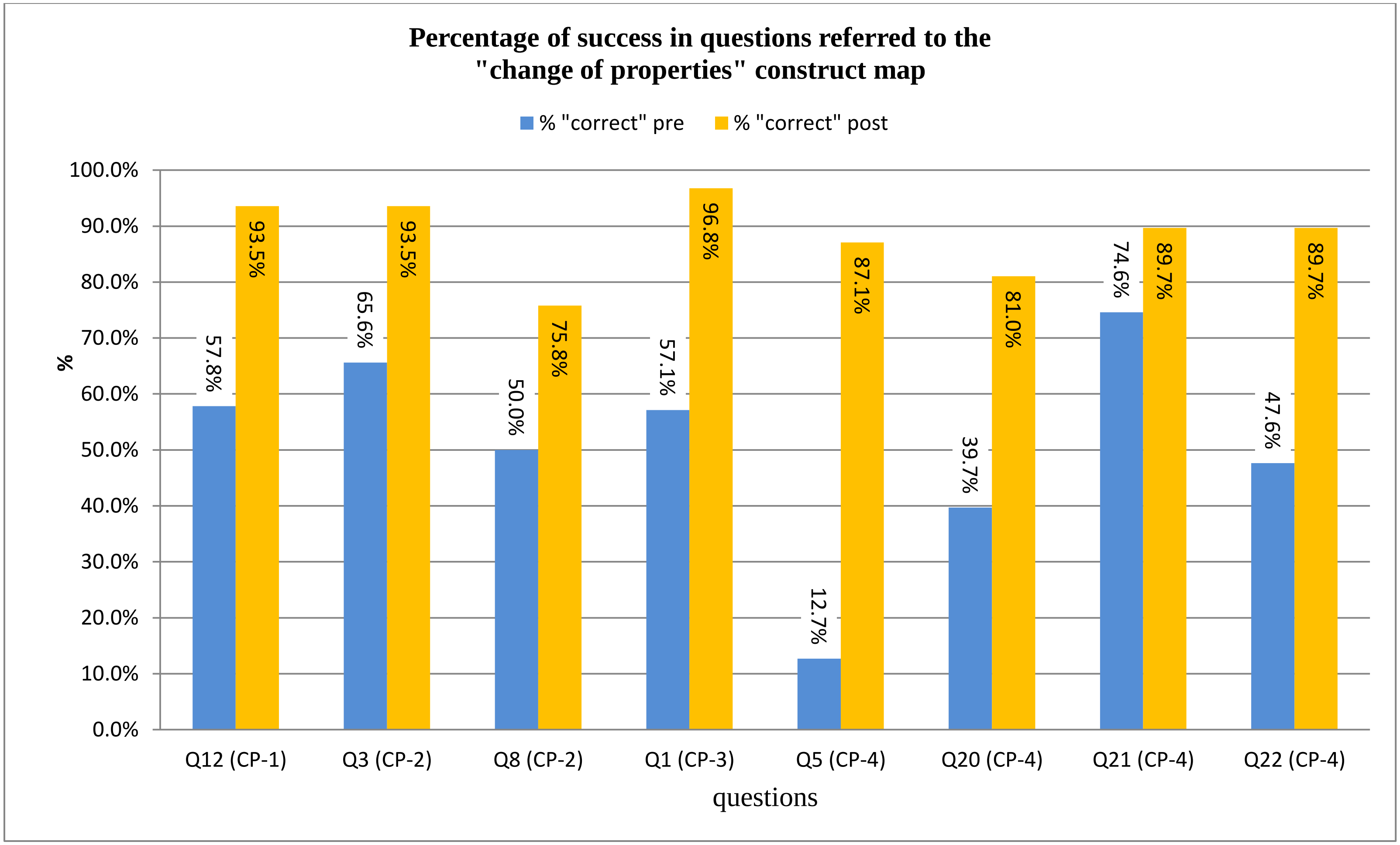


Figure E.1: Percentage of success in questions referred to the “change of properties” construct map

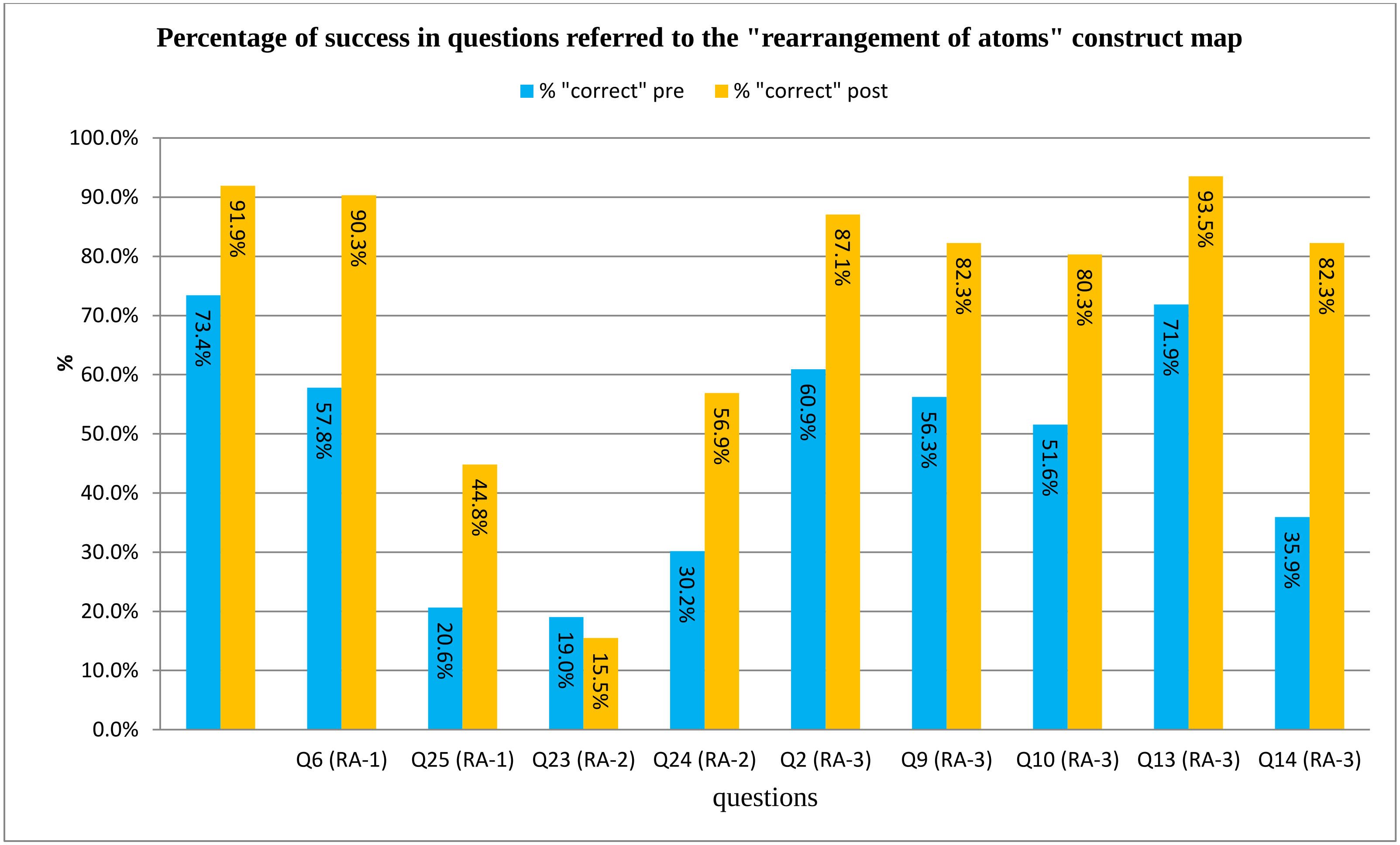


Figure E.2: Percentage of success in questions referred to the “rearrangement of atoms” construct map

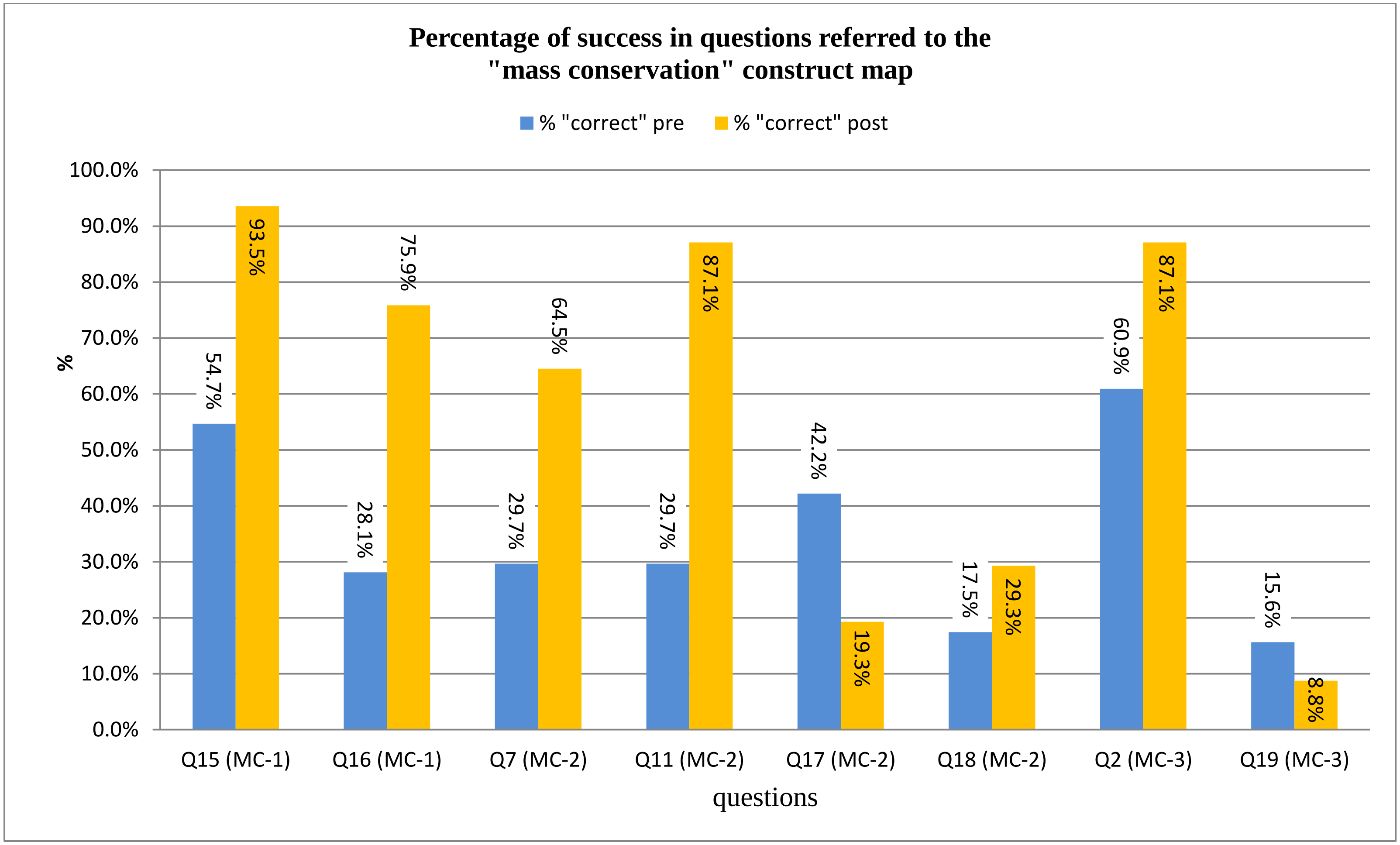


Figure E.3: Percentage of success in questions referred to the “mass conservation” construct map

Appendix F - Sample Analysis of Interview Questions

A Sample analysis of question 16 (3rd set of interviews)

Table F.1: A summary of students' responses to question 16 (3rd set of interviews)

Q16 parts 1-3 "mass conservation" CM	Sub-Q1: level 1 (open vs. closed system)	Evidence used			Sub-Q2: level 2 (macroscopic level)	Sub-Q3: level 3 (microscopic level)	
Student ID	Open / closed?	mass left the system	System set-up	Mass can enter to the system	Correct answer: C	More/less/same?	Referred to the mass change given in the Q?
C-29	open	Mass left	x	x	C	less atoms in the ash than the wood because some of the atoms turned into a gas	Yes
C-30	open	Smoke escaped. Because whenever you burn something there is smoke	nothing was covering it to stop it from going away	x		Less atoms because some of the atoms escaped with the smoke. The smoke is made of atoms, and the atoms were part of the wood, so yeah, it escaped	no
C-36	open	b/c smoke escaped. Ss can't make the macroscopic-microscopic connection between loss of mass and the loss of atoms	x	x		# of atoms stays the same: "it's like the same substance except it's just in a different form… wood, anytime you burn it, it turns into ash. That's how it is."	No
C-37	open	x. Ss mentioned that smoke left during the discussion later on, but didn't use this info to support why open/closed. In the end said that "if it weighs less than some escaped"	There is nothing around it making it closed.	x	At first thought that "A" (because all the other options do not make sense), but after discussion changed to	Less atoms – some escaped	Yes

					"C" because atoms do not disappear.		
C-39	open	x. Ss mentioned that smoke left during the discussion later on, but didn't use this info to support why open/closed	Because there was nothing preventing wood or fire from escaping… or "not enough info" they didn't tell you if there was something covering the wood or not… I guess you could assume they were open but you don't know.	x	C. Not A Because fire needs oxygen to survive. Not B because the atoms in the wood left, they didn't change.	Less because some left	No
B-15	open	x. Mentioned that smoke left during the discussion later on, but didn't use this info to support why open/closed.	Because the gas can go wherever. It doesn't stay with the wood.	x	C – Chose C over B just because C gives more details. Then explained "C because that's how the chemical reaction reacts with the fire. It burns, the oxygen gets in and makes a gas that lets the wood go out." About B he said that "It's good, it would work, but I thought C gave more depth to it. And it gave you more information about it… B says the atoms in the wood changed and became smaller. It's kind of summarizing what C says, but C gives more description to what it is. The atoms in the wood changed, so that's pretty much saying that the	The log will probably have more atoms because it's atoms. The log. It's bigger and needs more atoms…. Usually by the size of it, if it's big and if you burn it and it shrinks, you can tell that some of it has gone away. You can tell it has less atoms…there are less atoms because it's smaller	no

					wood reacted and the atoms became gas.”		
B-16	Open	“Because it’ll burn all the oxygen, well not really all the oxygen, but some of the oxygen out. And so it’ll make it smaller.” It is still the same substance “only it’s just burned off a little bit. Some of the oxygen and stuff escaped into the air.”	x	x	C	Less atoms because “some of the atoms burned off from the fire”	No
B-18	open	“Because you lost mass and that can only happen in an open system where you allow things to escape.”	x	x	N/A	Less because you’re losing atoms because it’s an open system	yes
B-19	open	yes	x	x	C	Less. … because it has less mass so it has less matter in it	no
D-47	open	yes	x	x	C	Less because some of the atoms would escape	yes
B-24	open	Yes. it is open because the mass can’t change unless something is getting out of the system.	x	x	C	less	Yes
B-26	open	Gas escaped. The student cannot make the macroscopic-microscopic connection between loss of mass and the loss of atoms.	x	x	C	The same number of atoms “because we burn it, that’s a chemical reaction, so it has the same number of atoms before and after…. Well, maybe it would be less because some of the gas was able to escape and that has some of the atoms.”	no
D-40	open	Because atoms were lost. And if it was a closed system, they would have to be trapped inside.	x	x	A – “Some of the atoms burned in the wood and disappeared and it was an open system.” Not B - atoms can become smaller, but “Because the atoms becoming smaller wouldn’t cause the wood	less	no

					to change because the atoms are still there."		
D-41	Open	Yes. Mass left. "the mass has changed, so that indicates that it's an open system because a chemical reaction happened." The student understands that it is an open system and support it with the weight loss, but also think that the number of atoms stayed the same. The student can't make the macroscopic-microscopic connection between loss of mass and the loss of atoms.	x	x	C. But, thought that A & C are about the same.	"It would be the same. In a chemical reaction, no atoms are lost, they can just be rearranged and can make new molecules. And the number of molecules could change but the number of atoms is always the same kind of atoms and the types of atoms are the same. Atoms are always there." She thinks that the number of molecules can change because the atoms rearranged, but number of atoms stays the same.	Yes
D-42	open	yes	x	x	C	Less because of the gases released from the wood	yes
D-48	open	"The mass is less because they are closer together." The student thought that the system is open, because its set-up, the mass is less because they are closer together, and the number of atoms stayed the same. Meaning that she can't make the macroscopic-microscopic connection between loss of mass and the loss of atoms.	Yes. "There is nothing surrounding it to prevent anything from leaving."	x	C	"Same. No atoms are lost so the numbers stay the same, but the number of molecules did change because it's a chemical reaction, the atoms joined together to form different types of molecules. And so the number of molecules did change, and the atoms didn't."	yes

My notes while synthesizing the data from question 16

At least five students did not make the macroscopic-microscopic connection between the mass change and the change with the number of atoms. Four of them justified that the system is an open because mass was lost, but thought that the number of atoms did not change. A student explained, for example, that “no atoms are lost so the numbers stay the same, but the number of molecules did change because it’s a chemical reaction, the atoms joined together to form different types of molecules. And so the number of molecules did change, and the atoms didn’t.” Another student gave a similar explanation: “It would be the same. In a chemical reaction, no atoms are lost; they can just be rearranged and can make new molecules. And the number of molecules could change but the number of atoms is always the same kind of atoms and the types of atoms are the same. Atoms are always there.” Those students can explain that in an open system the mass can leave the system, but do not realize that it means that atoms can leave as well. They state the mass conservation law at the microscopic level independence from open/closed systems. Additional student out of this latter group of students who could not make the macroscopic-microscopic connection, thought that there will be fewer atoms, but not because mass was lost, but because the powder left over after burning the wood takes less space. The students explained that “you can tell it has less atoms…there are less atoms because it’s smaller.”

Representative explanations for why there are fewer atoms in the powder (after burning) among students who made the connection between the mass change and the change with the number of atoms explained were: “less atoms because some of the atoms escaped with the smoke. The smoke is made of atoms, and the atoms were part of the wood, so yeah, it escaped”, or “less because of the gases released from the wood.”

All the students thought that the system is open.

The question explicitly said that “the powder weighs less than the wood prior to burning”, but only half of the students (8 out of 16) referred to the mass change information that was given in the question to support their decision that the system is open. A representative explanation was: “because you lost mass and that can only happen in an open system where you allow things to escape.” The rest of the students who did not refer to the data given in the question thought that it is an open system because smoke escape, but did not support it with the need to know whether the mass before and after has been changed.

About one-third of the students (5 out of 16) referred to the system set-up to explain why the system is an open. Students said, for example, “there is nothing surrounding it to prevent anything from leaving”, or “there is nothing around it making it closed”

None of the students referred to the ability to enter the system in an open system.

A sample analysis of question 17 (3rd set of interviews)

Table F.2: A summary of students' responses to question 17 (3rd set of interviews)

Q17 sub-Qs 1-3. "mass conservation" construct map	Sub-Q1: level 1. Comment: the reaction is taking place in a closed system (assuming that the balloon is airtight and nothing can get in or out)				Level 2: The mass doesn't change	Need to test mass ?	Level 3: the number and type of atoms do not change	Sub-Q2 (key: C)	comments on Sub-Q2	comments
		evidence used								
Student ID	Open/closed /not enough info?	nothing can get in	nothing can get out	System set-up						
C-29	closed	x	x	yes	same 1	After prompting	Same 1*	C		
C-30	closed	x	yes	x	Mass doesn't change		Same 2*	C		Macro-micro diff in subQ2
C-36	closed	x	x	yes			More	B	B then changed to A	Can't distinguish atoms from molecules
C-37	closed	x	yes	yes	Mass doesn't change	After prompting	Same 2	A		
C-39	closed	x	yes	x	Mass doesn't change		Same 2			
B-15	closed	x	yes	yes	Mass decrease	no	Same 2	C		# atoms the same, but mass decrease
B-16	closed	x	yes	yes	Mass doesn't change	no	Same 2	A		
B-18	closed	x	yes	x	Mass doesn't change	After prompting	Same 2	C		
B-19	closed	x	yes	yes	Mass doesn't change	After prompting	Same 2	C		

D-47	closed	x	x	yes	Mass doesn't change	no	Same 2	C		
B-24	NEI* - Because technically you don't have the data to figure that out yet				Same 1	yes	Same 1	C		
B-26	closed	x	yes	yes	Mass doesn't change	no	Same 2			
D-40	closed	x	yes	x	Mass doesn't change	no	Same 2	B	After discussion changed to C then changed to A	In subq2 thinking that atoms changed (not molecule) although said initially that # of atoms do not change
D-41	closed	x	yes	yes	Mass doesn't change	no	Same 2	C		# molecules change
D-42	closed	x	yes	x			Less atoms…. Then changed to Same 2	C		# atoms & molecules stay the same
D-48	closed	x	yes	yes	Mass increased		Same 2	D		Mass increasing, but Same # atoms "Because no atoms can appear or disappear."

*<u>Key</u>:

- "Same 1" - explicitly mentioned that the number of atoms do not change assuming that the system is closed (after verifying it with measuring the mass before and after)
- "Same 2"- did not mention the need to double check mass/closed system
- "NEI" - Not enough info because we do not have mass data.
- "NEI plus" - Not enough info because we do not have mass data PLUS explaining what if an open and what if a closed.

Sample quotes from students that may be used to support claims made about student understanding of the conservation of mass in question 17:

Same atoms

System set-up examples:

“Closed system, because the balloon makes it a closed system by making it airtight, keeping in the molecules that get turned into a gas.”

“Because when putting the balloon over it, it keeps all the air inside and all the chemicals that you put in, and so that’s what made the balloon inflate because of the closed system.”

Can’t leave the system examples:

“Because nothing has escaped”

“Closed because they had to go into the balloon and they couldn’t go into the air and escape”

Both system set-up & can’t leave:

“Because the balloon is covering the top, trying to catch whatever will come out from the vinegar and baking soda reaction”

“Because there is no way the oxygen can get out so it blows up the balloon… if there was a hole and it was an open system and stuff, it wouldn’t blow up the balloon. It would just go into the air”

“Because the balloon is over it, covering the test tube when the gas is created it caused the balloon to inflate because the gas cannot escape”

“Because the balloon is secured on top of the tube, so anything that leaves the tube will go into the balloon”

“Because the balloon is not allowing the molecules to escape”

# of atoms samples of quotations:

“They would probably be different just because before the balloon wasn’t inflated at all.. It was completely inflated so there are probably more atoms”

“The number of atoms doesn’t change, but there are different types of atoms and those can rearrange to make different molecules”

“The mass doesn’t change b/c the amount of atoms or molecules doesn’t change”

Less atoms:

“Because the atoms turned into a gas, breaking off from the liquid, and inflating the balloon”…. Then changed her decision to “Same” explaining that the number of atoms and molecules will stay the same. “They molecules would also stay the same because they are all being trapped inside the balloon in the closed system.”

My notes while synthesizing the data on question 17:

The question on purpose does not explicitly specify whether or not mass has been changed. At the highest level students are expected to say that the system is seemed to be closed but we cannot know for sure unless we get mass measurements before and after the balloon was inflated verifying that the mass of the system did not change. Students at that level are expected therefore to choose that there is not enough information to decide if the system is closed and that there is not enough information to decide if the mass changed and whether or not the number and types of atoms remained, but only after measuring the mass before and after.

Only one student (out of 16) chose that there is not enough information to decide because the question does not provide mass data before and after. The student explained that “technically you don’t have the data to figure that out yet.” All the rest of the students (15 out of 16) thought that the system is closed. After prompting whether or not they are sure about their decision that the system is closed, four additional students (out of 16) suggested measuring the mass before and after to verify that the system is closed, but only one of them kept referring to the missing mass data when he was what will happen to the mass and to the number of atoms, saying that if it is a closed system the mass does not change.

To justify why the system is closed all the students (15) referred to either the system set-up (the balloon is airtight and wrapped around the opening of the test tube), or to that nothing can get out (gas cannot escape) or to both pieces of evidence. Seven of them referred to both the system set-up and to that nothing can get out (gas cannot escape), and the rest of the students used only one of the two pieces of evidence; specifically, three students only referred to the system set-up, and five students only mentioned that nothing can get out. None of the students mentioned that nothing can get in.

Level 2:

In the vinegar – baking soda balloon inflation scenario (question 17 on the post-test) described above, students were also asked what happened to the total mass of the system after the balloon inflated. Three-quarters of the students (12 out of 16) thought that the mass did not change, where two of them also said that the mass did not change only if we verify that the system is closed. The rest of the students thought that the mass changed. A student who thought that the mass decreased explained that it is “because the gas formed by it is lighter so it would probably weigh less after that.” A student who thought that the mass increased explained that it is “because between the baking soda and vinegar, a chemical reaction happened and so when the chemical reaction happened there was gases but it went into the balloon, and so it added more mass to the system.”

2 students understand that mass can confirm if the system is closed/an open, but did not suggest it in the beginning of the scenario discussion saying that there is not enough information to decide until we measure the mass. The student suggested measuring the mass only after explicitly being asked what can he do to verify if the system is closed.

Level 3:

In the vinegar – baking soda balloon inflation scenario (question 17 on the post-test) described above, students were asked to choose what caused the balloon to inflate with the following alternatives:

a. The atoms changed into other atoms that take up more space.
b. The number of atoms increased.
c. The molecules changed into other molecules that take up more space.
d. The mass in the system increased.

About one-third of the students answered incorrectly, having difficulties in understanding that in a closed system the number and types of atoms do not change (alternatives A or B, 4 out of 14 students) or that during a chemical reaction in a closed system, the mass remains the same (alternative D, 1 out of 14 students). About two-thirds of the students (9 out of 14) answered correctly, but some gaps in understanding were found in their explanations. Two students thought that in a closed system, the number of atoms and the number of molecules always stay the same, showing difficulties in distinguishing molecules from atoms and having difficulties in understanding that as a result of a chemical reaction molecules change while atoms do not change. One of them explained, for example, “the molecules would also stay the same because they are all being trapped inside the balloon in the closed system.” Other two students confirmed that they are not sure what the differences between atoms and molecules, and one student thought that the number of atoms remained the same, but the types of atoms changed saying that “the number of atoms doesn’t change, but there are different types of atoms and those can rearrange to make different molecules.”

Then, students were also asked what happened to the total number of atoms in the system after the balloon inflated in comparison to the number of atoms before. Almost all the students (14 out of 16) thought that the number of atoms will be the same, while two of them added that only after measuring the mass before and after to verify that the system is closed. Out of the two students who thought that the number of atoms changed, one student thought that the number increased because “it was completely inflated so there are probably more atoms”, and one student thought that the number of atoms decreased “because the atoms turned into a gas, breaking off from the liquid, and inflating the balloon.”

Additional findings re: macroscopic-microscopic relationship:

In the vinegar – baking soda balloon inflation scenario (question 17 on the post-test) described above, students were also asked what happened to the total mass of the system after the balloon inflated, and if the number of atoms in the system after the balloon inflated the same, less or more than the number of atoms before.

One-quarter of the students (4 out of 16) did not make the macroscopic-microscopic connection between the mass change and the change with the number of atoms, thinking that the mass changed (decreases or increases), but the number of atoms remained the same, or vice-versa, thinking that the mass did not change, but the number or types of atoms changed. A students, for example, explained that the mass increased because “when the chemical reaction happened there was gases but it went into the balloon, and so it added more mass to the system", but thought that the number of atoms stayed the same "because no atoms can appear or disappear."

In addition to that group of students, difficulties with the macroscopic-microscopic connection were found also among the group of students who chose that both the mass and the number of atoms did not change. As part of question 17 on the post-interviews, students were asked to choose what caused the balloon to inflate and to explain why they did not choose the other alternatives. Alternatives B ("the number of atoms increased") and D ("The mass in the system increased") referred to an open system situation where mass/atoms are added to the system. At least two students could not see that both alternatives are associated with each other, but on a different level, where alternative B refers to the macroscopic level (the mass can change) and alternative D refers to the microscopic level (the number of atoms can change). A student, for example, was explicitly asked for similarities and differences in the meanings of the two alternatives B and D and could not find any relationship between the two "because atoms and mass are different" and added that "they both ask for something that is increased, but then one is about mass, one is about atoms."

Appendix G – A sample Analysis for Open-ended Questions on the Tests

Table G.1: Pre-test analysis and a summary of students' responses to questions 16-19

Key	A	B	D	A								
Student ID	Q16	Q17	Q18	Q19	Q16 explanation	Q16 analysis comments	Q16 sub-level	pre-Q19 explanation	Q19 analysis description	Q19 sub-level	comments	Difficulties / misunderstandings
A-1	A	B	D	A	IDK (I don't know)	guess/blank/IDK	x	IDK	guess/blank/IDK	x	The only student who answered all 4 items correctly (100% in multiple choice parts) but didn't explain at all, wrote IDK. In contrast in posttest did wrong in 3 out of the 4 multiple choice Qs.	
A-2	B	B	C	B	Because they are in container	b/c in container	1---	because it burned away some of the adams (atoms)	burned away /disappear	3--	knew that mass changed but in the wrong direction + atoms do not disappear, they can enter/leave the system but do not disappear/burned	atoms burned away (disappear)
A-3	C	C	C	B	I chose C because when magnesium burned you do not know how it happens	not relevant	x	less because the 2*con2 (???) magnesium is heavier.	not relevant	x		
A-4	A	C	C	B	I say that because if it was closed, the fire couldn't get in	not covered/fire couldn't get in	1-	The atoms joined in the air	Molecules/ atoms escaped	3-	Said atoms joined in the air but were wrong with interpretation that it will cause increase in mass. He knew that # of atoms changed but in the opposite way, assumed that atoms left the system rather than enters the system.	
A-5	A	A	D	C		guess/blank/IDK	x		guess/blank/IDK	x		
A-6	B	B	D	C	JUST GUESSED	guess/blank/IDK	x	JUST GUESSDED	guess/blank/IDK	x		
A-7	B	C	A	B	LEFT BLANK	guess/blank/IDK	x	LEFT BLANK	guess/blank/IDK	x		
A-8	B	C	D	C	IDK	guess/blank/IDK	x	IDK	guess/blank/IDK	x		
A-9	B	B	C	B	I would describe it as a guess. Closed system, though I do not know why	guess/blank/IDK	x	I chose less because some molecules may escape from the top of the burning	molecules/atoms escaped	3-		do not distinguish between atoms and molecules
A-10	C	C	C	B	There is not enough info to decide	not enough info to decide	x	It is less because some of the atoms burned away.	burned away/disappear	3--		
A-11	C	C	D	B	IDK	guess/blank/IDK	x	IDK	guess/blank/IDK	x		
A-12	A	C	C	C	I guessed	guess/blank/IDK	x	because the molecules are still the same in crampyness but when the Magnesium is burned they spread apart	molecules spread apart did not leave	3--		do not distinguish between atoms and molecules

A-13	A	C	C	C	there is nothing covering the system	not covered	1-	it is impossible to create or destroy atoms	general statement on mass conservation	3--	knew that there is the mass conservation rule but didn't relate it yet to the particular system, referring to the scenario as occurring in a closed system, in which nothing can be added/removed to the system	
B-14	A	B	B	B	I guessed	guess/blank/IDK	x	b/c the burning decreased the amount	burned away/disappear	3--		burning decrease amount
B-15	C	C	C	B	Complete guess	guess/blank/IDK	x	b/c there is less to hold the atoms	?	3--		
B-16	C	B	B	A	I guessed	guess/blank/IDK	x	I guessed	guess/blank/IDK	x		
B-17	C	A	A	C	I do not know about substance B	not enough info to decide	x	b/c it only went through a phase change	phase change	3--	know that # atoms will not change in phase change but assumed wrongly that the burning is a phase change rather than a chemical reaction	do not distinguish between chemical reaction and a phase change
B-18	B	B	C	B	In a closed system, none of the magnesium molecules will escape, so you can gather them up & reweigh them. This isn't true in an open system	compare closed vs. open	1-	When something burn, the mass decrease	re-state question in a different words -mass decrease in burning reaction	3--	Although chose the wrong answer (closed rather than open), provided a relevant explanation that in closed systems the magnesium molecules can't escape. He didn't mention anything about that in closed systems nothing also can get in and that is why he get the score of 1- and not 1	
B-19	B	B	D	A	The magnesium on side A burns but the fire doesn't spread to side B, so it is closed	?	1---	Oxygen atoms were added as the magnesium burned	oxygen atoms were added to the system	3		
B-20	C	B	D	B	complete guess	guess/blank/IDK	x	complete guess	guess/blank/IDK	x		
B-21	B	C	A	B	There will be more oxygen	not relevant	x	there is more on the empty side	not relevant	x	student clearly understand that the scale tip toward the heavier side but didn't explain anything why one side is heavier than the other one	
B-22	B	B	C	B	A closed system b/c they are in container	b/c in container	1---	less b/c the atoms where (were) releases when the magnesium was burned	burned away/disappear	3--	mentioned container which is a weak reference to the system, but didn't really refer to whether or not the container is closed/covered etc.	
B-23	C	A	A	C	You need to know how hot the fire was	not enough info to decide	x	none of the particles left	no particles left	3-	student is wrong thinking that no particles left, but if that was true his conclusion that the # will stay the same was correct	
B-24	A	C	C	B	b/c a sound better	not relevant	x	b/c the molecules probably evaporated when it got put on fire	molecules evaporated and left system	3--		do not distinguish b/w burning and evaporation
B-25	C	B	C	C	there isn't	not enough info to decide	x	they simply transmitted into the air	molecules/atoms escaped	3--	Student's thought that something went to the air but at the same time circles the choice that it will stay same #, inconsistency b/w the 2. If something left it should be less # of atoms	
B-26	B	C	N/A	A	I think it is a closed system b/c c the scale is balanced	not relevant	x	More b/c c once heated the molecules will move faster	not relevant	x		"More b/c c once heated the molecules will move faster".

											Wrong connection b/w # of atoms & atoms' motion
C-27	C	C	C	B	It's because we don't know what happened to the other substances	not enough info to decide	x	The answer is because some of the atoms disappear when the substance is burned.	burned away/disappear	3--		
C-28	A	C	B	A	I have no idea	guess/blank/IDK	x	I don't know	guess/blank/IDK	x		
C-29	B	C	C	B	Because close system's smoke wouldn't mess ??	not relevant	x	Because the atoms flew up into the air and evaporated.	atoms left system & evaporated	3-		distinguishing b/w burning & evaporation
C-30	C	C	C	C	LEFT BLANK	guess/blank/IDK	x	LEFT BLANK	guess/blank/IDK	x		
C-31	C	C	B	B	no clue	guess/blank/IDK	x	no clue	guess/blank/IDK	x		
C-32	A	B	C	B	IDK it was a guess (guess)	guess/blank/IDK	x	IDK it was a guess (guess)	guess/blank/IDK	x		
C-33	C	C	D	C	There is not enough information to decide. The scenario is not specific as to if it is an open or closed system.	not enough info to decide	x	The number of atoms of the scale is less after magnesium was burned. The burnt atoms are still in existence but they have floated elsewhere. If you could catch each atom and separate it from the oxygen the magnesium in side A and B will be the same weight.	guess/blank/IDK	x		
C-34	C	B	C	B	It's in a fire, witch (which) could be open or closed	not enough info to decide	x	when burned, some atoms disappear	burned away/disappear	3--		atoms disappear
C-35	A	A	A	C	I think this because fire needs continual oxygen and a closed space cannot provide that.	not covered/oxygen can get it	1-	IDK	guess/blank/IDK	x		
C-36	C	C	B	C	all we know is the picture, we don't have enough info+totell guess	not enough info to decide	x	the same because just because it got burned doesn't necessary mean it lost a lot of atoms+total guess	guess/blank/IDK	x		
C-37	C	B	B	C	IDK anything about it	guess/blank/IDK	x	IDK	guess/blank/IDK	x		
C-38	B	B	C	B	Both substances are enclosed in containers, IDK	b/c in container	1---	Because they burned away, IDK	burned away/disappear	3--		
C-39	A	C	D	A	Because the fire does not rap [warp???] the system	not relevant	x	Because the burnt atoms weigh more	re-stating choice in the question	x		
D-40	A	A	B	B	I would describe it as an open system b/c it	not covered/oxygen	1-	I would say less atoms b/c atoms disappear	burned away/disappear	3--	Caroline & Irina have identical explanations	

					was done openly without anything over it	can get it						
D-41	C	A	B	B	No response	guess/blank/IDK	x	No response	guess/blank/IDK	x		
D-42	C	B	C	C	No response	guess/blank/IDK	x	No response	guess/blank/IDK	x		
D-43	A	A	B	B	I would describe it as an open system b/c it was done openly without anything over it	not covered	1-	I would say less atoms b/c atoms disappear	burned away/disappear	3--		
D-44	A	B	B	B	IDK	guess/blank/IDK	x	IDK	guess/blank/IDK	x		
D-45	C	C	D	B	I chose C b/c it only told you that they put two pieces of magnesium on opposite sides of a scale, and that the piece on side A set fire and burns	not enough info to decide	x	I chose less b/c once the magnesium burns, there would be less on the scale		3--		
D-46	C	C	C	C	there wasn't enough information and so I couldn't decide	not enough info to decide	x	I don't see why they would leave the magnesium	not enough info	x		
D-47	B	B	D	A	IDK	guess/blank/IDK	x	IDK	guess/blank/IDK	x		
D-48	A	B	B	B	I chose open because it happens outside it is not a box or a closed area	not covered	1-	There are less atoms because when it burns the metal it not only burned but the atoms burn too	burned away/disappear	3--		
E-49	B	B	B	B	I guessed	guess/blank/IDK	x	I guessed	guess/blank/IDK	x		
E-50	B	A	C	A	No clue	guess/blank/IDK	x	I should I know	guess/blank/IDK	x		
E-51	B	B	B	B	IDK	guess/blank/IDK	x	O am not informed on this	guess/blank/IDK	x		
E-52	A	A	C	B	ashes are not heavy like metal	not relevant	x	I have no idea	guess/blank/IDK	x		
E-53	B	B	C	C	nothing will effect it that way	not relevant	x	nothing changes	re-stating choice in the question	x		
E-54	C	C	C	B	I chose C b/c as far as the scenario states both A and B are the same. There is no way knowing whether its in an open or closed system	not enough info to decide	x	When the burned magnesium goes into flames some molecules and atoms disappear into the air	burned away/disappear	3--		
E-55	B	C	C	A	No response	guess/blank/IDK	x	No response	guess/blank/IDK	x		
E-56	A	A	B	C	B/C you can see it out in the open on like a table or something	not covered	1-	B/C it is the same amount of magnesium just one side is liquid	phase change	x		distinguish between burn/melting
E-57	C	C	C	B	I'm not completely notified on the	guess/blank/IDK	x	It's less, because the rest was burned, the	guess/blank/IDK	x		

					situation			atoms, I think all disintegrated				
E-58	C	B	C	B	I have absolutely no idea what that means, therefore not enough info	guess/blank/IDK	x	if you burn something it might be wrong	not enough info	x		
E-59	B	B	A	C	No response	guess/blank/IDK	x	No response	guess/blank/IDK	x		
E-60	B	C	A	A	No response	guess/blank/IDK	x	No response	guess/blank/IDK	x		
E-61	C	B	B	C	No response	guess/blank/IDK	x	No response	guess/blank/IDK	x		
E-62	C	C	C	B	No response	guess/blank/IDK	x	As the molecules heat up they will escape causing smoke thus there will be less molecules	molecules/atoms escaped	3-		
E-63	A	B	C	B	The test is open?	not relevant	x	less, b/c when you burn molecules they generally smoke up into a gas, and the molecules left are in a smaller amount then (than) they were before	smoke up into the gas	3-		
E-64	C	B	C	B	No response	guess/blank/IDK	x	They didn't say anything relating to that	not enough info	x		

Table G.2: Post-test analysis and a summary of students' responses to questions 16-19

Key	A	B	D	A								
Student ID	Q16	Q17	Q18	Q19	post-Q16 explanation	Q16 analysis comments	Q16 sub-level	Q19 explanation	Q19 analysis description	Q19 sub-level	comments	Difficulties / misunderstandings
A-1	A	C	C	B	I chose that the burning magnesium is an open system b/c there is nothing holding the gas that the burning magnesium creates	set-up only	1-	I chose that the amount of atoms after the magnesium had burned completely would be less. This is b/c some of the atoms would escape in gas form since this reaction is an open system	atoms escape	3-	only refers to nothing covering, didn't explicitly explained in and out or refer back to specific example	
A-2	B	A	A	C	the container makes it so nothing gets out or in	nothing get out or in but said closed and it is an open	1-	the law of conservation of mass states that matter is never created or destroyed	general statement on mass conservation	x		
A-3	N/A	N/A	N/A	N/A	No exam	no exam	no exam	No exam	no exam	N/A		
A-4	A	C	C	C	there is nothing covering the reaction and that is what an open system is	system set-up	1-	The atoms have not changed yet they rearranged to form new molecules and the gas created did not stay on the scale	wrong	x	only refers to nothing covering, didn't explicitly explained in and out ir refer back to specific example	
A-5	A	C	D	B	Its an open system b/c any gas produced could escape, there is nothing forcing the gas to stay	mentioned leave but not enter	1-	There is less atoms w/ burnt magnesium b/c c/ some molecules went to form the gas and that went away so there is less atoms	gas escaped	3-		
A-6	A	C	C	B	This is an open system b/c the container is open and molecules can come in or escape while the magnesium burns	set-up + enter + leave	1+	Some atoms escaped when the magnesium was burnt, so it lighter	gas escaped	3-		
A-7	A	C	C	B	They didn't keep the gas that escaped	mentioned leave but not enter	1-	Some gas could have escaped	gas escaped	3-		
A-8	B	N/A	N/A	N/A	No response	guess/blank/IDK	x	No response	guess/blank/IDK	x		
A-9	A	B	D	B	this would be an open	set-up + leave	1-	Less b/c when the	gas escaped	3-		

					system b/c any of the gas produced could easily escape b/c there is no cap or anything to close it off	but didn't mention enter		magnesium was burned and it was an open system part of the gasses escaped into the air which made it weigh less				
A-10	A	C	C	C	It is an open system b/c gases can escape	mentioned leave but not enter	1-	It still has the same number and type of atoms, just fewer sets		x		
A-11	A	C	D	B	b/c the left over atoms can turn into a gas and float into the air	mentioned leave but not enter	1-	When it burns some atoms go into the air. This will tip the scale	gas escaped	3-		
A-12	A	C	C	C	I chose open system b/c the question says it is ON not IN a fireproof container so the magnesium is reacting with the air so some of the gas formed by the magnesium is gone	set-up +leave but didn't mention enter	1-	b/c the magnesium is still there just it rearranges itself. And some of the burned magnesium was in the air	wrong	x		
A-13	A	C	C	B	open system b/c it is not enclosed	set-up only	1--	less b/c some of the magnesium escaped into the air	gas escaped	3-		
B-14	A	C	C	B	open system b/c the gas escaped, which changed the mass of the gas	mentioned leave but not enter	1-	less b/c some of the atoms turned into gas and escaped through open system	gas escaped	3-		
B-15	A	C	C	C	B/C it tells you that they are placed on not in fire proof container	set-up only	1--	I choose same b/c of the mass conversation law were no matter (atoms) can be lost, created or destroyed	general statement on mass conservation	x		
B-16	C	C	C	B	open system b/c the gas escaped, which changed the mass of the gas	mentioned leave but not enter	1-	less b/c some of the atoms turned into gas and escaped through open system	gas escaped	3-		
B-17	A	B	A	C	An open system b/c the smoke escaped and is supposed if the system was closed, which is not	leave	1-	Same, b/c of the law of conservation of mass, no atom can be created or destroyed	general statement on mass conservation	x		
B-18	A	C	D	B	It's an open system. The magnesium is burning on an open, fireproof container, where the magnesium atoms can escape	set-up+leave but didn't mention enter	1-	the burned magnesium has less atoms than the unburned magnesium b/c some of the magnesium escaped to combine with the oxygen to	atoms escaped	3-		

								form oxygen magnesium				
B-19	A	C	C	C	The magnesium is simply placed on fireproof containers and allowed to burn. There is nothing to indicate that the balance is enclosed in any way. Because of this, some matter might escape the system in the form of gas (smoke).	set-up+leave but didn't mention enter	1-	The burned magnesium has as many magnesium atoms as the unburned magnesium. This is b/c according to the law of conservation of mass, no matter can be created or destroyed during a chemical reaction.	general statement on mass conservation	x		
B-20	A	C	C	C	This is an open system because it said the magnesium was ON a container	set-up only	1--	because of the law of conservation of mass	general statement on mass conservation	x		
B-21	A	B	B	A	It is open. You can tell b/c the gas escaped from the beaker	leave	1-	More, because the burned magnesium lost atoms.	inconsistency	x		More, because the burned magnesium lost atoms.
B-22	A	C	C	B	I know this is an open system b/c it says that the magnesium is ON not IN the fire proof container, so a top can't be put on it	set-up only	1--	I think the atoms will be less. I think this b/c if it is an open system the gas will escape and if it is a closed system, the gas will be in the container floating around but not on the scale	gas escaped	3-		
B-23	A	C	C	C	There is no top on the containers so smoke and other gases can escape so it is an open system	set-up+leave but didn't mention enter	1-	You cannot destroy matter so the number of atoms are the same. It may weigh less because the atoms are escaping, but they are still there.	general statement on mass conservation	x	do not connect b/w # of atoms & mass	You cannot destroy matter so the numbers of atoms are the same. It may weigh less because the atoms are escaping, but they are still there.
B-24	A	C	D	C	In an open system b/c that way gasses can escape	leave	1--	the same b/c of law conservation of mass	general statement on mass conservation	x		
B-25	C	A	D	C	There is not enough information to tell. It doesn't say if the box is closed or not.	not enough info	x	The law of conservation of mass states the mass cannot be lost or created. So nothing was lost.	general statement on mass conservation	x		
B-26	A	C	D	C	This is an open system b/c the magnesium is placed on the fire proof	set-up+leave but didn't mention enter	1-	The number of atoms are the same b/c c the burned magnesium	general statement on mass	x		

					containers not inside a fire proof container. This is also an open system b/c from the descriptions of the experiment gasses can escape showing it is an open system			and the unburned magnesium. Atoms rearranged to form new molecules. This was b/c of the chemical reaction. No new atoms were formed they just rearranging to make new molecules	conservation			
C-27	A	C	C	C	This is an open system because the magnesium was exposed to the air and not contained on anything	set-up only	1--	The molecules will stay the same b/c during a chemical reaction the number and type of molecules stays the same. However, since burning magnesium created a gas, and the experiment was done in an open system, some molecules escaped, causing the weight change.	general statement on mass conservation	x	do not distinguish between atoms & molecules and do not connect b/w # of atoms & mass	The molecules will stay the same b/c during a chemical reaction the number and type of molecules stays the same. However, since burning magnesium created a gas, and the experiment was done in an open system, some molecules escaped, causing the weight change.
C-28	C	C	C	B	I think it is an open system because the scale is not covered	set-up only	1--	when they burned it, some of the atoms went into the air	atoms escape	3-		
C-29	A	A	A	C	open system b/c there is nothing stopping things from exiting and entering	set-up+enter+leave	1+	it's the same b/c of the law of conservation of mass	general statement on mass conservation	x		
C-30	A	C	C	B	When the magnesium was burned, it was not covered or anything allowing gases to escape	set-up+leave but didn't mention enter	1-	Some of the atoms evaporated into the air of the burned one	atoms evaporated into the air	3--		distinguish b/w chemical reaction & phase change (e.g., evaporation/melting)
C-31	A	C	C	C	I would say it is an open system b/c the gas can escape (exit) or enter	enter/leave but not set-up	1	There are the same number of atoms b/c atoms do not just disappear	general statement on mass conservation	x		
C-32	B	B	C	B	it’s a closed system b/c it burnt up completely and also set on fire	not relevant+wrong conclusion	x	less b/c atoms are going away and disappearing	atoms disappear	x		
C-33	A	C	C	C	This scenario is open system b/c c nothing is covering the sides of	set-up	1-	the # of burned magnesium atoms are the same b/c of the	general statement on mass	x		

					the scales to keep all the atoms in			law of conservation of mass. If the experiment were in a closed system, the weights would be the same	conservation			
C-34	A	C	D	C	It burns on a container, but not in a container. It therefore is burning in air. If it is burning in air, with nothing keeping it closed, it is an open system.	set-up	1-	No molecules just disappear. They may have combined with the oxygen, but they are still there. There are therefore the same number of atoms.	general statement on mass conservation	x		
C-35	B	A	A	C	I chose this b/c the weight is the same before and after even though it would smoke	?	x	I chose this b/c in a chemical reaction there are the same type and number of atoms before and after.	general statement on mass conservation	x		
C-36	A	C	D	B	I chose C, b/c we don't know what happened all they tell us is that it burned. No signs of smoke, etc.	not enough info	x	I chose B b/c when the magnesium burns it gets lighter b/c it changes form	change form & get lighter	x		
C-37	A	C	D	B	I think that this occurring on open system because there is nothing covering the chemical reaction going on, this happens in open air	set-up only	1--	I think that there are less atoms in the burned magnesium than before, because in open system, some atoms can be lost in the air	atoms escaped	3-		
C-38	A	C	D	B	It is an open system b/c the substances aren't contained in a sealed containers. As "A" burns, the scale should tilt toward "B" b/c the atoms are escaping from "A", causing a weight difference.	set-up+leave but didn't mention enter	1-	There are less "burned magnesium" atoms in the end b/c as it burned, some of the atoms escaped into the air b/c it is an open system.	atoms escaped	3-		
C-39	A	B	B	A	It is an open system b/c the container with the magnesium doesn't have something to prevent a gas from leaving the container	set-up only	1--	The number of atoms is bigger because the burned magnesium was a chemical reaction. The burned magnesium created a new substance out of the magnesium and fire.	not relevant	3-		The burned magnesium created a new substance out of the magnesium and fire.

D-40	A	B	C	A	I chose A b/c I think this scenario is an open system b/c it doesn't change when it burns	not relevant	x	I picked A b/c when you burn stuff a black substance forms adding more atoms		3-	new substance with more atoms form but didn't specify where the additional atoms comes from	
D-41	A	B	C	C	This happen in an open system, we know this b/c c it says they burned it ON a fireproof container, this means it is set open something but left in the open	set-up only	1--	The weight of the burned magnesium is stayed the same from the magnesium. We know this b/c they were both magnesium to start with but when ones molecules rearranged but still stayed the same in burning the weight of the atoms wouldn't last. The law of conservation of mass says no matter what atoms have been rearranged, the mass will stay the same. None will disappear or reappear.	general statement on mass conservation	x		
D-42	C	B	D	C	It never tells if there is a lid on the fireproof container or if B burned completely or at all.	no enough info	x	During a chemical reaction (such as burning) no atoms are made or lost, and all atoms are used in the new substance.	general statement on mass conservation	x		
D-43	A	C	C	C	I would describe this as an open system b/c a gas is escaping	leave	1-	The number of atoms will be the same. Burning is a chemical reaction, and since the law of mass conservation of mass applies to this then no molecules are gained or lost, which means no atoms are gained or lost	general statement on mass conservation	x		
D-44	N/A	N/A	N/A	N/A	No test	no exam	no exam	No test	no exam	N/A		
D-45	C	C	C	C	I chose this b/c there isn't enough information. All it told you was that side A set on fire and burns	no enough info	x	They stay the same b/c when a chemical reaction happens, the number of atoms stay the same	general statement on mass conservation	x		

					completely							
D-46	A	C	D	B	I think open system, there is no item to contain the substance first off. Second when you heard burning it means the chemical reaction oxygen plus magnesium has taken place and notice OXYGEN	set-up only	1--	During the chemical reaction a gas occurred. In the end it was basically ash. It released atoms in the gas state and you know it didn't have as much in the end by just seeing fall apart	atoms escaped	3-		
D-47	N/A	N/A	N/A	N/A	No Response	guess/blank/IDK	x	No Response	guess/blank/IDK	x		
D-48	A	C	C	C	I chose an open system b/c the magnesium is outside in the open. There is no closed atmosphere around it.	set-up only	1--	Less b/c the atoms have evaporated and left b/c it's an open system	wrong	x	chose same but explained why less + in explanation was confused b/w chemical reaction & evaporation	distinguish b/w chemical reaction & phase change (e.g., evaporation/melting)
E-49	C	C	C	B	b/c it stays the same if it is the same weight	?	x	b/c if the molecule get faster	not relevant	x		less b/c molecules get faster
E-50	A	A	C	B	Open circuit nothing was beeping all of the gases from escaping the experiment	set-up+leave but didn't mention enter	1-	Some of the atoms "left" the experiment so there aren't as many atoms left	atoms escape	3-		
E-51	N/A	N/A	N/A	N/A	No response	guess/blank/IDK	x	No response	guess/blank/IDK	x		
E-52	A	C	C	C	This is an open system b/c the scale wasn't placed in a bag or box or other thing that could close off the system. There is just a scale in space, the molecules can escape	set-up+leave but didn't mention enter	1-	b/c the law of conversation of mass no molecules can be created or destroyed the number of molecules is the same, whether these molecules are still in the solid or are in the gas form is another story	general statement on mass conservation	x		
E-53	A	C	C	B	The magnesium could not burn in a closed system b/c there wouldn't be enough oxygen	can enter system (need oxygen from environment to burn) but didn't mention can leave	1-	There are less atoms b/c some escaped into the atmosphere	atoms escape	3-	nice reference to specific example	
E-54	A	C	C	B	you can tell it is an open system b/c you need oxygen to have	can enter system (need oxygen from	1-	the number of burned magnesium atoms are less b/c in an open	atoms escape	3-	nice reference to specific example	

					fire. If it were closed the fire would not start b/c the lack of oxygen would surricate the fire	environment to burn) but didn't mention can leave		system some atoms can escape into gas form				
E-55	N/A	N/A	D	N/A	No response	guess/blank/IDK	x	No response	guess/blank/IDK	x		
E-56	A	B	C	C	This is b/c there is nothing enclosing the magnesium so that gas or any molecules can't get away	set-up+leave but didn't mention enter	1-	There are less molecules now because some of the molecules escaped because the experiment was an open system	molecules escaped	3--		do not distinguish b/w atoms & molecules
E-57	C	C	C	B	The information was not a given choice and number. You need to know specifically the melting points of said substance (magnesium) to come to direct conclusion	not relevant	x	The burned atoms have evaporated because of the burning involved. So therefore it's technically less	burned atoms evaporated	3--		distinguish b/w chemical reaction & phase change (e.g., evaporation/melting)
E-58	A	B	C	B	b/c it is in the open air, it is not covered	set-up only	1--	Some atoms escaped b/c it is an open system	atoms escape	3-		
E-59	A	C	D	C	This was an open system b/c the magnesium was not covered and surrounding substances could have interfered	set-up +enter but not leave	1-	Atoms can't change in quantity in a chemical reaction	general statement on mass conservation	x		
E-60	C	C	D	A	Just guess	guess/blank/IDK	x	Just guess	guess/blank/IDK	x		
E-61	N/A	N/A	N/A	N/A	No response	guess/blank/IDK	x	No response	guess/blank/IDK	x		
E-62	C	B	D	A	There isn't enough information b/c it doesn't state if there is any form of cover	not enough info	x	The oxygen atoms combined with the magnesium to create a new substance with more atoms		3+		
E-63	A	C	C	C	There isn't anything around the piece of magnesium to contain the product of the burning. The gas that the burning produced can escape. Therefore it's an open system	set-up+leave but didn't mention enter	1-	the number of atoms stays the same in the burned magnesium. Because of the law of mass, no matter can be created or destroyed. There are the same number of atoms, but some of	general statement on mass conservation	x		

								them phase changed into a gas, so it wouldn't be there to see and weigh on the balance				
E-64	C	C	C	B	They do not say whether the mass was reduced, increased or stayed the same so you can't tell	not enough info	x	b/c some of the atoms would have flown away	atoms escape	3-		

Appendix H – 7th Grade Chemistry IQWST Unit Learning Goals

(Source: Stuff unit Teacher Guide)

Learning Set 1: How is stuff the same and different?

Lesson 1: How is stuff the same and different?
Students observe and describe substances qualitatively (including both properties and non-properties of the substances) in order to sharpen their observational and descriptive skills.
Students distinguish substances and mixtures by identifying chalk as a substance because it is made of the same type of material throughout.
Students construct a definition of property as a unique characteristic that helps identify a substance and distinguish one substance from another macroscopically.
Students explain how they know that two unknowns are different substances by constructing a scientific explanation that includes a claim, evidence, and scientific reasoning.

Lesson 2: Do fat and soap dissolve in the same liquid?
Students investigate solubility in order to expand their conception of substances and their properties.
Students identify, analyze, and interpret data about properties of substances to identify how the substances are the same or different.
Students' develop procedures for examining the solubility of substances.
Students construct a definition for solubility as the capacity of one substance to dissolve in another substance.

Lesson 3: Do fat and soap melt at different temperatures?
Students collect melting point and hardness data, and use it as evidence that substances are different from one another.
Students analyze and interpret data to construct an explanation of why two substances are different.
Using different amounts of substances, students determine that a property does not depend on the amount of the substance.
Students construct scientific explanations about heating and melting of a substance using reasoning about how energy is used in the heating and melting process.

Lesson 4: What other properties can distinguish soap from fat?
Students use evidence to explain that density is a property because it does not change based on the amount of a substance, so it can help identify a substance and distinguish one substance from another.
Students use evidence to explain that mass and volume are non-properties because they change based on the amount of a substance.
Students collect, analyze and interpret data about the density of substances. The differing densities of substances are evidence that they are different substances.

Lesson 5: How are fat and soap different?
Learning Performances
Students construct an evidence-based scientific explanation.

Learning Set 2: How can I make new substances?

Lesson 6: What happens to properties when I combine substances?

Learning Performances

Students construct the meaning of "chemical reaction" as a process in which two or more substances combine to form new substances with new properties.
Students analyze data about what happen to observable properties when they mix substances together.
Students use data to construct an evidence-based scientific explanation of what happens to particular substances when they are mixed together.

Lesson 7: Is burning a chemical reaction?

Learning Performances

Students identify burning magnesium as a chemical reaction.
Students gather data about the properties of magnesium before reacting and the solid substance after reacting.
Students use evidence to support the construction of a scientific explanation for whether a chemical reaction occurred.
Students construct different representations of chemical reactions: word equations, chemical formulas and molecular models.

Lesson 8: Does acid rain make new substances?

Learning Performances

Students identify combining copper and acetic acid (vinegar) as a chemical reaction.
Students gather data about the properties of a copper penny before reacting and copper acetate after reacting.
Students construct a scientific explanation for combining copper and acetic acid (vinegar) that include resulting in a chemical reaction.
Students construct different representations of chemical reactions: word equations, chemical formulas and molecular representations.
Students construct molecular models to represent the arrangements of atoms and molecules composing the reactants and products of a chemical reaction.

Lesson 9: Is this a new substance?

Learning Goals

Students gather data to determine if one substance can break down into two substances through a chemical reaction and use this data to construct a scientific explanation stating whether a chemical reaction occurred during electrolysis.
Students construct meaning that a chemical reaction also occurs when one reactant's atoms rearrange into two products.
Students compare the behavior of molecules during phase changes with the behavior of molecules during chemical reactions.
Students identify boiling water as a phase change.
Students identify electrolysis as a chemical reaction.
Students revise their current definition of chemical reaction to include one or more reactants going to form new products.

Lesson 10: How is a mixture different from a chemical reaction?

Learning Goals

Students distinguish between chemical reactions and mixtures.
Students construct a scientific explanation of whether dissolving is a chemical reaction.

Learning Set 3: Do new substances always come from old substances?

Lesson 11: How can I make soap from fat?

Learning Goal

Students conduct a scientific investigation of soap making in order to gather data about properties of the substances before and after a chemical reaction.

Lesson 12: Does mass change in a chemical reaction?

Learning Goals

Students construct a meaning for the principle of "conservation of matter" at both the macro and molecular levels.
Students design an investigation to determine whether total mass remains the same before compared to after a process.
Students construct a scientific explanations about the mass before and after a chemical reaction.

Lesson 13: Is my soap a new substance?

Learning Goals

Students conduct a scientific investigation to gather data about properties of the newly formed soap.
Students construct a scientific explanation about new substances forming from old substances in a chemical reaction.

Lesson 14: How does my soap compare? Or How can I improve my soap?

Learning Goal

Students design and conduct an investigation to gather data about whether their soap performs better than another soap on comparison tests (Activity 14.1)
OR
Students design and conduct an investigation for making an improving soap (Activity 14.2).

Appendix I – A Summary of the Development of the Construct Maps and the Related Key Content Standards

<table>
<tr><th></th><th>Sub-levels</th><th>Related standards</th><th>Comments</th></tr>
<tr><td rowspan="3">Mass conservation</td><td>Level 3: In a chemical reaction molecules change, but the number and types of atoms depends on the type of the system (open or closed)</td><td rowspan="2">Benchmarks, 4D6-8#7: No matter how substances within a closed system interact with one another, or how they combine or break apart, the total weight of the system remains the same. The idea of atoms explains the conservation of matter: If the number of atoms stays the same no matter how they are rearranged, then their total mass stays the same.</td><td rowspan="2">Key content standards - breaking the content into two levels of understanding, the macroscopic and the microscopic</td></tr>
<tr><td>Level 2: The total mass before and after a chemical reaction depends on the type of system (open or closed)</td></tr>
<tr><td>Level 1: A closed system and an open system are different</td><td></td><td>Necessary prior understanding</td></tr>
<tr><td rowspan="4">Rearrangement of atoms</td><td>Level 4: A chemical reaction can be distinguished from phase changes and/or mixtures (at the microscopic level)</td><td></td><td>A continuous understanding, difficulties that were reported in the literature</td></tr>
<tr><td>Level 3: A chemical reaction results in new substances with a new arrangement of atoms</td><td>Benchmark, 4D/M13: The idea of atoms and molecules explains chemical reactions: when substances interact to form new substances, the atoms that make up the molecules of the original substances combine in new ways to form the molecules of the new substances. (New AAAS Learning Goal)</td><td>Key content standards</td></tr>
<tr><td>Level 2: Differentiating between different types of particles</td><td rowspan="2">Benchmarks, 4D6-8#1: All matter is made up of atoms, which are far too small to see directly through a microscope. The atoms of any element are alike but are different from atoms of other elements. Atoms may stick together in well-defined molecules or may be packed together in large arrays. Different arrangements of atoms into groups compose all substances.</td><td rowspan="2">Necessary prior understanding- breaking the content into two sub-levels</td></tr>
<tr><td>Level 1: Basis of particulate nature of the matter</td></tr>
<tr><td rowspan="4">Change of properties</td><td>Level 4: A chemical reaction can be distinguished from phase changes and/or mixtures (at the macroscopic level)</td><td></td><td>A continuous understanding, difficulties that were reported in the literature</td></tr>
<tr><td>Level 3: A chemical reaction results in new substances with a new set of properties</td><td rowspan="2">NSES, 5-8 p.154: A substance has characteristic properties, such as density, a boiling point, and solubility, all of which are independent of the amount of the sample. A mixture of substances often can be separated into the original substances using one or more of the characteristic properties.
NSES, 5-8 p.154: Substances react chemically in characteristic ways with other substances to form new substances (compounds) with different characteristic properties.</td><td rowspan="2">Key content standards</td></tr>
<tr><td>Level 2: Different substances have different set of properties</td></tr>
<tr><td>Level 1: A property is a characteristic of a substance</td><td></td><td>Necessary prior understanding</td></tr>
</table>

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