Atomic-Molecular Theory:
A Key to Understanding Chemistry Concepts

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Plan B Project

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Abstract

The purpose of this project was to review Atomic-Molecular Theory (AMT), critique teaching methods associated with AMT, develop a National Board Certification entry, and reach conclusions about appropriate methods for teaching this topic in introductory high-school chemistry. In order to accomplish this, pertinent literature was reviewed. This included National Research Council publications and peer-reviewed journal articles, along with appropriate books and texts. Additionally, the National Board Certification process required unit development, classroom activities, and a written reflection. Conclusions and recommendations for effectively teaching AMT at the high-school level are offered.

Dedicated to my husband, Philip; my children, Sarah and Jeremiah;
and all of my students—past, present, and future

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Chapter 1

Introduction

Statement of the Problem

Characteristics of atoms and molecules, their movement, and interactions are described as the Atomic-Molecular Theory (AMT); one of the core ideas in science. To comprehend the concepts of chemistry, it is essential to understand the behavior and interactions of atoms and molecules. AMT is "well-tested, validated, and absolutely central" to chemistry (NRC, 2007, p. 223). An understanding of AMT clarifies concepts in physics, geology, and biology as well as chemistry. It guides research and can be understood in increasingly complex ways (NRC, 2007). However, what occurs at the particulate level (atomic or molecular) in chemical reactions and state changes is difficult to discern on a macroscopic level and is not necessarily intuitive. In fact, even with personal experience and exploration, a child will not arrive at the conclusion that matter is made of atoms and molecules without explicit instruction (Michaels, Shouse, & Schweingruber, 2008). Many chemistry students do not understand the nature and characteristics of atoms, molecules, and matter upon entry to and even after an introductory chemistry courses at the high-school and college levels (Ben-Zvi, Eylon, & Silberstein, 1986; Gabel & Samuel, 1987). A research-based approach to teaching AMT by educators may help increase student learning and comprehension at this level.

Purpose

The purpose of this study is to research and report findings pertaining to AMT in the form of a literature review. This paper will address the historical development and definition of AMT, determine how and why AMT is important, and identify methods and challenges for teaching AMT. Also, this research was a precursor to developing a unit submitted for Entry 1 for National Board Certification (NBC).

NBC is a one to three year professional development opportunity meant to promote and reward excellence in teaching. Candidates are required to write and submit four entries. Entry 1 is an analysis of a unit plan which the candidate developed and used for teaching a *big idea* in science with reflection about the unit and analysis of the work of two students in the class. Entry 2 requires video-recording and analyzing an inquiry investigation which includes small group interactions. Entry 3 is analysis of a different video-recorded class discussion. Finally, Entry 4 is a compilation and reflection of the candidate's role as a partner with families and the community, as a learner, and as a leader.

In addition to the four entries, NBC candidates in science education for adolescents and young adults take a rigorous content exam (completed June, 2012) which tests knowledge of four core areas of science: chemistry, physics, geology, and biology. The NBC process complemented the masters in middle-level science coursework through the College of Education at the University of Wyoming, the literature research of AMT, and writing this literature review. The Entry 1 submission for NBC addressed an AMT unit that was developed for and taught in an introductory high-school chemistry course this past school-year.

In reviewing the literature on teaching AMT, misconceptions emerged as an impediment to understanding AMT. Student misconceptions, pre-conceptions, or alternative conceptions—referred to as misconceptions in this literature review—concerning AMT are prevalent (Novick & Nussbaum, 1981). Language alone provides some clues about AMT misconceptions. For example, often used phrases mistakenly suggest that gases have no mass. Describing a container filled with air as "empty" is common and incorrect. Even the adage "Do you see the glass half empty or half full?" perpetuates the misconception that the air filling the top half is inconsequential. The American Association for the Advancement of Science's (AAAS) Project 2061 publication *Benchmarks for Science Literacy* (AAAS, 1993) contained misleading language in the kindergarten through 2nd-grade standards such as "Water left in an open container disappears, but water in a closed container does not disappear" (4B/P3). This language persisted in a later revision of the standards even though elsewhere in the publication the importance of student familiarity with the particulate nature of matter (AMT) was stressed. These examples highlight language that is confusing and reinforces student misconceptions about AMT.

Another source of linguistic confusion stems from the name of the scientific theory. The term Atomic-Molecular Theory essentially can be interchanged with the Particulate Theory of Matter, Particulate Theory, Particle Theory, the Particulate Nature of Matter, Atomic Theory, Kinetic-Molecular Theory, the Atomic Hypothesis, and the Atomic Model. Each of these terms was found in the literature and the potential for confusion is understandable. For the purpose of this literature review, Atomic-Molecular Theory or AMT will refer to the scientific theory that describes the characteristics of atoms and molecules.

Research Questions

The research topic explores AMT as applied to the high-school chemistry curriculum and the learning that occurs in an introductory high-school chemistry class. Four questions associated with this topic will be addressed and these questions will guide the literature review, development, and completion of the NBC entry:

1. How was AMT developed and what is the definition of AMT?
2. How and why is AMT a *big idea* in science?

3. What are the challenges to students and educators in bringing about understanding of AMT?
4. What are instructional methods for teaching AMT?

The literature that follows provides some insight into the topic and suggests answers to the four questions above.

Chapter 2

Literature Review

This section of the paper provides research-based information about teaching and learning of AMT within a chemistry curriculum. Research findings from the literature will also provide some insight into the historical development of AMT, how AMT is defined, how and why AMT is a *big idea* in science, challenges in bringing about understanding of AMT, and instructional methods of teaching AMT. This literature review also explores the concepts of AMT required for conceptual understanding for high-school chemistry students.

Historical development

Understanding the historical development of AMT and defining AMT were important first steps to constructing a unit and writing the NBC entry. A typical introductory chemistry text outlines the development of AMT through history to some extent. The chemistry text used in my introductory chemistry class introduces AMT by describing the Greek philosopher, Democritus, as the first person to postulate that atoms exist as tiny particles which are indivisible and indestructible (Wilbraham, Staley, Matta, & Waterman, 2012). Democritus proposed this idea around 400 B.C.E., but it was more than 2000 years later, in 1803, that John Dalton presented his scientifically-based atomic theory. His ideas stemmed from the results of his and other chemists' experiments. Dalton's atomic theory is summarized below.

a) All elements are composed of tiny indivisible particles called atoms.
b) Atoms of the same element are identical. The atoms of any one element are different from those of any other element.
c) Atoms of different elements can physically mix together or can chemically combine in simple whole-number ratios to form compounds.

d) Chemical reactions occur when atoms are separated from each other, joined, or rearranged in a different combination. Atoms of one element, however, are never changed into atoms of another element as a result of a chemical change (p. 103).

A summary of Dalton's atomic theory, such as the statements above, is typically found in introductory high-school chemistry texts. However, Dalton's framework tends to be a stopping point and the century-long controversy after Dalton's breakthrough is not fully addressed.

Other sources contribute historical perspective. To illustrate, Oliver Sacks in *Uncle Tungsten: Memories of a Chemical Boyhood* (2001) describes Dalton's atomic theory as embraced by some and rejected by others. According to Sacks, Dalton's ideas made sense to some chemists, such as Thomas Thomson. Thomson's life was "altered" after a conversation with Dalton about his atomic theory. He later wrote "I was enchanted with the new light which immediately burst upon my mind, and I saw at a glance the immense importance of such a theory" (p. 152).

Other chemists, such as H. E. Roscoe, were less enchanted. "Atoms," Roscoe wrote, "are round bits of wood invented by Mr. Dalton" (Sacks, 2001, p. 151). He was referring to Dalton's wooden models of atoms. As late as the early 1900's, many scientists considered atoms little more than a theoretical possibility or an "aid to representation" (p. 151). Understanding this historical perspective may help students grasp the importance of AMT as well as the inherent conceptual challenges to accepting AMT. With subsequent discovery of subatomic particles, radioactive decay, and isotopes, parts of Dalton's theory were demonstrated incomplete or incorrect. Specifically, the discovery of the phenomenon of radioactive decay showed that atoms are not indivisible and the existence of isotopes (atoms of a specific element which vary in number of neutrons) negates the idea that all atoms of a particular element are identical. Dalton's theory served as a starting point for AMT and the theory was revised as new evidence about atoms and atomic structure emerged. Further evidence of the existence of atoms was required before the scientific community as a whole would accept an atomic explanation of matter and embrace AMT.

That evidence was finally provided in 1905 by Albert Einstein in his publication of the prediction that Brownian motion of microscopic substances suspended in a fluid was caused by the motion of atoms and molecules in the fluid (Brush, 1983). Shortly after Einstein's paper was published, French physicist Jean Perrin quantitatively verified Einstein's predictions. The scientific community had a "dramatic new proof of the existence of the atom" (p. 97). Confirmation of the existence of atoms was a turning point in the history of science, which led to exploration of the structure of atoms, identification of numerous elements, explanation of the varied properties of matter, and a refinement of the early Atomic Theory to a more current definition of AMT. For the purpose of this study and for the NBC entry, this paper does not delve into educational research regarding quantum-mechanics or quantum theory characteristics of AMT. Many aspects of quantum-mechanics are not within the scope of the AMT definition used for this literature review and will therefore not be addressed. Although these concepts are left out, there is still the need for an accepted definition of AMT.

Defining AMT

Smith, Wiser, Anderson, and Krajcik (2006) provided a partial definition of AMT in their article describing a proposed AMT learning progression. The authors defined a learning progression as "a sequence of successively more complex ways of thinking about an idea that might reasonably follow one another in a student's learning" (p. 5). The learning progression from the article suggested assessment for conceptual knowledge of AMT, which would be appropriate for instruction for kindergarten through eighth-grade students. They asserted that comprehension of AMT at all grade-levels requires conceptual understanding of three important ideas: (a) atomic-molecular explanations of matter and material kinds, (b) atomic-molecular explanation of conservation and transformation of matter, and (c) epistemology of the atomic-molecular theory. The suggested learning progression culminates with grade eight—with no AMT learning progression for ninth through twelfth grades. This literature review explores learning progressions more in-depth when addressing research question 4, but the three important ideas from this study provided some insight into the definition of AMT.

In the 2007 National Research Council (NRC) publication, *Taking Science to School* (*TSTS*), the authors compiled a list of core tenets of AMT, which describe concepts that should be introduced in the learning progression for middle-school students. The tenets are:

a) Existence of discretely spaced particles (atoms).
b) There are empty spaces between atoms (idea of vacuum).
c) Each atom takes up space, has mass, and is in constant motion.
d) The existence of over 100 different kinds of atoms; each kind has distinctive properties including its mass and the way it combines with other atoms or molecules.
e) Atoms can be joined (in different proportions) to form molecules or networks—a process that involves forming chemical bonds between atoms.
f) Molecules have different characteristic properties from the atoms of which they are composed. (p. 243)

These tenets describe a scope of basic understanding of the concepts of AMT for middle-level students and include the concepts outlined in the Smith et al. (2006) study. The *TSTS* tenets will serve as the definition for AMT for the purpose of this literature review. This definition was helpful in developing the unit for NBC Entry 1 and for looking into the AMT literature to answer the other research questions.

AMT as a *big idea* in science

Having defined AMT, this section addresses the next research question: How and why is AMT a *big idea* in science? The NBC-unit entry required choosing a *big idea* in science and developing, teaching, and analyzing a unit based on that idea. AMT was a logical choice based on the research background and its status as a conceptual key to student comprehension of chemistry.

Fundamental concept

The literature suggests AMT is “fundamental to the learning of chemistry” (Griffiths & Preston, 1992, p. 611) and that AMT is a “source of coherence for many key concepts, principles, and even other theories within the discipline” (NRC, 2007, p. 223). Student lack of understanding of AMT indicates shortfalls in student comprehension of the “fundamental ideas that form the basis of the discipline” (Gabel & Samuel, 1987). In short, the atomic model (AMT) is central and vital to the study of chemistry (e.g. Ben-Zvi, Eylon, and Silberstein, 1986).

The late physicist Richard Feynman agreed that knowledge of AMT is essential to understanding science. He believed so strongly that AMT is a basis of modern scientific knowledge that he stated “if, in some cataclysm, all of scientific knowledge were to be destroyed, and only one sentence passed on to the next generation (that sentence should be)…The atomic hypothesis (AMT) that all things are made of atoms—little particles that move around in perpetual motion, attracting each other when they are a little distance apart, but repelling upon being squeezed into one another” (Feynman, Leighton, & Sands, 1989, p. 1-2).

Science education

Project 2061 was founded by AAAS in 1985 with a goal of helping all Americans become literate in science, mathematics, and technology by the year 2061. The Project 2061 group felt that such a lofty goal would take a lot time to accomplish. They chose the year 2061 because it marked the return of Halley's Comet to viewing distance from Earth—76 years from the 1985 sighting and potentially enough time to enact the proposed changes. With the ensuing publications of *Science for All Americans* (Rutherford & Ahlgren, 1991) and *Benchmarks for Science Literacy* (AAAS, 1993), Project 2061 coordinated a shift in focus for the science education community. In an effort to address the shortfalls of science education, Project 2061 worked to raise science education expectations by setting standards of what all students should know and be able to do in science, mathematics, and technology by completion of high school. As the result of the Project 2061 movement, numerous recommendations were made, including the publication of the *National Science Education Standards* (*NSES*) by the NRC in 1996. The *NSES* recommended revisions to schools' science programs and the implementation of voluntary science standards, teaching standards, and professional development standards.

The new recommendations included the concepts associated with AMT. In the segments of the *Benchmarks for Science Literacy* (AAAS, 1993) entitled "The Physical Setting" and "Historical Perspectives", the structure of matter and the development of AMT were addressed. The *NSES* also included aspects of AMT—the "structure of atoms" and "structure and properties of matter"—as content standards for grades 9-12 physical sciences. The recommendations espoused in these publications shaped science education through the 1990's and early 2000's.

Further advances in science education continued with the NRC publication of *How People Learn: Brain, Mind, Experience, and School* (Bransford, Brown, & Cocking, 1999). This book offered research-based recommendations for effective teaching and learning and proposals for schools to revise what is taught, how it is taught, and how knowledge is assessed. The suggestions for the revision of science education were grounded in brain and cognitive research efforts. The major science education publications based on this research include *TSTS* and *The Framework for K-12 Science Education,* published by the NRC in 2007 and 2012, respectively. *The Next Generation Science Standards* (*NGSS*), released in draft form in May, 2012, are a compilation of science standards recommended as a result of the recent focus on how children learn and the research base supporting science education. *TSTS*, *The Framework for K-12 Science Education*, and the *NGSS* all include recommendations for teaching AMT as part of a science curriculum.

TSTS (NRC, 2007) describes knowledge of AMT as essential to understanding the natural world and contains a detailed description of a learning progression for AMT. Like the assessment-focused learning progression outlined by Smith et al. (2006), the *TSTS* learning progression details increasingly sophisticated ways that students may think about AMT as they progress from kindergarten through eighth grade. *The Framework for K-12 Science Education* (NRC, 2012), stresses the importance of cross-cutting concepts which “help provide students with an organizational framework for connecting knowledge from the various disciplines into a coherent and scientifically based view of the world” (p. 83). The identified cross-cutting concepts include “energy and matter” and “scale, proportion, and quantity” which contain concepts crucial to understanding AMT such as conservation of matter and the unimaginably small size of atoms.

The Framework for K-12 Science Education includes AMT in the physical science categories of “matter and its interactions” and “the structure and properties of matter” (NRC, 2012). This document was used extensively to develop the draft of the *NGSS*. The physical science standards in the draft-*NGSS* include the structure, properties, and interactions of matter with increasingly sophisticated concepts from kindergarten through high-school (NRC, 2012). In sum, the prevalence of AMT in these science education documents and in the literature as well as statements of how AMT is fundamental to understanding chemical concepts demonstrates that AMT is indeed a *big idea*. Having traced the development of AMT, established a definition, and shown that AMT is a *big idea* in science, this review will next explore teaching and learning of AMT.

Challenges for teaching and learning AMT

Despite the importance of AMT to understanding chemical concepts, teaching and learning AMT has inherent difficulties which lead into the next research question: What are the challenges to students and educators in bringing about understanding of AMT?

Misconceptions

An important challenge for both students and teachers is that students often have misconceptions associated with the character of atoms and molecules. Misconceptions are defined by Cho, Kahle, and Nordland (1985) as, “any conceptual idea whose meaning deviates from the one commonly accepted by scientific consensus” (p. 707). Griffiths & Preston (1992) further this by stating the misconceptions associated with AMT abound and some of the misconceptions “parallel the historical development of scientific concepts” (p. 611). The literature shows that students’ misconceptions can exist and persist even after instruction about AMT (Ben-Zvi, Eylon, & Silberstein, 1986).

Andersson (1990) identified and categorized common misconceptions that students have with respect to AMT. Student misconceptions of chemical reactions were categorized into four general areas, namely, (a) disappearance, (b) displacement, (c) modification, and (d) transmutation.

Disappearance refers to thinking that to a substance undergoing chemical reaction or state change is disappearing because it is in a different form or becomes a gas—as in stating that a substance is disappearing when describing evaporation.

Displacement is the misconception that a substance disappears from a certain place and appears in another without change to its composition—for example, if water is a product of the combustion of an alcohol, the alcohol must have contained water before it was combusted.

Modification implies thinking that a product is the same as the substance that reacted but that substance now has new properties. An example would be misinterpreting the chemical reaction of a metal losing electrons to form a positively-charged metal cation. Students may consider the cation as the same substance as the original metal but the original metal now possesses new properties—the ability to dissolve in water and to conduct electricity in solution.

Finally, transmutation refers to considering a type of transformation that involves either part or all of a substance transmuted into energy, energy transmuted into a substance, or a given substance transmuted into a new substance (e.g. carbon formed from burning iron wool). All of these types of misconceptions contradict AMT and reflect a non-particulate misunderstanding of matter.

A common student misconception concerning AMT is that matter is continuous and static rather than particle-based and that there is some medium, which exists between atoms and molecules rather than empty space (Andersson, 1990; Ben-Zvi, Eylon, & Silberstein, 1986; Griffiths & Preston, 1992). Griffiths and Preston (1992) identified 52 specific misconceptions in a study of student ideas relating to atoms and molecules. They found that many students shared common misconceptions such as overestimating molecular size, the idea that molecules of the same substance may vary in size, the visualization that molecules of a substance will change in shape or in weight in different phases, that matter in a solid state is continuous, that matter exists between atoms of a pure element, and that atoms are alive.

These misconceptions and the difficulties students have understanding AMT may be due to a myriad of causes. The source of misconceptions might be confusion associated with scientific models of the atom (Osborne & Cosgrove, 1983) or textbook language and diagrams depicting models of the atom (Griffiths & Preston, 1992). Other sources of misconceptions are identified by Haider and Abrahan (1991), who suggest macroscopic types of reasoning,“the translation of observable (macroscopic) behavior of matter to the scale of atoms and molecules” as a possible source. Haider and Abraham identify another potential misconception source as instructional devices or analogies used to explain AMT concepts. Even if the concepts are correctly expressed, the analogies meant to simplify AMT may lead to misconceptions through misinterpretation or literal interpretation. Clearly, the prevalence, numerous variations, and multiple potential sources of student misconceptions pose a challenge for students and teachers in bringing about understanding of AMT.

Language

Another challenge, according to de Vos and Verdonk (1987), exists because there is a discrepancy between colloquial language and the language of a chemist who typically thinks in non-macro (atomic and molecular) terms. The authors contrast the terms diamond, glass, tin, and salt in common language with the specific meaning of these terms in chemistry. The article describes an example of students who, after heating pure copper in a flame and finding that a black substance forms on the surface, express that the copper has turned black rather than stating that a new substance has formed. The authors claim that teacher familiarity with atoms and molecules and an inability to express concepts that link a chemical understanding to student experiences becomes an obstacle. This language disconnect can make it difficult for instructors to communicate ideas to students in an introductory chemistry course.

Recall the description of evaporation as water disappearing in the K-2 standards from *Benchmarks for Science Literacy* (AAAS, 1993). This was another example of challenging language for students and teachers as they discuss the nature and structure of matter. Fortunately, in standards for later elementary and high-school, *Benchmarks for Science Literacy* adjusted the standard to reflect an explanation of evaporation more consistent with the tenets of AMT. However, any misconceptions gained in the early elementary years would have to be addressed and dispelled before a student can gain an appropriate understanding of AMT.

Macroscopic versus microscopic characteristics

Another challenge in understanding AMT is that students commonly project macroscopic properties of substances (such as color, smell, hardness, temperature) onto the atoms or molecules, which make up the substance (Andersson, 1990). Similarly, Ben-Zvi, Eylon, and Silberstein (1986) found that almost half of their samples of 10th-grade students were unable to distinguish the properties of a substance, such as metal conducting electricity, from the properties of a single, isolated atom. This specific challenge is typically the result of a view of matter as continuous and static rather than particulate. It also reflects a lack of understanding about the nature of certain characteristics such as bonding and lattice structure—characteristics associated with a group of atoms rather than a single atom.

Teaching AMT

If knowledge of AMT is essential to understanding chemistry and misconceptions abound with respect to AMT, what instructional strategies can educators utilize to effectively teach AMT and what does the literature suggest to guide curriculum development?

Instructional strategies

Many researchers espouse the conceptual change model, which uses discrepant events to confront existing misconceptions. The discrepant event facilitates a shift from misconception to the accepted scientific explanation of the event (Posner, Strike, Hewson, & Gertzog, 1982; Stepans, 2008). A related instructional model, constructivism, which addresses what students already know during instruction, has been identified as an effective strategy for teaching science (Driver & Easley, 1978) and has strong following in the science education community.

Haider and Abraham (1991) suggest an experiential and instructional balance in teaching AMT. They found that an emphasis on practical hands-on experiences in chemistry is most effective in combination with instruction that allows a connection between the macroscopic observation in the laboratory and the models that explain microscopic phenomena. Gabel (1993) studied outcomes of student understanding when AMT was directly incorporated into the curriculum. Not surprisingly, they found that the students who had direct AMT instruction showed a better understanding of the concepts of AMT.

Ben-Zvi, Eylon, and Silberstein (1986) promote a model-driven approach to teaching AMT which mirrors the development of the atomic model through history. They found that students were able to confront their misconceptions and/or avoid misconceptions through considering the scientific knowledge of atoms as an ever-developing model. Using, evaluating, and formulating conceptual and physical models can improve student understanding of scientific concepts such as AMT and help students understand scientific thinking and practices. Challenges arise when using models and a “key hurdle for students is to understand that models are not copies; they are deliberate simplifications” (NRC, 2007, p. 152). Effective instruction should use a variety of strategies throughout an AMT unit and multiple models with discussions to identify the specific strengths and weaknesses of the models.

Curriculum development

Some studies suggested adjusting methods of curriculum development to improve science instruction. Using learning progressions to guide vertical curriculum development has a strong current following (e.g. Smith et al., 2006). Learning progressions are recommended in *TSTS* (NRC, 2007) and *The Framework for K-12 Science Education* (NRC, 2012). *TSTS* suggests development of learning progressions that do the following; make use of the current research base, consider the interconnected strands of proficiency in science, provide organization around core ideas, and recognize multiple possible sequences and web-like growth (p. 221). *TSTS* uses AMT as the example of a learning progression shown in the *TSTS* appendix. The learning progression is formatted to answer questions about and address big ideas concerning AMT. There are recommendations for K-2nd grade, 3rd -5th grade, and 6th-8th grade (p. 360). The authors caution that, while learning progressions are a promising direction for curriculum development, they should be created considering the research base. Because these learning progressions are relatively new, further research will be required as they are implemented to evaluate their efficacy.

Smith et al. (2006) suggested learning progressions for developing science curriculum and also provided a learning progression for AMT through grade eight. The authors recommended that 9-12 grade students strengthen their conceptual understanding through "practices that build on these (the 6-8th grade) understandings and will generalize them as they study, for example, the periodic table and general principles of chemical reactions" (p. 69). The 6-8 grade learning progression in the Smith et al. paper and *TSTS* provided benchmarks for initial student understanding of AMT at a high-school level and might provide a framework for curriculum development as well.

Curriculum development can also be considered using the concept of "backward design" proposed by Wiggins and McTighe in *Understanding by Design* (2005). Backward design is a method of developing curriculum based on teaching big ideas with a focus on design, instruction, and assessment meant to achieve student understanding. This method of curriculum design helps educators avoid the common educational hazards of activity-focused teaching or coverage-focused teaching. Using backward design, AMT curriculum development would require identification of desired results, determining acceptable evidence of student understanding, and, only then, planning learning experiences and instruction (p. 18). With thought toward effective curriculum design and instructional strategies, educators will be able to provide students with the opportunity to learn about and understand AMT.

The literature has provided insight into the topic of AMT instruction and the research questions concerning the historical development of AMT, how AMT is defined, how and why AMT is a *big idea* in science, challenges in bringing about understanding of AMT, and instructional methods of teaching AMT. Conclusions and recommendations can now be made based on this information.

Chapter 3

Discussion

This chapter will include a discussion of my Entry 1 submission for NBC and conclusions based on the reflections of that submission as well as the literature review. I will also provide recommendations based on the research concerning AMT as well as the lessons learned from participating in the NBC process.

Entry 1 for NBC

For National Board Certification Entry 1, I was required to develop and teach a unit that addressed a *big idea* in science. I chose AMT because I felt strongly that understanding AMT is a key to understanding chemistry and I wanted to strengthen my teaching of AMT and my students' understanding of the concepts. Before writing the entry, I read research articles about teaching and learning AMT and was aware of the potential challenges to instruction. I practiced backward design to develop the unit. I started with the *big idea*, AMT, and determined what I wanted students to understand before developing the activities that I would use. I determined the students' prior knowledge and misconceptions using a pre-test. The results of the pre-test showed that some of my students held misconceptions that were identified in the research.

Some of the common misconceptions identified by the pre-test are listed below. The percent of respondents displaying the misconception are indicated in parenthesis. The sample size consisted of 52 introductory chemistry students.

- Applying macroscopic properties to individual atoms—the molecules in ice cream are very cold (50%)
- Misinterpreting a diagram of water molecules in ice by indicating that "air" or "water" exists between the molecules rather than nothing or a vacuum (50%)

- Violating the law of conservation of mass in a prompt describing sublimation (29%)
- Misconceptions about state change versus chemical change by indicating that boiling water produces oxygen and hydrogen gas (23%)
- Misunderstanding of terminology and the concept of molecules and atoms by indicating that two substances can be made of the same type of molecules but different kinds of atoms (44%)
- Confusing molecules with cells—cells are kinds of molecules (56%)

The language of the cell prompt may have been a source of confusion for students. I have since revised the prompt to "cells are a type of molecule" as a true/false question in the pre-test.

Some of the less prevalent, but still notable misconceptions are listed below:

- 10% thought that atoms and molecules do not have mass and weight
- 12% indicated that only things you can see are made of molecules
- 14% thought the atoms of a gas changed size as a gas sample is compressed or expanded in a syringe

Individual student responses to the pre-test prompts and collective data identified misconceptions and provided direction for developing the AMT unit. Addressing and correcting these misconceptions while strengthening conceptual understandings were instructional goals that guided choices for the unit activities and assessments.

Introduction of AMT concepts

Next, I introduced the concepts of AMT along with some applications in a poster-response format. Students worked in pairs and responded to AMT concepts displayed on posters around the room. For example, one poster displayed "All matter is made up of discretely spaced particles called atoms that are too small to be seen even with a powerful microscope". Student responses could include questions, commentary, drawings, and/or examples which they would write on the poster. By rotating through, students could read and respond to the prompt or to the additions of other students. After rotating through all of the posters, we had class discussion addressing each of the concepts and comments while addressing and correcting inconsistencies or misconceptions in the written responses. I used this activity to gauge emerging knowledge, prior understanding, and misconceptions. The prompts used for the poster/response activity as well as student responses are compiled in Appendix A.

Application of AMT to chemistry

The next stage of the unit was the application of AMT to chemistry. This included a lesson and class discussion on mole theory and a lesson on balancing chemical equations which included practice. Mole theory was a direct application of AMT because it addressed the defining AMT concepts of substances being composed of atoms and those different kinds of atoms each having a distinctive mass (average molar mass). This lesson also focused on the cross-cutting concept of scale using very large numbers (6.02×10^{23} atoms/mole) to describe substances which are extremely small (atoms and molecules). The application of AMT to chemistry ideas was assessed via a student essay which addressed one of the following questions: Are the atoms of a rock moving? Is a cell a type of molecule? Is an atom of copper malleable? The essay required an explanation of their ideas about the prompt and connections to the concepts of AMT as evidence backing up their ideas.

Application of AMT to living organisms and environmental issues

The final lessons of the unit expanded the application of AMT to living organisms and to current environmental issues. This was accomplished through a class discussion prompted by viewing the Private Universe video *Minds of Their Own* (Scheps & Sadler, 2003) which recorded the responses of Harvard graduates on graduation day as they grappled with the question “Where does the mass come from for a seed to grow into a tree?” I had students record and discuss their ideas before viewing the video. We then watched a clip of the Harvard graduate responses after which the interviewer posed the question: “What would you say to someone who told you that the mass comes from carbon dioxide in the air?” I stopped the video and asked the students to reflect in writing and verbally about that question.

As a class we discussed their ideas, addressed misconceptions about air having no mass, linked this idea to AMT, and discussed photosynthesis as a reverse reaction of combustion. Their responses indicated progress as they worked to apply the AMT concepts to biological systems. The lesson culminated in a discussion of carbon dioxide in the atmosphere and the importance of plants in removing carbon dioxide from the air as well as the role of burning fossil fuels in increasing atmospheric carbon dioxide concentration. In this lesson, I used a discrepant event and constructivism to guide students to a better understanding of AMT. The class discussion and student response sheets were assessment tools that allowed me to gauge improvements in student understanding of AMT.

Culminating assessment

The culminating assessment for the AMT unit was an experimental application of the concepts combined with a response sheet and, in some cases, an interview. There were three experimental situations set up that pairs of students could investigate; a deflated soccer ball with a pump and scale, an air-filled syringe for compression, and beakers with water and sodium chloride, which would be massed separately and then combined and massed. Students were asked to predict the experimental outcome and explain their prediction using the concepts of AMT. They then performed the experimental task, observed the outcome, and compared the outcome to their prediction. Students were required to explain their ideas using pictures and prose. I interviewed several students throughout the experiment, as I probed for understanding and for persistent misconceptions.

Conclusions

I have several conclusions pertaining to AMT in the introductory high-school chemistry class. These conclusions are based on the literature and the NBC process—including my experiences planning, implementing, and analyzing the AMT unit.

I conclude that for students to understand chemistry they must possess conceptual knowledge and understanding of AMT. Therefore, instruction addressing AMT should be incorporated in the introductory high-school chemistry class.

I believe that the definition for AMT from *TSTS* (NRC, 2007) is limited for use at the high-school level and should be expanded. My expanded definition would include the concept of absolute temperature of a sample of matter relating to the average kinetic energy of the atoms or molecules in the sample. The definition would also address the relative size of atoms and molecules through comparison with other matter that is considered small; a speck of dust, a cell, subatomic particles. Specifics about atomic structure, chemical reactions, and state changes would be added as well. Finally, the definition would include specific references to the basis for macroscopic characteristics and contrast macroscopic characteristics with those of a single, isolated atom or molecule. The *TSTS* definition is appropriate for 6-8 grades but an expanded definition is required for the high-school level because of the more complex nature of understanding required for introductory chemistry.

Related to this, the learning progressions developed for AMT through 8th-grade should be continued and expanded into the high-school level. Again, this should be research-based and additional research must be performed to determine the effectiveness of the learning progressions in guiding instruction. To aid students in understanding AMT, students would be provided with a historical perspective of how scientific understanding of AMT has evolved. This should include history beyond the typical introductory chemistry text—history which allows students to see the historical controversy in accepting AMT which may mirror their own ideas and help alleviate some misconceptions the students are experiencing. Including the historical development of the conceptual model of AMT and atomic structure will also contribute to student understanding of science as a process and help them to view scientific theories as fluid and constantly evolving.

It would also enhance student learning if teachers probe to uncover student prior knowledge, personal experiences, and misconceptions associated with AMT. Educators should be aware of the common AMT misconceptions, be able to ascertain their students' misconceptions, and use research-based strategies to address and dispel these misconceptions. Based on students' misconceptions and prior knowledge, instruction should be modified and adapted to provide the best possible learning experience for a particular group of students at a particular time.

I have determined that an effective method for developing curriculum for an introductory high-school chemistry course or an AMT unit is to start with the *big idea* and use backward design. Instruction should involve a variety of methods including the use of discrepant events, constructivism, experimentation, modeling, conceptual probes, historical perspective, and direct instruction—all of which purposefully address AMT. All of these methods and others should be utilized as appropriate for a given group of students and should confront and address student misconceptions associated with AMT. These strategies have support in the research and allow for students to improve their understanding through multiple venues.

After delving into the research pertaining to AMT, it is clear to me that educators should consult the research base and consider findings when designing curriculum, instruction, and assessment. Besides research specific to a topic, educators should look at general areas of research such as the brain and cognitive research described in *How People Learn: Brain, Mind, Experience, and School* (Bransford et al., 1999) and application of the research-base, as in *Understanding by Design* (Wiggins et al., 2005). Also, the *NGSS* (NRC, 2012) and the *Framework for K-12 Science Education* (NRC, 2012) will significantly aid teachers when designing curriculum and instruction.

In sum, these overarching conclusions suggest four broad recommendations:

- Develop a high-school level definition of AMT and a high-school level learning progression. These will facilitate instruction and aid in providing educators with a starting point to help develop a curriculum aimed at guiding students to a sufficiently complex understanding of AMT.
- Educators should incorporate a variety of instructional strategies and utilize conceptual and physical models when designing curriculum and instruction. Discussion of the strengths and weaknesses of the models used will help dispel and prevent misconceptions associated with the models. Guiding students as they develop and use models will also help them in interpreting and evaluating models as a means of explaining scientific concepts.
- Educators will need the time, resources, and administrative support to implement the changes necessary to improve science education and incorporate the suggestions of the *Framework for K-12 Science Education* and the *NGSS*.

- Teachers need to study, reflect on, and implement ideas from the body of research in their specific content area and science education as well as general educational research to continue to learn and improve their practice and student learning.

Finally, I believe that educators benefit from meaningful professional development. For me, pursuing NBC and participating in the Master's program have improved all aspects of my pedagogical content knowledge and supported my work with chemistry students. In addition to meaningful professional development, I conclude that educators need time and resources to reflect on new knowledge, study the research base, implement new ideas, and collaborate with colleagues within their department, district, and broader learning communities. Educators should also have the time and opportunity to evaluate the efficacy of design, instruction, and assessment. By implementing these changes, individual teachers will continue to learn and improve and student learning and understanding will improve as well.

References

American Association for the Advancement of Science. (1993). *Benchmarks for science literacy*. New York: Oxford University Press.

Andersson, B. (1990). Pupils' conceptions of matter and its transformations (age 12-16). *Studies in Science Education, 18*(1), 53-85. doi:10.1080/03057269008559981

Ben-Zvi, R., Eylon, B., & Silberstein, J. (1986). Is an atom of copper malleable? *Journal of Chemical Education, 63*(1), 64-66.

Bransford, J., Brown, A. L., & Cocking, R. R. (1999). *How people learn: Brain, mind, experience, and school*. Washington, D.C.: National Academies Press.

Brush, S. G. (1983). *Statistical Physics and the Atomic Theory of Matter: From Boyle and Newton to Landau and Onsager*. Princeton, NJ: Princeton University Press.

Cho, H., Kahle, J., & Nordland, F. (1985). An investigation of high school biology textbooks as sources of misconceptions and difficulties in genetics and some suggestions for teaching genetics. *Science Education, 69*(5), 707-719.

de Vos, W., & Verdonk, A. H. (1996). The particulate nature of matter in science education and in science. *Journal of Research in Science Teaching, 33*(6), 657-664. doi:10.1002/(SICI)1098-2736(199608)33:6<657::AID-TEA4>3.0.CO;2-N

Driver, R., & Easley, J. (1978). Pupils and paradigms: A review of literature related to concept development in adolescent science students. *Studies in Science Education, 5*, 61-84.

Feynman, R. P., Leighton, R. B., & Sands, M. L. (1989). *The Feynman lectures on physics*. Redwood City, CA: Addison-Wesley.

Gabel, D. L. (1993). Use of the particle nature of matter in developing conceptual understanding. *Journal of Chemical Education, 70*(3), 193.

Gabel, D. L., & Samuel, K. (1987). Understanding the particulate nature of matter. *Journal of Chemical Education, 64*(8), 695-697.

Griffiths, A. K., & Preston, K. R. (1992). Grade-12 students' misconceptions relating to fundamental characteristics of atoms and molecules. *Journal of Research in Science Teaching, 29*(6), 611-628. doi:10.1002/tea.3660290609

Haider, A. H., & Abraham, M. R. (1991). A comparison of applied and theoretical knowledge of concepts based on the particulate nature of matter. *Journal of Research in Science Teaching, 28*(10), 919-938.

Michaels, S., Shouse, A. W., & Schweingruber, H. A. (2008). *Ready, set, science.* Washington, D.C.: National Academies Press.

National Research Council. (2007). *Taking science to school: Learning and teaching science in grades K-8*. Washington, D.C.: National Academies Press.

National Research Council. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. Washington, D.C.: National Academies Press.

National Research Council (2012). *Next generation science standards* (Unpublished Draft). Washington, D.C.: National Academies Press.

Novick, S., & Nussbaum, J. (1981). Pupils' understanding of the particulate nature of matter: A cross-age study. *Science Education, 65*(2), 187-196. doi:10.1002/sce.3730650209

Osborne, R. J., & Cosgrove, M. M. (1983). Children's conceptions of the changes of state of water. *Journal of Research in Science Teaching, 20*(9), 825-838.

Posner, G. J., Strike, K. A., Hewson, P. W., & Gertzog, W. A. (1982). Accommodation of a scientific conception: Toward a theory of conceptual change. *Science Education, 66*(2), 211-227. doi:10.1002/sce.3730660207

Rutherford, F. J., & Ahlgren, A. (1991). *Science for All Americans*. New York: Oxford University Press.

Sacks, O. W. (2001). *Uncle tungsten: Memories of a chemical boyhood*. New York: Vintage Books.

Scheps, M., & Sadler, P. (2003). *A private universe: Minds of our own* (Video). Harvard-Smithsonian Center for Astrophysics.

Smith, C. L., Wiser, M., Anderson, C. W., & Krajcik, J. (2006). Implications of research on children's learning for standards and assessment: A proposed learning progression for matter and the atomic-molecular theory. *Measurement: Interdisciplinary Research and Perspectives, 4*(1-2), 1-98. doi:10.1080/15366367.2006.9678570

Stepans, J. I. (2008) *Targeting physical science misconceptions using the conceptual change model* (3rd ed.). Saint Cloud, MN: Saiwood Publications.

Wibraham, A., Staley, D., Matta, M., & Waterman, E. (2012). *Chemistry*. Boston, MA: Pearson Publishing.

Wiggins, G. P., & McTighe, J. (2005). *Understanding by design* (2nd ed.). Alexandria, Va.: Association for Supervision and Curriculum Development.

APPENDIX A

POSTER PROMPTS AND STUDENT RESPONSES

PROMPT 1: All matter is made up of discretely spaced particles called atoms that are too small to be seen even with a powerful microscope.

- *Block 5 comments*
  - Everything is composed of atoms
  - Agreed they are tiny.
  - This is not quite right because we now have microscopes that have that capability. (electron microscope)
  - Atoms that are ever moving.
  - But things made up of many atoms can be seen with a microscope.
  - You can know the speed but not the location, or you can know the location but <u>NOT</u> the speed!
  - Atoms are smaller than the light waves, so individuals don't reflect enough to be seen, with any amount of magnitude.
  - Marble in center of a football field example. Einstein used water jiggling pollen experiment as evidence to help prove existence.
  - Electron clouds form space between them.
- *Block 6 comments*
  - Everything is made up of atoms that are so tiny you can't see them!
  - They may be tiny, but they take up space still.
  - (Pointing to a circle with diameter of 4 – 5 mm) This is 1 Million times bigger than an actual atom and it's not moving.
  - Atoms are made up of e^-, p^+ and n^0.
  - Dalton pictured atoms as tiny, indestructible particles.
  - "There are many atoms in each object. Even though they are small we can make/do anything…" (a drawing of superhero atoms)
  - You cannot see an atom, but an atom makes up EVERYTHING!
- *Block 7 comments*
  - Makes perfect sense.
  - Matter is anything with mass and volume.
  - They're (atoms) basic building blocks.
  - Look an atom . ←
  - Why don't they like to touch each other?
  - Blood cells.

PROMPT 2: There are empty spaces (vacuum) between atoms.

- *Block 5 comments*
  - How particles stick together.
  - True, I read science magazines. False, hard to believe. Seems improbable a small vacuum exist in this gap.
  - They're definitely really close, so yeah.
  - True, there is nothing smaller than atoms/molecules to fit between atoms/molecules.

    - There are also big vacuums within the atom, and within the nucleus, and within the protons, and within the quarks, and within….
    - Yes. Not much to explain here….
    - Electron clouds within atoms.
- *Block 6 comments*
    - Gold leaf experiment.
    - Atoms and molecules are not connected in each other.
    - None of them touch.
    - They don't touch.
    - It's just space.
    - (a drawing of atoms not touching)
    - Vacuum.
    - They are kept in place (relatively) but electrostatic forces
    - (A drawing of two atoms in two houses with "lots of space " between them)
- *Block 7 comments*
    - Then what is supporting them?
    - Does that have to do with ionization energy?
    - Vacuum.
    - What if outer space is a vacuum and the planets are molecules?
    - Proven by Rutherford.
    - (In relation to the earlier comment) the gold foil experiment.
    - Electron cloud.
    - It makes sense because the actual molecule has empty space, so maybe that empty space is transferred.
    - What does the size of the vacuum depend on?

PROMPT 3: Each atom takes up space, has mass, and is in constant motion (the motion is related to temperature).

- *Block 5 comments*
    - True because heat only moves to things that are colder.
    - Rocks can never reach 0 Kelvin and everything else.
    - -273˚C = 0 K
    - When things are hot they have more energy. When things are cold they have less.
    - Brownian motion (vibration) occurs because of the energy.
    - True.
    - Nothing moves at absolute zero.
    - Rocks are moving actually.
    - Rock atoms are always moving even though the rock looks still.
    - Temperature varies – which means speed of atoms vary.
    - 0 K – absolute zero.
- *Block 6 comments*
    - As temperature decreases so does motion.
    - 0 Kelvin = absolute zero.
    - There is always a constant motion in each atom which means there is a temperature.

    - (A drawing showing an atom and a weight on a scale demonstrating that atoms have mass/weight)
    - Fast moving particles.
    - (A drawing that shows snowing on a rock and the description says “Slow moving” and another drawing showing the Sun shining on a rock with a description saying “Fast moving.”
    - (Scales showing the relation between the Kelvin and Celsius scales).
    - Heisenburg’s Uncertainty Principle.
    - (A drawing showing that as the temperature decreases so does the movement of the particles and as temperature increase so does the movement of the particles.)
- *Block 7 comments*
    - True.
    - If the object doesn’t move why does it concern me?
    - It’s just weird that things we see don’t move.
    - Can 0 Kelvin be achieved?
    - Kinetic energy maybe?
    - The colder atoms get the less they move.
    - The hotter atoms get the less they move?
    - How do do they know movement stops if they haven’t reached 0 Kelvin?

PROMPT 4: There are only just over 100 different kinds of atoms (all molecules and compounds are composed of combinations of these atoms).

- *Block 5 comments*
    - What are the different kinds of atoms?
    - 100 different kinds of atoms.
    - For now, there may be more to be discovered.
    - More exist, but they have not been achieved or discovered.
    - True, all things are composed of matter, and atoms are as well.
    - True because atoms are the basest form of matter. Atoms combine to make different properties.
    - All things are composed of atoms.
    - I’ll believe it, but maybe there is more.
    - Except for things made of antimatter.
- *Block 6 comments*
    - In every molecule or compound they are composed of some of the 100 different atoms.
    - Each element has its own atom.
    - I think that there are a lot more than just over 100 possible atoms, they just don’t last long.
    - They (atoms) can combine in many different ways.
    - Everything you know is made up of only 100 things.
    - Every little thing is made up of some kind of atom.
    - Everything is made from some element on the periodic table which has 103 elements.
    - 100 atoms = many, many molecules and compounds.

    - (A book titled “100 Breeds of Atoms”).
  - *Block 7 comments*
    - We have only discovered just over 100 atoms, there might be more.
    - They are on the periodic table.
    - How can there only be 100 different types? My brain cannot process that…. There has to be more we haven’t discovered.
    - Everything has atoms.
    - Everything is composed of atoms.
    - What atoms are people made of?
    - Even your body can be simplified into a chemical formula.
    - Can more atoms be discovered?

PROMPT 5: Each kind of atom has distinctive properties, including mass and the way it combines with other atoms or molecules.

  - *Block 5 comments*
    - Properties are determined by number of protons.
    - Each atom is different because of its number of protons and neutrons.
    - The charge of the ion of the atom.
    - Each atom has different protons and neutrons.
    - Agree.
    - Yes, protons determine atom and neutrons create different isotopes.
    - Mendeleev sorted by mass. Now we know number of protons determines the element.
    - The mass is tiny, and most from p^+ and n^0.
  - *Block 6 comments*
    - Defined by the number of p^+.
    - Each atom is unique.
    - (A drawing of 5 different atoms) These atoms have distinct properties.
    - No two atoms are the same. All atoms are distinct.
    - All atoms are different.
    - They’re as different as your fingerprint.
    - Everyone is different.
    - Copper has a rustic color and zinc (next to it) is a shiny silver-grey color.
  - *Block 7 comments*
    - True.
    - Affirmative.
    - We agree.
    - I can see that because atomic mass. Each atom only has one true atomic mass. Some elements are reactive, some are not. Makes sense I suppose.
    - H–F
    - It’s like people with different personalities who relate with others differently.
    - This results from unique ratios of protons, neutrons and electrons.
    - If all atoms were the same that would be problematic.

PROMPT 6: Atoms can be joined in different proportions to form molecules or networks—a process that involves forming chemical bonds between atoms.

- *Block 5 comments*
    - CO_2.
    - Network.
    - H_2O.
    - Ionic compounds.
    - Salt water.
    - Neutral charge
    - O=C=O.
    - New substances form. Covalent bonds.
    - NH_4^+.
- *Block 6 comments*
    - Ionic compound – NaCl
    - Could also include nuclear reactions
    - Covalent bonds.
    - The ratio of ion in an ionic compound is not necessarily the number of ions in the compound.
    - Molecules, compounds and networks are formed by bonds between atoms.
    - One is the loneliest.
    - Atoms can enjoy being together.
    - H_2O
- *Block 7 comments*
    - H–F
    - Yes, this is correct. Like water. H_2O.
    - It's kind of like baking.
    - What is this process called?
    - I guess in what we learned today this makes sense. SO_3^{-2} AND SO_4^{-2}have different proportions. Obviously they would need to be chemically bonded.
    - H–O–H
    - Compounds are formed from atoms.
    - (A drawing of two atoms. One says, "Let's hold hands!" and the other says, "And make a molecule!")

PROMPT 7: Molecules have characteristic properties that are different from the atoms of which they are composed.

- *Block 5 comments*
    - Same as what we learned about atoms.
    - True, because of bonds and the combinations of different atoms.
    - Would this be a chemical change?
    - Or a physical change.
    - The properties can change when they are combined.
    - 2 H atoms and 1 O atom form H_2O.
    - Yep they do, because there's a difference.
    - An ionic compound is a crystalline solid at room temperature whereas nonmetal at room temperature is a gaseous state.
- *Block 6 comments*

    - The properties of the atoms are not necessarily the same as the molecules they create.
    - Some molecules have the same characteristics as the atoms that form them.
    - Alloys.
    - Alloys like steel.
    - Alloy's properties are superior.
    - They are different than their parents!
    - They're their own man.
    - The properties of atoms and molecules they create are not the same.
    - No one is ever the same as their parents.
- *Block 7 comments*
    - Okay, that would make sense because when things(atoms) combine they make new things which often have properties that are superior.
    - Yep. Cuz' Hydrogen + Oxygen are both gases, but they combine to make a liquid.
    - Na is a soft metal and Cl is a poisonous gas, but NaCl is a salt.
    - They're similar but different.
    - Na reacts with water. NaCl does not.
    - Indeed.
    - Ionic compounds are examples.

PROMPT 8: The mass of an object is the sum of the masses of its atoms. The weight of an object is the sum of the weight of its atoms.

- *Block 5 comments*
    - Compounds can be broken into their parts but those parts cannot be destroyed.
    - Air is neither created nor destroyed, but distributed.
    - Same as what we learned about conservation of mass
    - Conservation of Mass.
    - Weight isn't constant, mass is. Weight changes with gravity.
    - It is the conservation of mass.
    - Law of Conservation of Mass.
    - (A drawing showing that mass on Earth and the Moon are the same, but weight on Earth and the moon are different).
    - Law of Conservation of Mass. All pieces still are there.
    - Because that's what the Law of Conservation of Mass says.
- *Block 6 comments*
    - You can break apart the atom but still have particles with mass.
    - Atomic mass.
    - Law of Conservation of mass says energy can neither be created nor destroyed.
    - The weight/mass of an atom cannot be more than the sum of the particles it's made of.
    - The Law of Conservation of Mass.
    - 8 = 8, both the same.

  - (A drawing that shows a before and after image of a car crash and the car says "But wait I'm still the same!")
  - The sum of the particles is not more than the weight/mass of the atom.
  - No matter how many pieces they are in they still have the same mass.
  - They can't lose weight!
- *Block 7 comments*
  - Conservation of Mass.
  - When you break it apart, it makes sense.
  - Law of Conservation of Energy.
  - You can destroy atoms in nuclear changes.
  - What is the difference between mass and weight?
  - Law of Conservation of Mass.
  - Where do atoms come from?
  - Simple math.