

ABSTRACT

ALBERT, JENNIFER LYNN. Using Student-Generated Animations about Water Boiling to Impact Student Understanding of the Particulate Nature of Matter. (Under the direction of Margaret R. Blanchard and Eric N. Wiebe.)

Atomic and molecular misconceptions are common place in most classrooms. This is not surprising, given that students' experiences with chemistry are mostly through macroscopic observations, yet what is taking place chemically occurs at the molecular level. In order to help students gain an understanding of what occurs at the sub-microscopic level of matter, teachers typically employ visualizations of atoms and molecules, which allow students to gain a window into this invisible level of molecular interactions. Thus, the particulate nature of matter is presented to students through various forms of visualizations such as models, pictures in textbooks, and computer animations. Typically, students view visualizations presented in the textbook as a part of reading assignments, and respond to questions. That is, students historically have had little control over the visualizations presented to them and therefore scant opportunities to evaluate these predominantly textbook models, or demonstrate what they have learned from them.

Recent research suggests that the evaluation of and/or creation of visualizations can help students make sense of underlying chemistry concepts. Van Meter and Garner's (2005) generative theory of drawing construction (GTDC) developed from work in which students refined their conceptual understandings of a science topic as they created drawings from text and compared their drawings to a provided illustration. Stevens, Delgado, and Krajcik (2010) suggest that activities, such as drawing, may be useful ways to help move students through more sophisticated levels of conceptual understanding. Stevens et al. collected data

on how students discussed phase change during a semi-structured interview in which they were asked to draw their model of atoms and molecules. Their findings form the basis for an empirically-based learning progression (LP) on the nature of matter, suggesting the relative order in which students in their study learned about atoms and molecules, as well as aspects of phase change and related concepts.

Drawing on the work of Van Meter and Garner (2005) and Stevens et al. (2010), this dissertation moves students' interactions with visualizations into the digital realm. Little is known about how students' interactions with digital animations impact their learning about chemistry. Wu and Shah (2004) reviewed several studies in which students viewing animations were compared to those not viewing animations. Each of these studies found that students who viewed animations performed better on questions related to dynamic processes.

Less is known about the relationship between students' involvement in creating animations and students' conceptual learning. Hübscher-Younger and Narayanan (2008) found that students who created animations explaining mathematical algorithms showed gains in conceptual understanding. To date, only one study has been published in which students constructed original animations. For this study, Chang, Quintana, and Krajcik (2010) investigated how students' understanding of chemistry was impacted by the construction of animations using *Chemation*. They found that students completing all three steps of the modeling process (design, interpret, & evaluate) showed greater understanding. This dissertation study focuses on one aspect of students' conceptual learning while creating digital animations.

This study is a mixed-methods analysis of 94 students in six Scientific Visualization (Sci Vis) classes of two instructors. The Sci Vis curriculum teaches students to use a variety of visualization tools (e.g. ArcView™, 3ds Max® and Flash™) to display different scientific concepts. For example, students use 3ds Max® to create an animation of DNA replication. Students in two of the classes (Sci Vis I) used CorelDRAW® to construct animations using .JPEG images supplied in a digital folder depicting different elements of water boiling (e.g. pot, steam, molecules). Students in the other four classes (Sci Vis II) used 3ds Max® to create original animations. Students were instructed to read the provided text and produce an animation of water boiling in enough detail that someone looking at the animation would be able to write the text.

The pre/posttest was developed by combining 12 questions from the Particulate Nature of Matter Assessment (Yeziarski & Birk, 2006), 15 questions from the Smith et al. (2006) learning progression study, and 3 questions from state end-of-course exams. On Day 1, students were provided with the text and asked to begin their animations. On Day 2, students spent 30 minutes working through a Web-based Inquiry Science Environment (WISE, Linn, Davis, & Bell, 2004) module, answering questions related to phases and phase change and looking at embedded animations. Students then returned to completing their own animations and asked to keep in mind the animations they had just watched as they finished their own. On Day 3, the Group 3 students met in small groups and discussed their animations. All student animations were graded using a rubric developed by Albert, Blanchard, and Wiebe (2012) based on key ideas on phase change in Stevens et al. (2010), for example ‘matter is made up of parts’.

Initial analyses of data indicated that of the 94 total participants in the study, only 35 students had non-zero scores on all assessments. Therefore, these 35 students were selected for analysis and students who did not participate fully were removed. Analyses included repeated measures ANOVA on the pre/posttest, scoring of student animation projects and WISE module question responses according to developed rubrics, and constant comparative coding of informal student interview data. Although there were no statistically significant gains by any of the three groups on the pre/posttest, there was a statistically significant correlation between scores on the pretest and posttest and the total project score. In their animations, students included many of the key elements from the provided text, as suggested by Van Meter and Garner (2005), and in the Stevens et al. (2010) learning progression. Unlike the Van Meter and Garner findings, few students saw a relationship between their animation and those they viewed in the WISE module. Findings indicate that the creation of animations seemed to affect students' understanding of motion and of the composition of atoms and molecules. This indicates that, for students who engaged cognitively with the activity that employed tenets of Van Meter and Garner's GTDC, creation of digital animations enhanced conceptual learning.

Findings indicate that it is possible to replicate Van Meter and Garner's GTDC in a digital environment. Students were able to integrate elements into their own animations from their mental models, the provided text, and the viewed animations. Interestingly, the appearance of students' animations differed greatly, demonstrating a surprising degree of student creativity. In this study, animations were nominally useful in reducing students' misconceptions related to motion and atomic/molecular composition, corroborating findings

from other studies (e.g. Wu & Shah, 2004). However, this was found only in the classes in which students created original animations, not in the classes in which students constructed animations with supplied images. The limited increases in gains scores suggest that all steps – reading the text, beginning the animations, answering questions, and comparing their animations to provided models - are needed in order to have meaningful learning gains when students create digital animations. The modest learning gains by students also suggest that students may need more teacher scaffolding in order to maximize results. Further, students' creativity seems to have been sparked by the creation of computer animations and many students showed gains in conceptual understanding, as evidenced in their interviews. This implies that the use of digital animation creation may be a way to increase student interest in chemistry.

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Using Student-Generated Animations about Water Boiling to Impact Student Understanding
of the Particulate Nature of Matter

by
Jennifer Lynn Albert

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APPROVED BY:

Alton J. Banks, Ph.D.

Margaret R. Blanchard, Ph.D.
Co-Chair of Advisory Committee

M. Gail Jones, Ph.D.

Eric N. Wiebe, PhD
Co-Chair of Advisory Committee

DEDICATION

To all science teachers and Scientific and Technical Visualization teachers who strive to implement more creative and useful ways to help students learn science.

BIOGRAPHY

Jennifer Lynn Albert was born in 1981 in Grass Valley, California. Her parents, Jim and Laura Shuffield, moved to North Carolina when she was three. Laura stayed at home with Jennifer and her brother, Craig, until they both started school. Laura then began the nursing program at FTCC, graduating with a RN in 1990. Jim owns and operates an automotive repair shop and races dirt track with Craig on the weekends. Craig is also a mechanic, married to Brannigan, and has three wonderful children, Owen, Axel, and Piper.

Jennifer excelled in science during high school, taking several AP level courses, and ultimately falling in love with chemistry. She graduated from Terry Sanford High School in 2000 and was a finalist for the Park Scholarship at North Carolina State University. She attended NCSU, ultimately awarded the Joyce Hall Aspnes Scholarship and Target All-Around Scholarship. As an undergraduate, Jennifer participated in Habitat for Humanity, traveling to Columbus, GA to build an entire house over Spring Break. Jennifer graduated with a B.S. in Chemistry in 2003.

In 2003, Jennifer received her first education position, teaching Life Science and Physical Science at Northwest High School in Clarksville, TN and began a Master's in Curriculum and Instruction at Austin Peay State University. The next year she moved to Rossview High School where she taught Chemistry and AP Chemistry. She graduated with her Master's in 2005 and returned to North Carolina State University in the summer of 2006 to begin the doctoral program, receiving assistantships to work on projects with Dr. Lisa Grable, Dr. Eric Wiebe, and Dr. Margaret Blanchard. During her doctoral research, she

received the John and Nell Penick Fellowship and the College of Education Doctoral Dissertation Support Grant.

In 2009, Jennifer took the position of Fayetteville Outreach Coordinator at The Science House. There she conducting professional development for hundreds of teachers and thousands of students across the state of North Carolina. But, ultimately she returned to the College of Education to run the NSF ITEST grant (STEM Teams) awarded to Dr. Margaret Blanchard.

Jennifer is married to Timothy Joseph Albert who has the patience of a saint and married Jennifer, even knowing what he was getting in to. Words cannot describe how instrumental he and their families have been in enabling the completion of this degree through their encouragement and babysitting hours. Jennifer and Tim live in Fayetteville, NC with their two children, Logan and Lily, and Weimaraner, Lizzie.

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CHAPTER ONE: INTRODUCTION

Physics, chemistry, biology, and environmental science are the main STEM areas in which high school students are required to take courses and consequently shape their views of STEM as a whole. Chemistry is a core STEM topic that many students shy away from because of the assumed level of difficulty in the current way it is taught (Johnstone, 1997). One of the barriers to change is the requirement of a cumulative exam to pass on to the next grade level or course (Bishop et al., 2001). These exams, including those in chemistry, include static images of atoms and molecules that students must interpret to answer the questions. In North Carolina, Virginia, and New York, approximately one-third of the chemistry end-of-course exam assesses knowledge of atomic/molecular structure and behavior (e.g. NCDPI, 2010). Due to the prevalence of this topic, much time and attention in the classroom is spent on atoms and molecules, but mostly from the perspective of mathematical algorithms (e.g. $PV=nRT$) (Habraken, 2004). Habraken asserts that this "convey[s] a false and long-since abandoned conception of chemistry in chemistry classrooms" (p.93).

The Nature of Chemistry

According to Oversby (2000), "the discipline of chemistry occupies a special place in science since few of the macroscopic observations can be understood without recourse to sub-microscopic representation or models" (p.227). This presents a problem for researchers and students in the classroom because atoms are on the picometer (1×10^{-12} m or 1/1,000,000,000,000 of a meter) scale, invisible to the naked eye and therefore abstract in concept (Tretter, Jones, & Minogue, 2006). Despite this invisibility, many refer to chemistry

as “the most visual of sciences” (Habraken, 1996, p. 193). Chemists make use of visual abstractions such as models, diagrams, and other visualizations to get a sense of the structure and components of atoms that cannot be seen, such as the Fischer Projection (see Figure 1.1). Most of the methods used in teaching chemistry, the verbal and mathematical, require some degree of abstract thinking, which is difficult for many students (Habraken, 1996). Habraken (2004) argues that the visual-spatial abilities of most students who regularly use computers suggest the need for us to re-think how we teach chemistry.

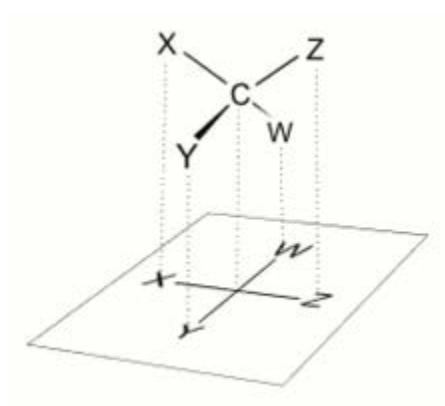


Figure 1.1. *Example of Fischer Projection* (Downloaded from http://en.wikipedia.org/wiki/Fischer_projection).

Chemistry has three levels of study: symbolic, macroscopic, and sub-microscopic (particulate and molecular). Students experience phenomena at the macroscopic level (e.g. watching water condense on the outside of a cold glass) and tend to apply those characteristics to the sub-microscopic level (e.g. the molecules in ice cream are cold). Interestingly, “current literature supports the idea that students can work algorithmic or symbolic problems using equations, without having a conceptual particulate understanding of

the phenomena” (Williamson & Abraham, 1995, p. 530). Despite the ability of students to potentially respond correctly to questions without a deep understanding, these experiences represent discreet knowledge that students are not able to transfer to new problems and therefore, become sources of misconceptions. For example, students may be able to pick from a set of multiple choice responses that molecules break apart when water boils but in their minds, molecules ‘breaking apart’ means that they separate into atoms instead of individual molecules. It is not until students go beyond the particulate nature of matter and truly understand atomic-molecular theory that they gain the capacity for “deep and satisfying answers to key questions that we all ask about the world around us” (Smith, Wiser, Anderson, & Krajcik, 2006, p. 11).

Students are taught about the structure of materials from the macroscopic perspective and later the molecular perspective (Margel, Eylon, & Scherz, 2008) because students need a clearly articulated conception of the macroscopic before being able to construct an adequate interpretation of the microscopic (Smith et al., 2006). For example, students in physical science may learn that metals are malleable, but students do not necessarily understand the underlying chemistry of metals that allow for them to have this property. However, this means they tend to apply macroscopic properties to particulate and molecular phenomena, creating resistant, unique misconceptions that need to be addressed (Smith et al., 2006). So students from the above example may think that the atoms in the metal are bending and compressing to make the metal malleable. Nakiboglu (2003) points out that “misconceptions pertaining to some chemical phenomena...are fundamentally different because the existence of atoms and molecules are not directly within the realm of everyday experience” (p. 172). For instance, a student who thinks that metals bend or not based on thickness will never

learn, through experience, that it is due to the structure of the atomic bonds in the metal.

Many researchers (e.g. Garnett, Garnett, & Hackling, 1995; Griffiths & Preston, 1992) have worked to compile a list of common misconceptions related to atoms and molecules. Examples of these misconceptions are: “atoms are large enough to be seen under a microscope, molecules within a phase move at the same speed, and matter is continuous and there is no vacuum or space between them” (Garnett et al., 1995, p. 73) The depth and breadth of these lists is such that “one may expect to find significant variability in students’ ideas about matter even within the same grade level” (Talanquer, 2009, p. 2126). These findings about the nature and number of misconceptions indicate the need to address a set of key foundational conceptions that are needed to understand most physical science topics taught in later grades.

To demonstrate the difficulty of abstract thinking in students, Margel, Eylon, and Scherz (2008) completed a longitudinal study of grade 7-9 students’ conceptions of the structure of materials, over a three year period. The curriculum they used introduced the macroscopic view of materials and then proceeded to “spiral” down to the particulate view, and finally the molecular view. Most students in the United States and abroad learn about materials in a similar fashion. The study found that over the three year period, only 23% of students retained a molecular view of materials, acquired through the curriculum intervention, based on their delayed posttest drawings. The majority of the students either retained or reverted back to a particulate or macroscopic view of the materials. This suggests that students’ understandings of the molecular level of materials was not robust enough to last, indicating perhaps that more time and attention is needed to strengthen students’ understanding of what occurs at a molecular level. This study also suggests that having

students draw their conception of materials is a promising avenue for assessing their understanding.

Learner-Generated Drawings

The value of drawing, as a vehicle for learning, has been explored by a few researchers such as Van Meter and Garner (2005), who have developed a theoretical framework for learner-generated drawings. The framework is modeled after Mayer's (1993) work with illustrations and textbook design, both frameworks focus on the selection, organization, and integration of aspects of representation. Learner-generated drawings are defined as "pictorial representations (a) that are intentionally constructed to meet a learning goal, (b) that are meant to depict represented objects accurately and, (c) for which the learner is primarily responsible for construction and/or final appearance" (Van Meter & Garner, 2005, p. 290). Thus, drawing is a process that is meant to aid students in the representation of "invisible" phenomena and convey information to student and teacher that may not be apparent without the drawing (Van Meter, Aleksic, Schwartz, & Garner, 2006).

Van Meter et al. (2006) have had varying degrees of success with students who participated in drawing interventions, based on the amount of support provided to the students. In a recent study, Van Meter et al. (2006) compared knowledge gains of students who received different levels of support ranging from simply drawing from the text to comparing their drawings to illustrations and answering questions. They found that the more support students were given (i.e. illustrations and illustrations with questions), the greater the learning gains. An earlier study also found that drawing is more effective when students are given at least an illustration to compare their drawings to (Van Meter, 2001). Both studies

reveal that a constraint mechanism, in the form of support, is needed to “guide comprehension and constrain understanding” (Van Meter et al., 2006, p. 160). Regardless of the support provided, though, empirical evidence supports the notion that drawing by hand helps students with the creation of a mental model (Van Meter & Garner, 2005).

Mental models are the internal representations of a student’s ideas (Vosniadou, 1994). Researchers (e.g. Harrison & Treagust, 2000; Van Meter et al., 2006) have used drawing to help students express these mental models. Although, we cannot precisely assess their mental models (Harrison & Treagust, 2000), the drawings give us an idea of the students’ conceptions and alternative conceptions, what Vosniadou (1994) called “synthetic mental models” (p.50). Drawings also provide us with an external representation, which can also be considered a visualization. According to Scheiter, Wiebe, and Holsanova (2009, pp. 68-69) “visualizations are a specific form of external representation that are intended to communicate information by using a visuo-spatial layout of this information and that are processed in the visual sensory system”. Visualizations cover a wide range of representations, from 2-dimensional (2-D) and 3-dimensional (3-D) to static and dynamic, and can be used to communicate a wide range of ideas in many different ways.

Creating Visualizations

Although many teachers ask students to draw their visualizations by hand, most visualizations they view, in textbooks, on the computer, etc., are now created using computers. It stands to reason that students would want to use computers to create their visualizations too. Barnea and Dori (1996) found that students who used computerized molecular modeling software were able to construct molecules more easily, more accurately,

and with enjoyment. Many studies have found that computer software improves student understanding and visualization skills (e.g. Sanger & Badger, 2001; Williamson & Abraham, 1995; Wu, Krajcik, & Soloway, 2001). However, the focus of most research studies deals with computerized visualizations that the students either view or interact with, and to date, little is known about student learning with learner-generated computer visualizations. Only in the last two years have we seen studies begin to make use of learner-generated animations.

Digital animations have been used recently in studies by Chang, Quintana, and Krajcik (2010) and Hoban, Loughran and Nielsen (2011). Chang et al. (2010) studied how the steps of the modeling process (design, interpret and evaluate) affected middle-school student learning as students used *Chemation* on Palms to create three animations. They found that students performed best when using all three steps. Hoban et al. (2011) used *Slowmation* with preservice teachers to document how these teachers represent their understanding of science concepts. They called for research into “simpler ways for learners such as preservice teacher to make [these animations]” (p. 990). However, both studies have students combining already created elements in the production of their learner-generated animations.

A variety of other tools exist to aid students in the creation of visualizations. Barnea and Dori (1999) used Computerized Molecular Modeling (*CMM*) allowing students to try out different 3-D configurations and make calculations such as bond energy. Wu, Krajcik, and Soloway (2001) used *eChem* to help students manipulate 3-D molecular models and observe characteristics at the microscopic and macroscopic levels. Many of the Career and Technical Education courses, such as the one that will be used in this study, use other forms of computer drawing and modeling (e.g. Wiebe & Clark, 1998). Regardless of the software

package being used, computers can add a type of scaffold, such as the order in which students must add elements, for student learning and explanation through features in the software (Linn & Hsi, 2000). However, computer use alone does not guarantee student understanding. It is important to select the “appropriate computer [software] tool with students’ [having] high competency in its usage” (Hsieh & Cifuentes, 2006, p. 138).

Visualizations are an important tool in education because they illustrate phenomena that cannot be observed (Buckley, 2000) and are connected to how we think as evidenced by information processing theory (Wickens, 2002). Most of the visualizations students encounter are in textbooks or curriculum material that accompanies textbooks. According to Mayer, Steinhoff, Bower, and Mars (1995), between one-third and one-half of the space in science textbooks is filled with some form of visualization. The problem is that “teachers cannot predict how students will interpret” these visualizations and that their interpretations can lead to misconceptions (Harrison & Treagust, 2000, p. 353). In an effort to investigate student understanding and interpretation of visualizations, Zhang and Linn (2011) have studied the difference between students who interact with dynamic online visualization modules and answer questions versus students who draw, by hand, what they understand from the visualizations. Although both groups did well, the drawing group was more accurate and expressed more ideas. This suggests an added benefit to drawing. In another study, Chang et al. (2010) had students create animations using a Palm. The groups varied in the steps of the modeling process they used (design, interpret, evaluate). Overall, they found that the hands-on nature of scientific modeling and the constant peer evaluation and feedback helped students deal with their misconceptions and promote conceptual change (Chang et al., 2010).

Visualizations may come in different forms. They may be 2-D or 3-D and either static or dynamic. Two-dimensional (2-D) visualizations have length and width and appear to be on the same plane as the computer screen, textbook, or paper. Three-dimensional (3-D) visualizations add depth and appear to be coming out of the computer or paper. Static visualizations are those that do not move, such as textbook pictures. Dynamic visualizations are those that move, similar to animations in video games. Both 2-D and 3-D visualizations have the option of being static or dynamic. Hoffler and Leutner (2007) conducted a meta-analysis of educational uses of both static and dynamic visualizations and found animations to have more advantages. Other studies by Williamson and Abraham (1995) and Chang et al. (2010) investigated specifically the animation of molecules in different treatments. Findings were inconclusive; therefore it is still unclear if there is a specific approach that is particularly efficacious.

Scientific Visualization

A promising avenue for helping students draw, develop and use visualizations of atoms/molecules is a course called Scientific and Technical Visualization (Wiebe & Clark, 1998). Scientific and Technical Visualization (Sci Vis) is a high school course developed by Wiebe, Clark and Shown in 2000. This Career and Technical Education course is typically offered at the high school level to juniors and seniors who also are enrolled in science and mathematics courses. Sci Vis is intended to compliment basic science and mathematics content knowledge and add 21st century computer and communication skills, a goal of state reform efforts (Partnership for 21st Century Skills, 2004). According to Wiebe and Clark (2001), “the goal of this two-course curriculum is to help develop students’ ability to

communicate technical and scientific information to a variety of audiences. Graphic design principles, along with 2-D and 3-D graphical techniques, are used to represent both empirically and theoretically derived data in visualizations” (p. 40).

Consensus visualizations

Not only does the Sci Vis curriculum lend itself to the creation of visualizations by providing students with expertise in computer software, but it also provides a forum for discussion. The course is designed for students to work both independently and in groups. Group work or collaborative learning is a technique used by in many classrooms and described most prominently with Vygotsky’s (1978) zone of proximal development. Essentially, students at higher levels are able to guide or assist students at lower levels. When applied to visualizations, the product is a consensus model. Schwarz et al. (2009) found that as students worked together to create a consensus model, usually a pen/paper drawing, they “moved from unprincipled decisions about changes in their models to using criteria of accuracy and explanatory value” (p. 648). Thus, group work centered on the development of a visualization enhanced student reasoning.

Research Questions

This study seeks to provide insight into how students’ self-generated visualizations of the particulate nature of matter impact student understanding. Understanding the particulate nature of matter, with emphasis on atoms and molecules, “is fundamental in the learning of chemistry” (Griffiths & Preston, 1992, p. 612). The particulate nature of matter is also an area of chemistry with well documented misconceptions (e.g. Garnett et al., 1995; Griffiths & Preston, 1992) and accompanying research on conceptual change (e.g. Niaz, 2002; Wu et

al., 2001) but no clear answers to many pressing questions about instructional practices that best address these misconceptions. Visualizations generated by curriculum developers have long been used to aid student learning, either through simply viewing or using ready-made objects to construct (Wu & Shah, 2004). Thus, this proposed research will evaluate the strategies in a wider context and as an agent for conceptual change.

The research questions pertaining to this study are:

1. Do student-generated computer animations enhance student conceptual understanding as suggested by Van Meter and Garner's (2005) Generative Theory of Drawing Construction (GTDC)?
2. To what extent do student-generated animations relate to elements in the phase change learning progression and/or the provided text?
3. Does the process of students generating animations affect specific misconceptions?

Summary

In this chapter, I describe the use of visualizations in chemistry, a topic with particulate and molecular properties. In the chapter that follows, Chapter 2, the literature concerning learner-generated drawings and learning progressions is reviewed. Chapter 3 details the methods used to conduct and analyze the study. Finally, Chapter 4, formatted as a publication-ready manuscript, describes the findings and conclusions of this study.

Chapter 4, entitled "Do student-generated digital animations enhance student progress along a phase change learning progression? A study of 35 students in six Scientific Visualization classes investigates a subset of the 94 total participants who participated fully

in the activity. This study describes how Van Meter and Garner's (2005) GTDC may be applied to digital animations and how the students' understanding translates to a phase change learning progression.

CHAPTER TWO: REVIEW OF THE LITERATURE

The study of chemistry is built on a foundation of atomic and molecular behavior. Because of this, the field makes use of abstractions in the form of visualizations to represent this atomic and molecular behavior. What is represented in these visualizations is based on indirect measures made with instrumentation (including the human senses). Most of the experiences students have had with science are macroscopic—that is, what they experience and measure is what happens at the scale the human eye can see. For example, they watch as a chemical reaction causes bubbles or a color change. Students have trouble making connections between those macroscopic observations and the underlying microscopic mechanisms (e.g. Wu, 2003). To compound the problem, students have trouble correctly conceptualizing the scale of an atom and the molecules involved in chemical processes (e.g. Tretter et al., 2006).

Teachers use many different pedagogical strategies to help students enhance their conceptual understanding of atomic-molecular theory (Stevens et al., 2010). These strategies cover the range of modeling, drawing, and static and dynamic visualization. Wu and Shah (2004) reviewed many different types of these strategies and tools including concrete models, animation, computer-based construction and multimedia tools, and integrated learning environments. They suggested principles for designing and using these strategies but were not able to make any clear comparisons among the strategies. Sanger and Greenbowe (2000) suggest the combination of conceptual change based instruction with computer animations as a way to affect student misconceptions.

Conceptual Change Model

Misconceptions, on a variety of topics, are prevalent among students. Chi (2005) asserts that misconceptions can either be fragmented or coherent. diSessa (1988) defines fragmented misconceptions as “a set of loosely connected and reinforcing ideas” (p. 52). According to Chi, “a coherent view claims that misconceptions are *not merely* inaccurate or incomplete isolated pieces of knowledge (with respect to the correct scientific conceptions), but rather, they can be portrayed as *alternative* conceptions” (p. 162). Driver et al. (1994) describe how “young people have a range of knowledge schemes that are drawn on to interpret the phenomena they encounter in their daily lives. These are strongly supported by personal experience and socialization into a ‘commonsense’ view” (p. 7). Therefore, taken together, these researchers indicate that students’ conceptions or misconceptions are primarily created from personal experiences and individualized.

In contrast to conceptions or misconceptions based on daily experiences, Nakiboglu (2003) suggests that “misconceptions pertaining to some chemical phenomena... are fundamentally different because the existence of atoms and molecules are not directly within the realm of everyday experience” (p. 171). Indeed, science teachers, and particularly chemistry teachers, face the special challenge that little of what is occurring, for instance, in a chemical reaction, is visible to students. In order to address this, teachers use models to help students better understand chemical phenomena. Paradoxically, these macroscopic models may help to promote many of students’ common misconceptions at the microscopic level.

Griffith and Preston (1992) cite the following misconceptions relating to atoms from interviews with 12th grade students:

8.1 An atom resembles a sphere with components inside.

8.2 An atom resembles a solid sphere

8.3 An atom looks like several dots/circles

8.4 Electrons move in orbits

8.5 Atoms are flat

8.6 Matter exists between atoms

9.1 Atoms are large enough to be seen under a microscope

9.2 Atoms are larger than molecules

9.3 All atoms are the same size

9.4 The size of an atom is determined primarily by the number of protons

9.5 Heat may result in a change of atomic size

10.1 All atoms have the same weight

11.1 All atoms are alive

11.2 Only some atoms are alive

11.3 Atoms are alive because they move

Misconceptions 8.1-8.6 can, in some part, be attributed to a misunderstanding of models.

These students see models as concrete objects and probably lack the developmental capability to see beyond the concrete. Teaching students about models and having them create models to represent more concepts could help to overcome these misconceptions.

Misconceptions 9.1-9.5 concern size and scale. Students have no direct experience with the sub-microscopic world and therefore little understanding as to why macroscopic properties do not translate to atomic particles.

Conceptual change model (CCM) was proposed by Strike & Posner (1985) as a way to theorize how to help students overcome their misconceptions. According to the CCM, in order to change their initial conceptions, learners must “judge a competing conception to be more intelligible, plausible, and fruitful than alternative in order for the new conception to be used in place of the old” (Demastes, Good, & Peebles, 1996, p. 408). A final step of CCM is that the learner accepts the new conception. Slotta and Chi (2006) describe conceptual change as “a matter of developing new conceptualizations alongside existing ones and understanding how and when to differentiate between alternatives” (p. 266). Later, Strike and Posner (1992) expanded their notions of CCM by suggesting that learners’ value of the subject matter and motivation were important considerations, as well, describing a *conceptual ecology* to include additional contextual aspects. Although Strike and Posner assert that CCM was not intended to be a comprehensive learning theory, its use has been instrumental in developing studies to gain more understanding of how students learn subjects, such as chemistry concepts, when they are at odds with initial conceptions.

Learning Progressions

What is a learning progression?

Learning progressions (LPs) are a way to look at how students develop more sophisticated ways of thinking about an idea over time (Schwarz et al., 2009). They not only can be used to assess student progress but also to organize and guide instructional strategies. However, there is no true consensus on the definition or guiding methodology of LPs within the science education community (Stevens, Shin, & Krajcik, 2010). Two types of learning progressions informed this study. Smith et al. (2006) use a learning progression to track

student understanding of specific *scientific content*, specifically the particulate nature of matter. Most learning progressions in science education are similar in that they deal with specific content. In contrast, Schwarz et al., (2009) use a learning progression to track the *scientific process* of modeling. These two learning progressions complement each other because they can both be used to guide the same activity but track different but equally important aspects of scientific ways of knowing. They can help students progress through the levels to achieve a greater understanding (Baroody, Cibulskis, Lai, & Li, 2004).

Learning progression is a general term covering many ideas. A learning progression may be either hypothetical (HLP) or empirical (EP). Both learning progressions used in this study are hypothetical in that they are based mostly on logic and current research in the area. There has been some but not extensive empirical testing. An empirical learning progression typically has been extensively refined through several assessment tasks and there has not been enough research to fully flesh out progressions in science. Learning progressions are also made up of smaller steps called trajectories. Learning trajectories may also be hypothetical (HLT) or empirical and address much more specific content than the “big ideas” of the overall progression (Stevens, Shin, & Krajcik, 2009). For example, a learning progression may deal with students perceptions of phase change, and within it, a learning trajectory describes how students move from “matter made up of molecules” to “particles are atoms and molecules” (Stevens et al., 2010).

Most approaches to learning are narrow in focus, tackling only a single topic in a larger theory, such as memorizing the structure of the atom without learning any of the properties or characteristics of the atom. Learning single concepts often means that students do not understand the linkages between these topics. Schwarz et al. (2009) suggest that

students are rarely asked to engage in thinking about phenomena, such as the movement of molecules as water boils. Duschl, Schweingruber, & Shouse (2007) assert that we have failed to “systematically develop students’ epistemological understanding of the nature of models and theories” (p.102). Learning progressions seek to uncover the linkages that help students better understand, organize curricula and standards around those linkages and encourage students’ metacognitive skills that will help them gain a more fully developed way of thinking. For example, it can enhance student learning if students learn about particles before specifying atoms and molecules (Marbach-Ad, Rotbain, & Stavy, 2008).

Characteristics of a Learning Progression

Every learning progression is developed differently. The escalated approach has a specific set of anchors that define the upper and lower levels of the progression backed by empirical evidence. The landscape approach is a series of levels and threads that are founded on previous research (Salinas, 2009). The variation approach is a newer, less used approach based on phenomenography and contains a hierarchical set of experiences of increasing understanding (Park, Light, Swarat, & Drane, 2009). The escalated approach is the evidence-centered assessment design (Mislevy & Riconscente, 2005) while the landscape approach is the learning-goal-driven design (Krajcik, McNeill, & Reiser, 2007). The escalated and landscape approaches are two relevant examples under design-based research (Collins, Joseph, & Bielaczyc, 2004). While the escalated approach has been the most used thus far, researchers are constantly constructing new ways to develop and validate their learning progressions.

In mathematics education, a field that first promoted learning progressions research, the focus is on learning trajectories instead of the overall progression. Simon (1995) defined

hypothetical learning trajectories as “the learning goal, the learning activities, and the thinking and learning in which the students might engage” (p.133). Clements and Sarama (2004) believe that the value of learning progressions over learning sequences and other approaches is the interconnection between psychological developmental progressions and instructional sequences. Learning trajectories grew out of combinations of information-processing theory, constructivism, and cognitive theory but have become less linear and ladder-like with a wider and deeper range of sources for development (Baroody et al., 2004).

Atomic-Molecular Theory Learning Progression

Smith et al. (2006) describe a learning progression detailing specifically how conceptual understanding of atomic and molecular level phenomena are linked through progression of conceptual development. A progression of conceptual understandings around atomic-molecular theory includes related misconceptions that can be understood as either intermediate developments along the progression or deviations from the progression that impede movement along the progression.

This learning progression is developed for grades K-8 and organized around three key questions and six big ideas. One set of the big ideas (1-3) are centered on matter and its properties. The second set (1AM-3AM) discuss the atomic-molecular theory of matter, which is not introduced until middle school or high school. Each big idea is elaborated on further and supported with learning performances and assessment suggestions. They are (Smith et al., 2006, pp. 12-13):

- 1.) What are things made of?

- a. **1. Matter and material kinds.** Objects are constituted of matter, which exists as many different material kinds. Objects have properties that can be measured and depend on the amount of matter and on the material kinds they are made of.

- b. **1AM. Atomic-molecular account of matter and material kinds.** All matter on earth is made of a limited number of different kinds of atoms (a little over 100 have now been identified), which are commonly bonded together in molecules and networks. Each atom takes up space, has mass, and is in constant motion. The mass, weight, and volume of objects and the properties of materials are determined by the nature, arrangement, and motion of the atoms and molecules of which they are made.

2.) What changes and what stays the same?

- a. **2. Conservation and transformation of matter and material kinds.**
Matter can be transformed, but not created or destroyed, through physical and chemical processes.

- b. **2AM. Atomic-molecular explanation of conservation and transformations.** Mass and weight are conserved in physical and chemical changes because atoms are neither created nor destroyed. In chemical changes new substances are formed as atoms are rearranged into new molecules. The atoms themselves remain intact. In physical changes,

molecules change arrangement and/or motion but remain intact, so the chemical substance remains the same.

3.) And how do we know?

- a. **3. Epistemology.** We can learn about the world through measurement, modeling, and argument.
- b. **3AM. Epistemology of the atomic-molecular theory.** Atoms are too small to be seen directly with tools available in classrooms. The properties of and changes in atoms and molecules have to be distinguished from the macroscopic properties and phenomena for which they account. We learn about the properties of atoms and molecules indirectly, using hypothetico-deductive reasoning.

Stevens et al. (2010) expanded and extended the Smith et al. (2006) learning progression for grades 7-14. Their model is much broader but more sophisticated than the original Smith et al. learning progression. They used Smith et al.'s upper elementary grades model for the lower 'anchors' and national standards documents (AAAS, 1993; NRC, 1996) and nanoscale science and engineering learning research (Stevens, Sutherland, & Krajcik, 2010) for the upper 'anchors'. These upper and lower anchors guide the principles and theories that the students can be expected to learn (see Table 2.1) but do not provide a ladder-like path through which students go from the lower to upper anchors. Further, it helps define to what extent students should know the content (Stevens et al., 2010).

Table 2.1

Science content defined between the upper and lower anchors for the hypothetical learning progression for atomic structure (Stevens et al., 2010, p. 692).

Atomic Structure
Atoms are made up of electrons, neutrons, and protons
Protons are positively charged, electrons negatively charged and neutrons are neutral
Protons and neutrons are of similar mass, but electrons have a much smaller mass
The number of protons defines the type of element and is the atomic number on the Periodic Table
Neutral atoms of the same type (element) have the same number of protons and electrons, but not necessarily the same number of neutrons
Different numbers of neutrons for a given number of protons creates different isotopes of the same element
The nucleus takes up only a very small percentage of the volume of an atom, but makes up the vast majority of the atomic mass
The electrons are distributed in “shells” that surround the nucleus. These shells represent energy levels (n)
The outer shell of electrons is different than the inner shells of electrons. The inner shells plus the nucleus make up the atomic core
The configuration of the outermost electrons determines how an atom can interact with other atoms
Each shell (or level) of an atom contains a certain number of orbitals (e.g., 1–1s; 2–2s, 2px, 2py, 2pz)
Electron distribution within an atom cannot be predicted well by the solar system model; electrons are better described by the electron cloud model, which describes the electron probability density
Electrons exhibit particulate and wavelike behavior
The position and momentum of an electron cannot be determined simultaneously (Heisenberg’s Uncertainty Principle)
Energy changes in isolated atoms (or molecules and other confined systems) can only occur in certain defined (quantized) amounts
Different energy levels are associated with different configurations of atoms (and molecules)

In building their learning progression, Stevens et al. (2010) use a construct-centered design (CCD) process (Krajcik, Shin, Stevens, & Short, 2009) which combines the two approaches mentioned previously. In this process, once the anchors have been established by researchers/developers, the claims, evidence and tasks were assembled. They are defined as: “a) a claim describes the knowledge, skills, or other attributes to be assessed or learned; b) the evidence describes what behaviors or performances are needed to support the claim; and c) tasks [are] situations that will elicit those behaviors or help students develop the knowledge to provide the desired evidence” (Stevens et al., 2010, p. 692). This study will make use of the anchors and levels for atomic structure (see Table 2.1) and phase change (Stevens et al., 2010).

Learning progressions are an innovative approach to teaching about atomic-molecular theory. Most students are subjected to a list of facts or “rhetoric of conclusions” that they are expected to memorize and regurgitate for a test (Duschl et al., 2007). Duschl et al. assert that when students are exposed to experiments dealing with atoms and molecules, they are seen as “little pieces of materials that inherit all of their macroscopic properties” and do not see them as “preexisting entities with distinct properties and characteristics” (p.102). As such, learning progressions seek to engage students in true model-based scientific reasoning.

Learning progressions encourage deep, meaningful conceptual learning by focusing on a few key ideas and helping “students make connections between the ideas [that] will help them develop an integrated knowledge structure that allows them to apply their knowledge to a range of new situations” (Stevens et al., 2010, p. 707). The empirical testing of learning progressions is underway (Stevens et al., 2009) with details on the process but with few published results to date.

During the development of their learning progression Stevens et al. (2010) asked students “to draw their model of an atom and explain it” (p. 693). The study undertaken in this dissertation research recreated this task with a molecule of water. The task was then extended to a model of water boiling at the sub-microscopic scale in accordance with Stevens et al. suggestion to use models to help students connect macroscopic and sub-microscopic phenomena. This instructional strategy represents only a portion of what could be considered a learning trajectory, in that the goal, in accordance with the work of Stevens et al., is to help students progress up a level while making connections to prior and future learning within a narrow set of learning goals.

Using learning progressions to inform practice

The National Research Council’s (2007) report *Taking Science to School* includes an entire chapter on learning progressions in the hopes that they will one day help link content and assessment. Alonzo (2010) furthers this discussion by examining three major considerations in linking learning progressions to assessment, the third of which involves the validation of learning progressions. Many different methods are being used by science education researchers to develop learning progressions and there is not a standard in this development or even in the language used. In light of this, Alonzo charges researchers to set attainable goals for students and create well-designed instruction to further the development of learning progressions linked to assessment.

Generative Theory of Drawing Construction

As learning progressions have become the new approach in looking at the development of student learning, learner-generated drawing is a promising new line of

research that focuses on students creating their own visualizations. This drawing approach adds greater structure to the model creation process and a different option for assessment of student products. A learning progression provides overarching goals for student learning; the theory of learner-generated drawing provides insight into the role student drawing (e.g., modeling) plays in learning.

Learner-generated drawings are student created visualizations that are meant to look like the object (or idea) that they represent (Van Meter & Garner, 2005). It is a strategic process “because drawing is goal-oriented, improves knowledge organization, and can improve learning outcomes” (Van Meter et al., 2006, p. 143). Furthermore, drawing has the potential of integrating verbal and nonverbal representations because the drawing can be done in response to written text (Van Meter & Garner, 2005). The benefits of using drawing as opposed to exclusively written or verbal methods lies in a human’s capacity for pictorial memory. According to Paivio’s (1986) dual coding theory, pictures “yield a perceptual code and a verbal code in memory, which doubles the chances of retrieval” (Sawyer, 2006, p. 284). Therefore, it seems logical that student creation of drawings will improve student understanding of the selected topic.

According to Schwartz and Heiser (2006), “good readers spontaneously construct deterministic structures of what they are reading” (p. 289). This is because reading is a “guided experience” (Zwaan, 2004). Reading about something that happened is not the same as being there when it happened. However, Schwartz and Heiser (2006) suggest they are similar, and that the “common mechanisms permit people to construct spatial mental models and draw inferences, almost as though they were there” (p. 288). This idea is based around

common human-scale experiences (e.g. a precipitate falling out of solution) and may well extend to developing common understandings around invisible processes at the atomic scale.

The generative theory of drawing construction is an extension of Mayer's Generative Theory of Textbook Design (Mayer & Sims, 1994; Mayer et al., 1995). The GTTD discusses the relationship between illustrations in textbooks and the corresponding text. Mayer et al. found that students received higher scores when illustrations were accompanied by text in close proximity. The GTTD discusses that it is the selection of words/images, organization of words/images and finally, the integration of words/images that help students gain information from illustrations in their textbooks. In a similar way, learner-generated drawing supports student learning in three ways (Van Meter et al., 2006): "1) constrain the construction of drawings; 2) prompt checking the accuracy of constructed drawings; 3) and/or direct learners' attention to key elements and the relationships amongst these" (p. 148).

The generative theory of drawing construction is similar to the process of modeling. Both modeling and drawing encourage students to create visualizations of a specific topic, assess and redesign that visualization, and pay close attention to details of the visualization. In other words, both processes have an imbedded cycle of reflecting about the thinking going into the visualization which modeling experts call meta-modeling (Schwarz & White, 2005).

Stull and Mayer (2007) studied the effect of learner-generated graphic organizers, such as a hierarchical table of subatomic particles to macromolecules, as a means for students to process the information in a selection of text "is based on the idea that deep learning occurs when students are encouraged to engage in productive learning activities" (p. 810). They compared learner-generated graphic organizers to a group that only viewed author-

provided organizers and found in their first experiment that neither group produced significant gain scores. The two variations of Experiment 1 showed that author-provided organizers facilitated more learning. The possible explanation was that the generative process may be confusing and create extraneous cognitive load.

To combat the confusion and overburden that can potentially occur due to the generative process, Van Meter and Garner (2005) purposefully reviewed 30 articles (15 on classroom application and 15 dealing with empirical research). Their goal was to identify ideal characteristics to create a best practices framework for incorporating drawing in the classroom. They state, “when drawing, a learner must select to-be-represented elements and organize them into a symbolic verbal representation” (p. 315). This leads to three cognitive processes that Van Meter and Garner (2005) adapted from Mayer’s Generative Theory of Textbook Design (e.g. Mayer et al., 1995); selection, organization, and integration.

Elements of Learner-Generated Drawings

Selection determines what elements are chosen from the text, such as molecules, steam or a pot. If an illustration is also provided, these elements then become the focus of inspection of the illustration. For instance, a selection of text may be accompanied by an illustration of a pot with water molecules and arrows indicating movement. Then, “inspection of the illustration may, in turn, cause the learner to notice something important...which leads to closer inspection of the text and, possibly, the selection of additional elements, in this back and forth consideration, the two internal representations act as mutual constraints during construction of the mental model” (Van Meter & Garner, 2005, p. 317). This became evident during a pilot study (Albert & Wiebe, 2011) when the elements

(e.g. steam, ice, bubbles) from the demonstration were analyzed for frequency among student visualizations (see Table 2.2).

Table 2.2

Characteristics of Water Boiling Drawings – Frequency (%) of appearance in Paper (P) versus Computer Drawings (C) (Albert & Wiebe, 2011)

Macroscopic Characteristics	% P vs. % C	Molecular Shape	% P vs. % C	Other Characteristics	% P vs. % C
Beaker	100 / 70	Circles	40 / 83	Macro/micro overlapping	28 / 62
Hot plate	91 / 16	Space-fill	25 / 33	Movement	40 / 54
Water	100 / 66	Lewis	5 / 0	Labels	62 / 95
Steam	85 / 37	Ball and Stick	20 / 25	Level of H ₂ O Changed	14 / 0
Ice	5 / 37	Ions	2 / 0		
Magnifier	80 / 33				
Microscope	5 / 20				
Bubbles	74 / 37				
Scale	5 / 54				

Organization is the result of the representations and constraints available. In order to organize representations, they either need to exist in prior knowledge or a student must construct them based on the description provided in the text. Therefore, when drawing, “the

internal verbal elements are organized into a coherent representation. This representation then serves as the foundation for constructing the internal nonverbal representation” (Van Meter & Garner, 2005, p. 317). The process is not necessarily linear and, depending on the skill and knowledge of the student, this can force the student to go back and forth between the verbal and nonverbal or even the original text (Van Meter & Garner, 2005).

Finally, *integration* brings all the pieces together. “[A]s the organized verbal representation is used to construct the nonverbal representation, these two representations are necessarily integrated” (Van Meter & Garner, 2005, p. 318). It is this overlap that may make learner-generated drawing a successful strategy. If inconsistencies arise in either the text or illustrations, there is a back-up to clear up any confusion which leads to drawing accuracy and knowledge gains (Van Meter & Garner, 2005).

Drawing vs. Constructing

Many studies relating to student-generated projects deal with students constructing visualizations using elements provided to them. In a recent study by Chang, Quitana, and Krajcik (2010), students built 2-D molecular models using the program *Chemation*. All of the products were animations (dynamic) and the study focused on what elements of the modeling process helped student achievement. Many other studies have measured student gains following a similar construction type task (e.g. Schwarz & White, 2005), with much success. In these activities, students simply take the pieces (e.g. H and O) given to them and put them in the “correct” places focusing on organization and not selection. In contrast, during the drawing process, the selection process is just as important as the organization process. Students must decide what elements ought to be included, what those elements will

look like, and how they are best incorporated together. It means that the student is less supported in the production of the project but also given more room to discover and learn.

In conclusion, learner-generated drawings are a promising avenue for helping students gain knowledge from text and illustrations. The steps overlap those of the modeling process and have a built in meta-cognitive element that forces students to reflect on what they are thinking and doing. However, the drawing process must be properly supported to create constraints on the drawing construction that will enable the process to be efficient and effective. Similarly, the knowledge gains must be assessed using higher-order assessments to reveal the deep, predictive nature of the knowledge gains (Van Meter & Garner, 2005). These needs have been explored and addressed in research and the proposed study.

Scientific Visualization

Visualizations are important components of learning and understanding science. In subjects like chemistry, they become vital given that so much of the subject deals with ‘invisible’ phenomenon that must be represented with visualizations. In science education, a visualization can be defined as “a specific form of external representation that is intended to communicate information by using a visuo-spatial layout of this information and that is processed in the visual sensory system” (Scheiter et al., 2009, p. 68). External visualizations are those that we typically think of and use, yet there also are internal visualizations. Internal visualizations are those that are created in our mind. Many refer to them as mental models or “a special kind of mental representation, an analog representation, which individuals generate during cognitive functioning” (Vosniadou, 1994, p. 48). Reisberg (1997) further divides visualization into three categories; visual perception, visual imagery, and spatial imagery. For

the purpose of this paper, the term visualization will be used generally and without categories.

The ability to create, manipulate, and explore visualizations in one's mind is a valuable skill. Psychology refers to this skill as spatial ability and research has found high correlations between this skill and achievement among college chemistry students (e.g. Carter, LaRussa, & Bodner, 1987; Pribyl & Bodner, 1987). In fact, spatial relation is one of the many factors that sets visual representations apart from verbal representations (Scheiter et al., 2009). Beyond its importance in achievement, spatial ability has been linked to other cognitive abilities such as logical reasoning. It is a way for students "to consolidate and clarify ideas...[and] an important memory strategy" (Baker & Pilburn, 1997, p. 178). Finally, spatial skills are another avenue to help students to solve problems. Schools traditionally teach the analytical, linear method for solving problems and shy away from the more holistic paths that make use of spatial skills (Baker & Pilburn, 1997). And since spatial ability seems to be such a strong component of science and helpful in problem solving, it makes sense that it be a skill that is fostered in schools (Bodner & McMillen, 1986; Zhang, 1997).

A large body of research exists that tries to explain how we process visualizations. According to Paivio's (1986) dual-coding theory, pictorial and verbal information are coded differently by the brain. Visualizations exploit the perceptual-motor system and are unique in that they "partake of perceptual processes and experiences" (Schwartz & Heiser, 2006, p. 283). In fact, Scheutz (1999) states that they cannot exist without the "individuals for whom they are 'meaningful'" (p. 35). But the value of visualizations goes beyond the unique meaning they create, and extends to their capacity to remain in our memory. Standing (1973)

found that people will recognize pictures from an original set of 10,000 at a rate of 83% when presented with both new and original pictures. So not only do pictures remain in memory and are easily recalled, but there are also other advantages to visualizations. Gilbert (2005) suggests that “‘metacognition in respect of visualization’ be referred to as ‘metavisualization’” (p. 15) and that, as suggested above, it is a skill necessary for all.

Visualizations are used in education in a variety of formats. Pozzer and Roth (2003) suggest that “representations [i.e., visualizations] lie on a continuum depending on the amount of contextual detail that they carry in the background of the central object proper” (p. 1092) where photographs have less abstraction and more details, and graphs and tables have more abstraction and less detail. Pozzer and Roth (2003) analyzed what students really get out of photographs in textbooks and found that it depends on how those photographs are situated and the information provided with those photographs. They also found that textbook authors do not necessarily keep these in mind nor do they have the same format throughout an entire textbook. Niaz (1998) did a specific study on how different structures of the atom were used in chemistry textbooks. Her findings re-confirmed an earlier study by Schwab (1974) showing that textbooks ignore “heuristic principles” and focus on the experimental details of the models. Mayer, Steinhoff, Bower, and Mars (1995) address these issues and more in their *Generative Theory of Textbook Design*.

Chemistry Models

Science classrooms, especially chemistry classes, make extensive use of visualizations. A specific form of visualization, classroom model, is often used to display phenomena too small, too large, too fast, or too slow (e.g. ‘invisible’) to display at human-scale in the classroom. In chemistry, models of atoms and molecules are extremely

important. The term 'model' is used to describe a variety of objects and has no true agreed upon definition. Halloun (2006) presents a sample list of definitions used throughout the last two decades but it is clear there is not a consensus. For the purposes of this work, only analogical and mental models will be discussed. Harrison and Treagust (1996) define analogical models as those that "have one or more of the target's attributes represented in the analog's concrete structure" (p. 512). These are the models shown to and produced by students (a drawing of a water molecule). Vosniadou (1994) defines mental models as those that "refer to a special kind of mental representation, an analog representation, which individuals generate during cognitive functioning" (p.48). These are the models that the students first create in their minds and then use to create the analogical models on paper or computer. Furthermore, models are distinct from other visualization in their purpose. As Schwarz et al. (2009) point out, the true power behind models are their ability to help students predict, explain, and create dynamic knowledge. Gilbert (1993) suggests that models are an important tool for teaching and learning, yet Harrison and Treagust (2000) caution that using models is not without significant problems. These problems stem from the inability to predict how students will interpret models and their ability to learn the modeling language. Therefore, they "argue that teachers should teach modeling skills, encourage students to use multiple rather than isolated analogical models, and take the time to discuss and critique the models used in class" (p. 353).

The process of scientific modeling takes into account the recommendations made by Harrison and Treagust (2000). As discussed above, it is a generative process that is taught and used to continuously evaluate and revise the models that students create. Grosslight, Unger, Jay, and Smith (1991) developed three levels of understanding that explore the way

that students think about models and the modeling process. This analysis is also incorporated into the learning progression developed by Schwarz et al. (2009). Essentially, the goal of using models and modeling in science is to not only help students learn concepts but to also spark creative thinking using an important tool of science.

Models in the classroom can either be 2-D or 3-D. Physical 2-D models are typically anything drawn or printed on paper or stock, projecting either two or three dimensions of the represented object, while 2-D computer modeling software works on a similar “virtual paper surface”. 3-D physical models are, as stated, three physical dimensions while 3-D computer models allow you to construct in all three dimensions (virtually) but are still projected in only two dimensions. Harrison and Treagust (2000) explored the use of modeling throughout the year in a chemistry class. The majority of the models created by the case study student were 2-D paper-based static drawings of atoms and molecules (with limited use of a modeling kit being the expectation). Over the course of the year, the student developed into a level 2/3 modeler (using Grosslight et al. (1991) terminology) with only a few remaining misconceptions about the structure of the atom, and the ability to use models to predict certain properties. Although 2-D paper-based static drawings have been shown to be useful ways for students to express models, the advent of computers has created a shift towards 3-D computer modeling software. Wu, Krajcik, and Soloway (2001) reported on the use of *eChem* as a way to help students understand atoms and molecules. They found that the 3-D static computer modeling software can be a useful means of helping students generate appropriate mental models. Finally, the more traditional model is a 3-D physical (concrete) model such as the modeling kits, marshmallows and toothpicks, play dough, etc. that students can physically manipulate. Hyman (1982) found that regardless of whether student

manipulate or simply watched a demonstration of these models, it increased their spatial abilities.

Static vs. dynamic

In addition to models, other visualizations in 2-D and 3-D—both static and dynamic—are prevalent in science classrooms. They come in textbooks, PowerPoint presentations, overhead transparencies, and videos and computer software. Hoffler and Leutner (2007) conducted a meta-analysis of 26 studies comparing static and dynamic visualizations. They compiled a list of situations when dynamic visualizations may be better than static to enhance student learning and vice-versa. In a study by Tversky, Morrison, and Betrancourt (2002), animation was not necessarily a better media in all cases, a study by Hegarty (2004) determined that dynamic visualization was better in some cases. Marbach-ad, Rotbain and Stavy (2008) took the question a step further and tested the effectiveness of computer animation and illustration for learning about molecular genetics. They found that the computer animation better aided students in understanding the dynamic processes. Therefore, it stands to reason that computer animation may be useful in enhancing student understanding of other dynamic, molecular processes.

Scientific and Technical Visualization Course

There are other ways beyond having students draw by hand or showing them static and/or dynamic visualizations to help students understand ‘invisible’ phenomena. A course called Scientific and Technical Visualization (Sci Vis) was created to help students learn how to create 2-D and 3-D visualizations using the computer. Through this visualization process, students learn or reinforce the underlying science and technology concepts being portrayed. The course evolved from an outdated technical graphics curriculum and makes use of 2-D

CAD and 3-D modeling, in combination with the latest computer software (Wiebe & Clark, 1998). The North Carolina Department of Public Instruction (2010) website describes the course as providing

students with advanced skills in the use of complex visualization tools for the study of mathematical and/or science concepts. Students design and develop increasingly complex data and concept driven visualization models. Focusing on scientific and technical concepts, students learn how to communicate and analyze phenomena using statistical, graphic, and conceptual visualization computer applications.

Communication, computer, technical, mathematics, and science skills are reinforced in this course.

Essentially, it is a course meant to enhance the mathematics and science content knowledge students receive in their core courses and help them apply it through the creation of graphs, 2-D static, 3-D static and dynamic visualizations. The course has three levels with each level consisting of more complex and independent work. In level I, students hone basic skills using both 2-D and 3-D software by completing independent projects. At level II, students have had enough exposure to the 3-D software to create visualization with a reasonable level of complexity of form and motion without the software becoming a factor. The focus of this study is Sci Vis I and II. The Sci Vis curriculum usually has a biology, physics and earth science project, but rarely a chemistry unit. This study will create a chemistry unit based on the boiling of water, potentially to be used in the curriculum in the future.

Sci Vis lends itself to incorporating the elements of learner-generated drawings into a computer based atmosphere. The students are already familiar with the computers, software, and many design processes. The intervention used in this dissertation study will test the

compatibility of learner-generated drawing principles and modeling processes with the computer media.

Summary

In this chapter, three areas of research were outlined: Learning progressions, generative theory of drawing construction, and scientific visualization. Students' creation of their own models can improve their understanding of atomic-molecular theory. First, learning progressions were described from their creation to implementation. They provide a map on which student learning can be tracked and assessed. Next, the generative theory of drawing construction provides us with a process through which we can scaffold student learning about a topic. The variations of scaffolding are discussed. Finally, the types of scientific visualizations commonly used in science are discussed. They suggest that a picture truly can be worth a thousand words.

CHAPTER THREE: METHODOLOGY

This study is a quasi-experimental, mixed-method design. The focus of the study was student generation of visualizations to learn about atomic and molecular concepts.

Therefore, the research took place in the classrooms of two teachers teaching Sci Vis I and II.

The research questions guiding this study were:

Research Questions

1. Do student-generated computer animations enhance student conceptual understanding as suggested by Van Meter and Garner's (2005) Generative Theory of Drawing Construction (GTDC)?
2. To what extent do student-generated animations relate to elements in the phase change learning progression and/or the provided text?
3. Does the process of students generating animations affect specific misconceptions?

Setting

Two senior high schools in a southeastern state in the US participated in this study. These schools were selected on the basis of school, teacher, and course (Sci Vis I & II) availability and therefore represent a convenience sample (see Table 3.1). Both schools operate on a block schedule, reside in the same county and have similar demographics. The study took place in two Scientific Visualization I (Sci Vis I) classes and four Scientific Visualization II (Sci Vis II) classes (each teacher taught one Sci Vis I and 2 Sci Vis II). In Sci Vis I, students learn 2-D and 3-D image software such as ArcView™, 3ds Max® and Flash™, and use that software to create basic visualizations. In Sci Vis II, students further

develop their understanding of these software programs through the production of animations and multiple representation projects. These courses were chosen to help control for technology skills among students and help isolate student understanding as the dependent variable. To ensure that the groups are equivalent and comparable, a one-way ANOVA was run on the pretest scores to check for statistically significant differences.

Table 3.1

School Setting Demographics

	High School #1 (SE)	High School #2 (SW)
Total No. of Students in school	1319 students	1439 students
Avg. No. students per teacher	16	16
Student ethnicity	White 66%	White 43%
	African American 29%	African American 44%
	Hispanic 4%	Asian 7%
	Asian 1%	Hispanic 6%
	Native American <1%	Native American <1%
Students eligible for free and reduced-price lunch	23%	32%
EOC* Biology - 2010	80%	81%

* EOC refers to passing rates on end of course tests.

Participants

Each teacher implemented the project in their three classes. The three classes at these two schools enroll between 12 and 19 students. The students are 9th, 10th, 11th, or 12th grade students with varying backgrounds in science. Demographic information was taken from each student and each school allowing for comparison based on grade level, gender and science courses taken. Students will work independently so that each student's progress may be assessed. See Table 3.2 for summary.

Table 3.2

*Description of Participants**

<i>Teacher 1</i>	Yrs Teaching – 33 years	<i>Teacher 2</i>	Yrs Teaching – 12 years
<i>(Ms. C)</i>	Yrs Teaching Sci Vis – 12 years	<i>(Mr. T)</i>	Yrs Teaching Sci Vis – 12 years
	Degrees:		Degrees:
	-BS in Biology and Chemistry		-BS in Physics
	-MA in Secondary Science		-MS in Materials Science and
	-MA in School Administration		Engineering
<i>Group 1</i>		<i>Group 1</i>	
	Males-10		Males-4
	Females-6		Females-4
	9 th grade – 4		9 th grade – 1
	10 th grade – 7		10 th grade – 2
	11 th grade – 1		11 th grade – 3
	12 th grade – 4		12 th grade – 2
<i>Group 2</i>		<i>Group 2</i>	
	Males-14		Males-15
	Females-2		Females-2
	10 th grade – 4		10 th grade – 0
	11 th grade – 7		11 th grade – 6
	12 th grade – 5		12 th grade – 11

Table 3.2 Continued

<i>Group 3</i>	<i>Group 3</i>
Males-10	Males-9
Females-3	Females-1
10 th grade – 3	10 th grade – 1
11 th grade – 2	11 th grade – 5
12 th grade – 8	12 th grade – 4

*demographics represent the 81 students who supplied information but 94 were used for the study

Lesson Design

This water boiling animation activity lasted 2-3 days. The schools are on block schedule so each class period lasted 1 hour and 30 minutes in length for a total of 3 - 4.5 hours. Projects were completed individually by students and then analyzed for content and understanding. The groups proceeded as follows (see Table 3.3 for summary):

Day 1: Students received text explaining what happens as water boils at the macroscopic and molecular levels and construct/create an animation based on that text.

- Group 1 - Students began constructing a short animation using pictures (.jpg) of elements (water, molecules, pot, etc.) they were provided in a digital folder.
- Group 2 - Students began creating a short animation using their own original elements.
- Group 3 – Students began creating a short animation using their own original elements.

Day 2: Students spent 30 minutes reading through the Phases of Matter and Phase Change WISE module, watched several animations, and answered online questions. Then students were asked to complete their animations keeping in mind the animations they watched in the WISE module.

Day 3: Group 3 students peer evaluated their animations and discussed changes that would make them more closely match the provided text. Each group had a Flip Camera to record the student who was talking.

Table 3.3

Study Design

Group	Steps of Activity						
1	Pre-test	Construct*	WISE Module – Phases of Matter and Phase Change	Revise animation			Post- test
2	Pre-test	Create**	WISE Module	Revise animation			Post- test
3	Pre-test	Create**	WISE Module	Revise animation	Group discussion (groups of 3 based on pretest)	Create consensus animation	Post- test

* construct – students use elements (molecules, pot, water, steam, etc.) that have already been created and are supplied as .jpg to put together an animation that portrays their interpretations on the important ideas from the text

** create – students open a new document in 3ds Max® drawing each element and putting them together to create an animation that portrays their interpretations on the important ideas from the text

Data Sources and Analyses

Pretest/Posttest. The pretest and posttest was composed of 30 multiple-choice items, 12 were drawn from Version 1 of the Particulate Nature of Matter Assessment (Yeziarski & Birk, 2006), 3 from released Chemistry and Physical Science end-of-course standardized tests (NCDPI, 2010) and 15 from Smith et al.'s (2006) learning progression. This pre/posttest had a Cronbach α of 0.65 with the sample of high school students. Test items measured students' factual knowledge of atoms, molecules, and phase change and identify specific common misconceptions students may hold. Pretests were assessed with a one-way ANOVA to ensure that all classes were equivalent. The pre/posttests were analyzed with a repeated measures ANOVA to determine any significant gains among students and then items were separated by categories and specific misconceptions to identify differences

Table 3.4

Description of Data Sources

Data Source	Description
Pre/Post Test	30 question multiple choice test
Student animation scores	Animations were scored with a rubric (Albert, Wiebe & Blanchard, 2012) based on the phase change learning progression (Stevens et al., 2010)
Student question scores	Short answer and multiple choice questions within the WISE Module based on phase change
Student Interviews	Students were asked questions while they worked on days 1 and 2 (e.g. "What are you doing now?" and "What are you planning to do next?")

among students.

Sample Test Questions:

A pot of water is placed on a hot stove. Small bubbles begin to appear at the bottom of the pot. The bubbles rise to the surface of the water and seem to pop or disappear.

What are the bubbles made of?

- A. heat
- B. oxygen or hydrogen
- C. air
- D. oxygen and hydrogen
- E. steam**

Which of the following statements is incorrect?

- A. Water molecules move at the same speed in the solid, liquid, and gaseous phases.**
- B. Water molecules move the fastest when they are in the gaseous phase.
- C. Water molecules in the solid phase vibrate.
- D. Water molecules in the liquid phase move faster than molecules in the solid phase.
- E. Water molecules in solid phase are in the form of ice.

Student Projects. Students were given a selection of text (see selection below and Appendix D for complete text) and asked to construct/create an animation about water boiling from the description in the text.

As water boils, the water turns into steam (also known as water vapor or water gas.)

You can probably watch this happen if you pay close attention when you boil your pot of water. First, the water begins to form bubbles at the bottom of the pot near the heating device. Then, the bubbles begin to rise until the bubbles begin to pop off the surface of the water and seemingly evaporate into the air. What's happening here?

...As more energy goes into making those bubbles though, they will begin to be able to stand up to the outside air pressure. When they get to the point where they can stand up to the outside air pressure, you'll see massive bubbles coming off of your water, the temperature of your water will stay the same and your boiling point will be reached.

They were told that someone should be able to write the text after viewing their completed animation. The projects were completed in two different formats. Sci Vis I students used .JPEG images provided to them in a folder on their network to incorporate into an animation in CorelDRAW®. The images themselves were 21 .JPEG files that included various pots at different stages of boiling, water molecules, thermometers, water, and bubbles. These were all the items mentioned in the text. Both classes had previously completed at least one animation using CorelDRAW® but Ms. C had her students complete a quick (10-15 min) tutorial because it had been some time since they had worked with the animation feature. Students were instructed to use the provided images for the majority of the animation but would be able to draw in arrows, add text, etc. to supplement the images.

Students in the Sci Vis II classes also were asked to complete an animation from the text provided in a way that someone would be able to create the text from their animation. These students used 3ds Max® and created their own original animations. Students in both groups were provided only technical support by their teacher and were asked to direct all content or project specific questions to the researcher. In all classes, students worked individually but there were varying degrees of discussion in each class amongst students as to how to achieve a certain effect. Students' projects were graded according to a rubric (Table 3.5) developed by Albert, Wiebe, and Blanchard (2012) that is based on the nature of matter learning progression anchors and levels developed by Stevens et al. (2010). Scores can range from 0-21 with a maximum of 3 points on each of 7 items. All projects were coded by the researcher and 20% were coded by a second researcher with an inter-rater reliability of 85.3%.

Student Project Rubric. The concepts for the Project Rubric were taken from the phase change learning progression developed by Stevens et al. (2010) and chosen as the ideas students may have as they think about the task of creating an animation of water boiling. These concepts represent a subset of the ideas in Level 4, the highest level of the learning progression containing all ideas about phase change, and were chosen as being identifiable in student animations (see Table 3.5 for coding rubric). In order to develop the specific levels of the rubric, the constant comparison method was used. According to Lincoln and Guba (1985), the constant comparison method has four steps:

1. comparing incidents applicable to each category,
2. integrating categories and their properties,

3. delimiting the theory, and
4. writing the theory. (p. 339)

Stevens et al.'s (2010) Level 4 ideas about phase change were examined for items that could be recognized in a student animation. The compiled list was compared to 10 different animations, identifying which ideas were present. Properties of the ideas present in the animations were then listed with three levels of proficiency and applied to 20 more animations. The list and properties compiled were then compared to the original list of ideas to ensure no other ideas or properties were present.

Table 3.5

Student Project Rubric

	Concept	0	1	2	3
BASIC STRUCTURE	Matter is made of particles * (SHAPE)	No shapes are drawn	Water and gas represented by different shapes (indicating different particles)	Water OR gas represented by shapes but not both	Both water and gas represented by circles or other shape
	Particles are atoms and molecules* (PARTS)	No shapes are drawn	Shapes are drawn but do not indicate atoms and/or molecules (Shapes do not have parts)	Hydrogen and oxygen are clearly discernible in water OR gas but not both	Hydrogen and oxygen are clearly discernible in both water and gas
ADDING HEAT –MOTION	Particles in constant random motion* (MOTION)	No movement indicated	Shows particles in motion but they are all moving	Shows particles in motion, they are moving on different paths (random) but	Shows particles in motion, they are moving on different paths (random) in both

Table 3.5 Continued

		together (coordinated movement)	only in one of the phases	phases
Particle motion related to temperature* (SPEED)	No movement indicated	Shows particles in motion but they are all moving at the same speed	Shows particles moving faster in one of the phases	Shows particles moving faster but distinctly in both phases (i.e. fast in liquid but faster in gas)
Changes in the balance between kinetic and potential energy* (UPWARD MOTION)	No gas bubbles	Bubbles appear at the bottom of the “pot” but nowhere else	Bubbles appear at the bottom of the “pot” and rise through the liquid water	Bubbles appear at the bottom of the “pot” and rise through the liquid water and then appear to break open at the surface and “disappear”

Table 3.5 Continued

“The temperature at the boiling point remains constant despite the continuous addition of energy.” (BOILING POINT)	No boiling point indicated or the temperature is shown as changing while the liquid is boiling	The boiling point is shown at some point during the animation	The temperature is shown increasing through the animation and stabilizes at the boiling point as the water begins to boil	The temperature is shown increasing through the animation and stabilizes at the boiling point as the water begins to boil. Once all the water has boiled and only gas remains, the temperature increases again
Interactions between particles in a liquid weaker than those in a solid; interactions	No particles shown	Particle proximity is the same regardless of phase	Liquid particles are close together (bonded) and seem to flow over one another	Liquid particles are close together (bonded) and seem to flow over one another AND

Table 3.5 Continued

between	OR	Gas particles are
particles are	Gas particles	far apart with
negligible in a	are far apart	little or no
gas*	with little or no	interaction
(PROXIMITY)	interaction	

*Adapted from the Level 4 portion of the phase change learning progression in Stevens et al, 2010

** Taken from Davis, Metcalfe, & Williams, 2005, p. 344

Student Questions Responses for WISE Module. Students spent approximately 30 minutes completing a 3 part modified version of the Phases of Matter and Phase Change module from the WISE website. While viewing information and animations, students were asked to respond to multiple choice and open-ended questions. All of the animations depicted molecular water as a single sphere. Each student worked individually answering questions. It was observed that there were varying degrees of discussion amongst students as to how to achieve a certain effect. Students' question responses were coded according to the rubric (Table 3.6). All questions were coded by the researcher and 20% were coded by a second researcher with an inter-rater reliability of 91.9%.

Table 3.6

Coding Rubric for WISE open-ended questions

Question	Sample Responses		
	0	1	2
1. What happened to the marked molecule when you added heat to the model?	Don't know OR Blank	Faster OR Further	Moves faster and/or breaks bonds with the molecules around it. Moves further away from the other molecules.
2. Define: Heat (thermal energy)	Opposite of cold OR When something feels warm OR Blank	Thermal to kinetic OR Molecules move faster OR Change in temp	a. the energy transferred as a result of a difference in temperature b. thermal energy that is absorbed and converted to kinetic energy by the substance it is added to. c. therefore, the molecules move faster*

Table 3.6 Continued

3. Define: Temperature (kinetic energy)	What you have when you are sick OR Blank	the degree of hotness of a body, substance, or medium (Macroscopic description only)	the degree of hotness of a body, substance, or medium; the average kinetic energy of the atoms or molecules of a substance*
4. Define: Liquid water (molecules)	Melted ice OR Blank OR Something you get out of the faucet	. a transparent, odorless, tasteless liquid OR definite volume but no definite shape (Macroscopic description only)	a. a transparent, odorless, tasteless liquid, a compound of hydrogen and oxygen, H ₂ O, freezing at 32°F or 0°C and boiling at 212°F or 100°C, b. definite volume but no definite shape c. molecules are bonded together but move fluid over each other* (does not have to be all of these)

Table 3.6 Continued

<p>5. CHALLENGE: The concepts in this page were not directly discussed in the previous steps. Use your prior knowledge in defining them. Boiling (phase change)</p>	<p>Very hot OR Blank</p>	<p>to change from a liquid to a gaseous state, producing bubbles of gas that rise to the surface of the liquid, agitating it as they rise. (Macroscopic description only)</p>	<p>to change from a liquid to a gaseous state, producing bubbles of gas that rise to the surface of the liquid, agitating it as they rise.* Molecules begin to move faster, breaking bonds between molecules by overcoming intermolecular forces and moving further away (does not have to be all of this but a good portion)</p>
<p>6. Boiling point (temperature)</p>	<p>When something gets hot and is thinking about</p>	<p>When water reaches 212°F (100°C) –or just before it does (The temperature only)</p>	<p>the temperature at which the vapor pressure of a liquid is equal to the pressure of the atmosphere on the</p>

Table 3.6 Continued

	boiling		liquid, equal to 212°F
	OR		(100°C) for water at sea
	Blank		level.*
7. What happened to the molecule that was added NEAR the others? Explain why this happened by referring to intermolecular forces.	Blank	Limited description/explanation	The NEAR molecule was attracted to the other molecules and forms bonds with its neighboring molecules. Intermolecular forces depend on proximity and the closer the molecules, the greater the intermolecular forces acting on them. The FAR molecule is not affected by intermolecular forces and therefore remains unbounded.
		OR	
		Lack of explanation	

Table 3.6 Continued

<p>8. How would the motion of the molecules change if you could add heat (like in the first model you investigated)?</p>	<p>It slows down OR Blank</p>	<p>Faster OR Farther OR Solid -> liquid</p>	<p>If we add heat to the model, we expect that the molecules will move faster and farther apart breaking some of the bonds. The solid would become a liquid.</p>
<p>9. What is an “intermolecular force”? Give an example for such a force from the dynamic model of liquid.</p>	<p>Irrelevant OR Blank</p>	<p>Intermolecular force is a force that exists between two molecules. (Answer with no example)</p>	<p>Intermolecular force is a force that exists between two molecules. The force (dotted line) between 2 blue balls in model. It causes the molecules to attract each other.</p>
<p>10. How would the motion of the molecules in the liquid state change if you could cool the model down?</p>	<p>It speeds up OR Blank</p>	<p>Liquid can become a solid (Macroscopic level only)</p>	<p>The molecules would move more slowly and move closer together. Liquid can become a solid</p>

Table 3.6 Continued

<p>11. How would the motion of molecules in the gaseous state change if you could cool the model down?</p>	<p>It would speed up OR Blank</p>	<p>Gas -> liquid only</p>	<p>We expect that the molecules would slow down and move closer together in a defined area. Gas could become liquid</p>
<p>12. Describe what happens to the gas molecules when pressed by a piston.</p>	<p>Blank OR Don't know</p>	<p>They are compressed (move closer together)</p>	<p>The gas molecules are pushed down into a smaller area. They move closer together and begin to move slower. (Pressure is increased)</p>
<p>13. Why do bubbles of vapor rise to the surface when a liquid is boiling?</p>	<p>Heat rises OR Blank</p>	<p>They are made of gas (or something similarly brief)</p>	<p>The pressure of the vapor in the bubbles is less than that of the surrounding water and therefore rise to the surface. (The molecules in the bubbles are less dense)</p>

Table 3.6 Continued

14. Based upon your previous answer, will it take longer to hard-boil an egg in the mountains than at sea level? Explain why or why not. Click the Panda icon for hints.	Blank OR No, it does not take longer	“Yes”, but No explanation OR “Yes”, Brief answer/explanation which may be incorrect	It takes longer because the boiling point of water is lower and therefore cooks an egg at a lower temperature which takes longer.
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*definitions from dictionary.com

Informal Student Interviews. Students were informally interviewed on Day 1 and Day 2 of the activity as they worked. The interviews were semi-structured and lasted 1-5 from minutes. Student responses were used to identify atomic misconceptions the students currently hold, document what they were thinking about as they worked, and their thoughts about the project itself. Student interviews were transcribed verbatim (52 pages) and analyzed for differences in classroom environment, activity, and nature of student reasoning and sense making.

Day 1 Student Questions:

1. What are you doing right now?
2. Did you learn anything new from the paper you read?
3. What are you planning to do next?

Day 2 Student Questions:

1. What are you doing right now?
2. Did you learn anything new from the module that you worked through?

3. What are you planning to do next?

Examples of other miscellaneous questions:

1. Is it easier to draw by hand or using a computer? Which one do you like more?
2. Do you think it's easier to draw it from scratch, or do you think it's easier to use the pictures?

Teacher Interviews. Teachers were interviewed for their overall impressions of the activity, their perceptions of the progress of their students during the activity, and their impressions of the Sci Vis curriculum. Teacher interviews were transcribed verbatim (17 pages total) and analyzed for differences in classroom environment, activity, and nature of student reasoning and sense making.

Classroom Observations and Student Videos. Each day of class was observed and videotaped. Classes were observed to develop an understanding of how students think about atomic structure in the context of the water boiling animation activity. Videos were taken to document teachers' instruction. Additionally, students in Group 3 videotaped each other during their group session explaining their animations to usually two other students in the heterogeneous (high, middle, low pretest score) groups. The audio from the student videotapes during group work was transcribed verbatim.

Summary

In this chapter, the methods for gathering data on a water boiling activity in two teachers' classrooms, with two levels of Sci Vis classes, was described. Data collected from students included a pre/posttest, WISE module questions, student project, and informal student interviews. In particular, the development of the Student Project Rubric using ideas set forth in the phase change learning progression is discussed.

In Chapter Four, 35 students in the three groups of the two teachers are followed to investigate if student-generated animations enhance student understanding of water boiling.

CHAPTER FOUR: DO STUDENT-GENERATED DIGITAL ANIMATIONS ENHANCE STUDENT PROGRESS ALONG A PHASE CHANGE LEARNING PROGRESSION? A STUDY OF 35 STUDENTS IN SIX SCIENTIFIC VISUALIZATION CLASSES

Abstract

The particulate nature of matter, with emphasis on size, phase, composition, and motion of atoms and molecules, is fundamental to chemistry. It also is an area of chemistry with well documented misconceptions. Despite a large body of research focused on ways to address students' conceptual misunderstandings, they persist. Visualizations, mostly in the form of illustrations, are used liberally throughout chemistry textbooks with the goal of enhancing student understanding of sub-microscopic phenomena. Newer textbooks also employ links to web-based animations. Research has shown that viewing animations can result in greater student understanding. There also is some promising research on more active learning strategies such as learner-generated drawing strategies, which may give students the opportunity to think more deeply about chemistry phenomena and enhance their conceptual learning. This dissertation research investigates students' positioning along a phase change learning progression as a result of constructing or creating digital animations. In this study, 35 students (who fully engaged in the activity, a subset of 94 total participants) in six Scientific Visualization classes of two instructors constructed or created an animation of water boiling. Students in two introductory classes (Sci Vis I) constructed animations with pre-existing images; students in four advanced courses (Sci Vis II) created original animations, two classes of which had an additional day working in groups. The research questions guiding this study are: *Do student-generated computer animations enhance*

student conceptual understandings as suggested by Van Meter and Garner's Generative Theory of Drawing Construction (GTDC)? To what extent do student-generated animations relate to elements in the phase change learning progression and/or the provided text? Does the process of students generating animations affect specific misconceptions? Data analyses of pre/posttests, conceptual question responses, and student-created animations indicate that for students who cognitively engage, creation of digital animations can enhance conceptual learning, resonant with Van Meter and Garner's GTDC. Additionally, animation quality is linked to achievement. Students have many misconceptions about water boiling, and those that are addressed by creating animations were specifically related to the motion of the animation. Implications regarding ways to enhance student learning are discussed.

Introduction

Physics, chemistry, biology, and environmental science are the typical STEM areas in which high school students are required to take courses and consequently shape their views of STEM as a whole. Chemistry is a core STEM topic that many students shy away from because of the assumed level of difficulty based on the current way it is taught (Johnstone, 1997). The exams in chemistry often contain static images of atoms and molecules that students must interpret to answer the assessment questions. In North Carolina, Virginia, and New York, approximately one-third of the chemistry end of course exam assesses knowledge of atomic/molecular structure and behavior (e.g. NCDPI, 2010). Due to the prevalence of this topic, much time and attention in the classroom is spent on atoms and molecules, but mostly from the perspective of mathematical algorithms (Habraken, 2004). This singular approach to teaching atomic/molecular structure can contribute to misconceptions held by students.

To assist students, research in this area has employed a learner-generated drawing strategy (Van Meter et al., 2006) to facilitate scientifically correct conceptions through visualization. Learner-generated drawings differ from previous strategies because the student is responsible for every aspect present in the visualization which is different from simply viewing a visualization created by another. In this strategy, students create a pictorial representation of the phenomena they are learning about and, most importantly, are responsible for making those visualizations representational of the phenomena (Van Meter & Garner, 2005). This generative theory is a reflective method for integrating verbal and nonverbal representations. In this recursive process, students make changes to their drawing each time the verbal representation they are reading does not match their nonverbal

representation (e.g. water molecule) they are constructing (Van Meter, 2001). The goal of this process is to enhance students' understanding of atoms and molecules through student-generated drawings. In Van Meter and Garner's (2005) research studies using this strategy students read a short passage of text and then illustrated the text in two drawings with pencil and paper. Multiple trials have shown that the intervention helps increase student understanding. This study set out to investigate a similar process, with students using computer software to generate their drawings in the form of an animation.

Stevens, Delgado, and Krajcik (2010) have worked on a series of learning progressions with relation to how students learn about aspects of atomic-molecular theory through interviews with students that include drawings of molecules. The purpose behind learning progressions is the idea that there may be an order to the way students learn, in this case, about phase changes at the macro and microscopic level. Understanding patterns to this order, or learning progressions, potentially reveals linkages that could enhance student understanding. Additionally, it could help teachers and curriculum developers to organize curricula and standards around those steps or linkages to maximize learning. Stevens et al. suggest student drawing as a strategy to help students connect content. Further, it is the reflective process encouraged by Van Meter and Garner's (2006) drawing theory that engages students' metacognitive skills as they create drawings and flip back and forth between the text and their drawing, that seeks to help students gain more fully developed ways of thinking.

Literature Review

Visualizations are important components of learning and understanding science. In subjects like chemistry, they become vital, given that so much of the subject deals with ‘invisible’ phenomena that must be represented with visualizations. In science education, a visualization can be defined as “a specific form of external representation that is intended to communicate information by using a visuo-spatial layout of this information and that is processed in the visual sensory system” (Scheiter et al., 2009, p. 68). External visualizations are those that we typically think of and use, yet there also are internal visualizations. Internal visualizations are those that are created in our mind. Many refer to them as mental models or “a special kind of mental representation, an analog representation, which individuals generate during cognitive functioning” (Vosniadou, 1994, p. 48). Reisberg (1997) further divides visualization into three categories; visual perception, visual imagery, and spatial imagery. For the purpose of this paper, the term visualization will be used generally and without categories.

The ability to create, manipulate, and explore visualizations in one’s mind is a valuable skill, particularly when students are creating their own drawings. Psychology refers to this skill as spatial ability and research has found high correlations between this skill and achievement among college chemistry students (e.g. Carter et al., 1987; Pribyl & Bodner, 1987). In fact, spatial relation is one of the many factors that sets visual representations apart from verbal representations (Scheiter et al., 2009). Beyond its importance in achievement, spatial ability has been linked to other cognitive abilities such as logical reasoning. It is a way for students “to consolidate and clarify ideas...[and] an important memory strategy” (Baker & Pilburn, 1997, p. 178). Finally, spatial skills are another avenue to help students to

solve problems. Schools traditionally teach the analytical, linear method for solving problems and shy away from the more holistic paths that make use of spatial skills (Baker & Pilburn, 1997). And since spatial ability seems to be such a strong component of science and helpful in problem solving, it makes sense that it be a skill that is fostered in schools (Bodner & McMillen, 1986; Zhang, 1997).

Cognitive Engagement

Many classroom teachers attribute student lack of participation to apathy. However, Fredricks, Blumenfeld, and Paris (2004) introduce the concept of school engagement as “an antidote to declining academic motivation and achievement” (p. 59). In particular, they discuss *cognitive engagement*, defined as “thoughtfulness and willingness to exert the effort necessary to comprehend complex ideas and master difficult skills” (p. 60). This third type of engagement discussed by Fredricks et al. is most relevant to the complexity of animation creation. The researchers discuss cognitive engagement as the self-regulation of metacognitive processes. Van Meter (2001) described a similar process as self-regulation when students were doing think-alouds as they drew.

Chemistry Models

Science classrooms, especially chemistry classes, make extensive use of visualizations. A specific form of visualization, classroom model, is often used to display phenomena too small, too large, too fast, or too slow (e.g. ‘invisible’) to display at human-scale in the classroom. In chemistry, models of atoms and molecules are extremely important. The term ‘model’ is used to describe a variety of objects and has no true agreed upon definition. Halloun (2006) presents a sample list of definitions used throughout the last two decades but it is clear there is not a consensus. For the purposes of this work, only

analogical and mental models will be discussed. Harrison and Treagust (1996) define analogical models as those that “have one or more of the target’s attributes represented in the analog’s concrete structure” (p. 512). These are the models shown to and produced by students (a drawing of a water molecule or classroom model of an atom). Vosniadou (1994) defines mental models as those that “refer to a special kind of mental representation, an analog representation, which individuals generate during cognitive functioning” (p.48). These are the models that the students first create in their minds and then use to create the analogical models on paper or computer. Furthermore, models are distinct from other visualization in their purpose. As Schwarz et al. (2009) point out, the true power behind models are their ability to help students predict, explain, and create dynamic knowledge.

Gilbert (1993) suggests that models are an important tool for teaching and learning, yet Harrison and Treagust (2000) caution that using models is not without significant problems. These problems stem from the inability to predict how students will interpret models and their ability to learn the modeling language. Therefore, they “argue that teachers should teach modeling skills, encourage students to use multiple rather than isolated analogical models, and take the time to discuss and critique the models used in class” (p. 353).

Models in the classroom can either be 2-D or 3-D. Physical 2-D models are typically anything drawn or printed on paper or stock, projecting either two or three dimensions of the represented object, while 2-D computer modeling software works on a similar “virtual paper surface”. 3-D physical models are, as stated, three physical dimensions while 3-D computer models allow you to construct in all three dimensions (virtually) but are still projected in only two dimensions. Harrison and Treagust (2000) explored the use of modeling throughout the

year in a chemistry class. The majority of the models created by the case study student were 2-D paper-based static drawings of atoms and molecules (with limited use of a modeling kit being the expectation). Over the course of the year, the student developed into a level 2/3 modeler (using Grosslight et al. (1991) terminology) with only a few remaining misconceptions about the structure of the atom, and the ability to use models to predict certain properties. Although 2-D paper-based static drawings have been shown to be useful ways for students to express models, the advent of computers has created a shift towards 3-D computer modeling software. Wu, Krajcik, and Soloway (2001) reported on the use of *eChem* as a way to help students understand atoms and molecules. They found that the 3-D static computer modeling software can be a useful means of helping students generate appropriate mental models. Finally, the more traditional models are 3-D physical (concrete) models; such as the modeling kits, marshmallows and toothpicks, play dough, etc. that students can physically manipulate. Hyman (1982) found that regardless of whether student manipulate or simply watched a demonstration of these models, it increased their spatial abilities.

Static vs. dynamic

In addition to models, other visualizations in 2-D and 3-D—both static and dynamic—are prevalent in science classrooms. They come in textbooks, PowerPoint presentations, overhead transparencies, in videos and computer software. Hoffler and Leutner (2007) conducted a meta-analysis of 26 studies comparing static and dynamic visualizations. They compiled a list of situations when dynamic visualizations may be better than static to enhance student learning and vice-versa. In a study by Tversky, Morrison, and Betrancourt (2002), animation was not necessarily a better media in all cases, a study by

Hegarty (2004) determined that dynamic visualization was better in some cases. Marbach-ad, Rotbain and Stavy (2008) took the question a step further and tested the effectiveness of computer animation and illustration for learning about molecular genetics. They found that the computer animation better aided students in understanding the dynamic processes. Therefore, it stands to reason that computer animation may be useful in enhancing student understanding of other dynamic, molecular processes.

Animations in chemistry

Wu and Shah (2004) completed a review of several studies using animations to help students understand chemistry content. They found that in studies where students viewed animations, those students outperformed their counterparts that did not view animations. Zhang and Linn (2011) combined students viewing animations as part of the WISE module with drawing and found that students who drew along with viewing animation showed higher gains. However, Chang et al. (2010) is the only currently existing study in which students create digital animations concerning the particulate nature of matter. The groups in their study varied in the steps of the modeling process they used (design, interpret, evaluate). Overall, they found that the hands-on nature of scientific modeling and the constant peer evaluation and feedback helped students deal with their misconceptions and promote conceptual change (Chang et al., 2010).

Theoretical and Conceptual Frameworks

A number of theoretical and conceptual frameworks and pedagogical strategies have been used to explore the relationship of the visualization strategies and their effects on student understanding. This study makes use of a portion of Stevens, Delgado, and Krajcik's

(2010) learning progression for the nature of matter as a conceptual framework. This learning progression was used to map students' progress and provide insight into the connection between the students' animations and the understanding of atomic-molecular theory. Van Meter and Garner's (2005) generative theory of drawing construction was used as a theoretical framework to help gain an understanding of the efficacy of student-generated animations and the cognitive processes students may experience while creating their animations.

Learning Progressions

Smith et al. (2006) describe a learning progression for grades K-8 detailing specifically how conceptual understanding of atomic and molecular level phenomena are linked through progression of conceptual development. A progression of conceptual understandings around atomic-molecular theory includes related misconceptions that can be understood as either intermediate developments along the progression or deviations from the progression that impede movement along the progression.

Stevens et al. (2010) have expanded and extended the Smith et al. (2006) learning progression for grades 7-14. Their model is much broader but more sophisticated than the original Smith et al. learning progression. They used Smith et al.'s upper elementary grades model for the lower 'anchors' and national standards documents (AAAS, 1993; NRC, 1996) and nanoscale science and engineering learning research (Stevens et al., 2010) for the upper 'anchors'. These upper and lower anchors guide the principles and theories that the students can be expected to learn but do not suggest that students go through a ladder-like path from the lower to upper anchors. The learning progression helps define to what extent students should know the content (Stevens et al., 2010).

Learning progressions act as a guide for educators suggesting levels through which students may understand specific content. To develop their learning progressions, Stevens et al. (2010) developed a set of open-ended questions that students answered in a semi-structured interview with the researchers. As part of the interview, students were asked to “draw their model of an atom and explain it” (p. 693). Depending on the student’s drawing, they were asked additional questions (e.g. number of sub-atomic particles). This demonstrates the value of students’ drawings not only in the development of a learning progression, but also in assessing their current understanding.

Generative Theory of Drawing Construction

Learner-generated drawings are student created visualizations that are meant to look like the object (or idea) that they represent (Van Meter & Garner, 2005). It is a strategic process “because drawing is goal-oriented, improves knowledge organization, and can improve learning outcomes” (Van Meter et al., 2006, p. 143). Furthermore, drawing has the potential of integrating verbal and nonverbal representations because the drawing can be done in response to written text (Van Meter & Garner, 2005). The benefits of using drawing as opposed to exclusively written or verbal methods lies in a human’s capacity for pictorial memory. According to Paivio’s (1986) dual coding theory, pictures “yield a perceptual code and a verbal code in memory, which doubles the chances of retrieval” (Sawyer, 2006, p. 284). Therefore, it seems logical that student creation of drawings will improve student understanding of the selected topic.

The generative theory of drawing construction is an extension of Mayer’s Generative Theory of Textbook Design (Mayer & Sims, 1994; Mayer et al., 1995). The GTTD discusses the relationship between illustrations in textbooks and the corresponding text. Mayer et al.

found that students received higher scores when illustrations were accompanied by text, in close proximity. The GTTD asserts that it is the selection of words/images, organization of words/images and finally, the integration of words/images that help students gain information from illustrations in textbooks. In a similar way, learner-generated drawing supports student learning in three ways (Van Meter et al., 2006, p. 148): “1) constrain the construction of drawings; 2) prompt checking the accuracy of constructed drawings; 3) and/or direct learners’ attention to key elements and the relationships amongst these” (p. 148).

The generative theory of drawing construction is similar to the process of modeling. Both modeling and drawing encourage students to create visualizations of a specific topic, assess and redesign that visualization, and pay close attention to details of the visualization. In other words, both processes have an imbedded cycle of reflecting about the thinking going into the visualization, which modeling experts call meta-modeling (Schwarz & White, 2005).

In an effort to avoid the confusion and overburden that can potentially occur due to the generative process, Van Meter and Garner (2005) purposefully reviewed 30 articles (15 on classroom application and 15 dealing with empirical research). Their goal was to identify ideal characteristics to create a best practices framework for incorporating drawing in the classroom. They state, “when drawing, a learner must select to-be-represented elements and organize them into a symbolic verbal representation” (p. 315). This leads to three cognitive processes that Van Meter and Garner (2005) adapted from Mayer’s Generative Theory of Textbook Design (e.g. Mayer et al., 1995); selection, organization, and integration. These three processes remain constant throughout Mayer’s GTTD, Van Meter and Garner’s GTDC, and this study in meaning. However, the “steps” of the cognitive processes differ in each case. For example, Mayer defined selection as choosing elements from the nonverbal

representation (picture) but Van Meter and Garner started with only text making the selection process the choosing of elements from verbal representation.

Research Questions

This research investigates the change in student understanding along a phase change learning progression as a result of assembly of digital animations or original creation of animations with students in science visualization classrooms. Therefore, the research questions guiding this study are:

1. Do student-generated computer animations enhance student conceptual understanding as suggested by Van Meter and Garner's (2005) Generative Theory of Drawing Construction (GTDC)?
2. To what extent do student-generated animations relate to elements in the phase change learning progression and/or the provided text?
3. Does the process of students generating animations affect specific misconceptions?

Methods

Setting

Two senior high schools in a southeastern state in the US participated in this study. These schools were selected on the basis of school, teacher, and course (Scientific Visualization I & II) availability, and therefore represent a convenience sample. Both schools operate on a block schedule, reside in the same county and have similar student demographics. The study took place in two Scientific Visualization I (Sci Vis I) classes and four Scientific Visualization II (Sci Vis II) classes (each teacher taught one Sci Vis I and two

Sci Vis II sections). In Sci Vis I, students learn 2-D and 3-D image software such as ArcView™, 3ds Max® and Flash™, and use that software to create basic visualizations. In Sci Vis II, students further develop their understanding of these software programs through the production of animations and multiple representation projects. These courses were chosen to help control for technology skill level among students and help isolate student understanding as the dependent variable.

Participants

There were two teachers at two different high schools (see Table 4.1). Each teacher implemented the project in their three classes. The three classes at these two schools enroll between 12 and 19 students. The students were 9th, 10th, 11th, or 12th grade students with varying backgrounds in science. Of the 94 students who participated in the project, 35 were selected for this study based on level of participation. Each of the selected students completed all aspects of the water boiling animations activity with scores above zero on all measurements. Demographic information was taken from each student and each school allowing for comparison based on grade level, gender and science courses taken (see Table 4.1). Students worked independently so that each student's progress may be assessed.

Table 4.1

Description of Subset Participants

<i>Teacher 1</i>	Yrs Teaching – 33 years	<i>Teacher 2</i>	Yrs Teaching – 12 years
<i>(Ms. C)</i>	Yrs Teaching Sci Vis – 12 years	<i>(Mr. T)</i>	Yrs Teaching Sci Vis – 12 years
	Degrees:		Degrees:
	-BS in Biology and Chemistry		-BS in Physics
	-MA in Secondary Science		-MS in Materials Science and
	-MA in School Administration		Engineering
<i>Group 1</i>		Males-5	
		Females-4	
		9 th grade – 1	
		10 th grade – 2	
		12 th grade – 3	
		unknown – 2	
<i>Group 2</i>		Males-13	
		Females-1	
		10 th grade – 2	
		11 th grade – 7	
		12 th grade – 4	
		unknown – 1	

Table 4.1 Continued

	Males-12
<i>Group 3</i>	10 th grade – 2
	11 th grade – 5
	12 th grade – 5

Lesson Design

The water boiling animation activity lasted 2-3 days. The schools were on block schedule so each class period lasted 1 hour and 30 minutes in length for a total of 3 - 4.5 hours. The groups proceeded as follows (see Table 4.2 for summary):

Day 1: Students received text explaining what happens as water boils at the macroscopic and molecular levels and constructed/created an animation based on that text.

- Group 1 - Students constructed a short animation using pictures (.jpg) of elements (water, molecules, pot, etc.) provided in a digital folder.
- Group 2 - Students created a short animation using their own original elements.
- Group 3 – Students created a short animation using their own original elements.

Day 2: Students spent 30 minutes reading through the Phases of Matter and Phase Change WISE module, watched several animations, and were asked to answer embedded online questions. Then students were asked to complete their animations, keeping in mind the animations they watched in the WISE module.

Day 3: Group 3 students peer evaluated their animations and discussed changes that would make them more closely match the provided text. Each group had a Flip Camera to record the student who was talking.

Table 4.2

Study Design

Group	Steps of Activity						
1	Pre-test	Construct*	WISE Module – Phases of Matter and Phase Change	Revise animation			Post- test
2	Pre-test	Create**	WISE Module	Revise animation			Post- test
3	Pre-test	Create**	WISE Module	Revise animation	Group discussion (groups of 3 based on pretest)	Create consensus animation	Post- test

* construct – students use elements (molecules, pot, water, steam, etc.) that have already been created and are supplied as .jpg to put together an animation that portrays their interpretations on the important ideas from the text

** create – students open a new document in 3ds Max® drawing each element and putting them together to create an animation that portrays their interpretations on the important ideas from the text

Data Sources and Analyses

Pre/Posttest. The pretest and posttest was composed of 30 multiple-choice items; 12 were drawn from Version 1 of the Particulate Nature of Matter Assessment (Yeziarski & Birk, 2006), 3 from released Chemistry and Physical Science end-of-course standardized tests (NCDPI, 2010) and 15 from Smith et al.'s (2006) learning progression (see Appendix C). This pre/posttest had a Cronbach α of 0.65 with this sample of high school students. Test items measured students' factual knowledge of atoms, molecules, and phase change and identify specific common misconceptions students may hold. The pre/posttests were analyzed with a repeated measures ANOVA to determine gains in overall understanding of phase change among students and then items were separated by categories and specific misconceptions to identify differences among students.

Table 4.3

Description of Data Sources

Data Source	Description
Pre/Post Test	30 question multiple choice test
Student animation scores	Animations were scored with a rubric (Albert, Wiebe, & Blanchard, 2012) based on the phase change learning progression (Stevens et al., 2010)
Student question scores	Short answer and multiple choice questions within the WISE Module based on phase change
Student Informal Interviews	Students were asked questions while they worked on days 1 and 2 (e.g. “What are you doing now?” and “What are you planning to do next?”)

Sample Test Questions (Yeziarski & Birk, 2006):

A pot of water is placed on a hot stove. Small bubbles begin to appear at the bottom of the pot. The bubbles rise to the surface of the water and seem to pop or disappear.

What are the bubbles made of?

- A. heat
- B. oxygen or hydrogen
- C. air
- D. oxygen and hydrogen
- E. steam**

Which of the following statements is incorrect?

- A. **Water molecules move at the same speed in the solid, liquid, and gaseous phases.**
- B. Water molecules move the fastest when they are in the gaseous phase.
- C. Water molecules in the solid phase vibrate.
- D. Water molecules in the liquid phase move faster than molecules in the solid phase.
- E. Water molecules in solid phase are in the form of ice.

Student Projects. Students were given a selection of text (see Appendix D for complete text) and asked to construct/create an animation about water boiling from the description in the text. They were told that someone should be able to write the text after viewing their completed animation. The projects were completed in two different formats. Sci Vis I students used .JPEG images provided to them in a folder on their network to incorporate into an animation in CorelDRAW®. The images themselves were 21 .JPEG files that included various pots at different stages of boiling, water molecules, thermometers, water, and bubbles. These images all corresponded to items mentioned in the text. Both classes had previously completed at least one animation using CorelDRAW® but Ms. C had her students complete a quick (10-15 min) tutorial because she believed students needed a refresher on using the animation feature. Students were instructed to use the provided images for the majority of their animation but were allowed to draw in arrows, add text, etc. to supplement the images.

Students in the Sci Vis II classes also were asked to complete an animation from the text provided in a way that someone would be able to create the text from their animation. These students used 3ds Max® and created original animations. Students in both groups were provided technical support only by their teacher and were asked to direct all conceptual or project specific questions to the researcher. In all classes, students worked individually but there were varying degrees of discussion in each class amongst students as to how, for example, to achieve a certain effect with the animation, such as making the air bubbles move. Students' projects were graded according to a rubric (see Appendix G) developed by Albert, Wiebe, and Blanchard (2012) that is based on the nature of matter learning progression anchors and levels developed by Stevens et al. (2010). Rubric scores can range from 0-21, with a maximum of 3 points on each of 7 items. All projects were coded by the researcher and 20% of project randomly selected were coded by a second researcher with an inter-rater reliability of 85.3%.

Student Question Responses for WISE Module. Students spent approximately 30 minutes completing a 3-part modified version of the Phases of Matter and Phase Change module on the WISE website. While viewing information and animations, students were asked to respond to multiple choice and open-ended questions. All of the animations depicted molecular water as a single sphere. Each student worked individually but there were varying degrees of discussion amongst students as to how to achieve a certain effect. Students' responses were coded according to the rubric (see Appendix F). All questions were coded by the researcher and 20% of students randomly selected were coded by a second researcher with an inter-rater reliability of 91.9%.

Interviews. Students were interviewed as they worked during Day 1 and Day 2 of the activity. The interviews were informal and semi-structured, lasting from 1-5 minutes. They were used to identify atomic misconceptions the students currently held, document what they were thinking about as they worked, and their thoughts about the project itself. Teachers were interviewed for their overall impressions of the activity, progress of their students during the activity, and thoughts about the Sci Vis curriculum. Student and teacher interviews were transcribed verbatim and analyzed for differences in classroom environment, activity, and nature of student reasoning and sense making.

Questions used on Day 1 &2:

1. What are you doing right now?
2. Did you learn anything new from the paper you read (or WISE module)?
3. What are you planning to do next?

Examples of other miscellaneous questions:

1. Is it easier to draw by hand or using a computer? Which one do you like more?
2. Do you think it's easier to draw it from scratch, or do you think it's easier to use the pictures?

Classroom Observations. Each class period was observed and videotaped. Classes were observed to develop a deeper understanding of how students process and demonstrate their understanding of atomic structure. Classroom videos were recorded to document instruction in the two teachers' classrooms. Field notes were used to triangulate with student interviews and projects.

Student Exemplars. Of the 35 students selected for this study, 5 students were

selected as exemplars. Satisfactory (Sat.) scores on both the WISE and project are those with 10 or more points. Unsatisfactory scores (Unsat.) on both the WISE and project are those with 6 or fewer points. Each exemplar (see Table 4.4) is representative of a category of student found to exist within the set of 35 selected students (Sat./Unsat. WISE Score, Sat./Unsat. Project Score, and +/-Gain on Pre/Posttest).

Table 4.4

Summary of data from student exemplars

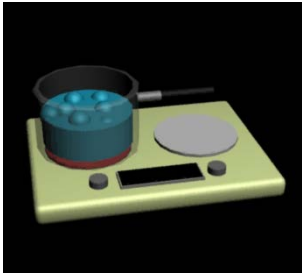
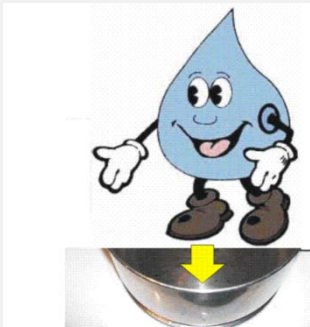

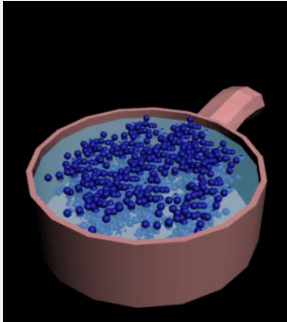
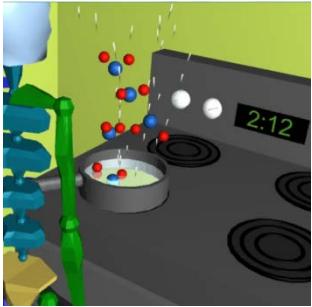
Student	Screenshot from Student Project	Description of Student Project	Project Score	Pre Test	Post Test	WISE Score
C1-10 (Sat. WISE/ Unsat. Proj/ -Gain)		A pot on a stove with water, red burner beneath, and spherical objects bobbing within the water	2	18	17	13
C4-1 (Unsat. WISE/ Unsat. Proj/ -Gain)		Water droplet moves across screen into pot then pot displayed with water boiling and then steam	4	13	12	5

Table 4.4 Continued

<p>C3-2 (Unsat. WISE/ Sat. Proj/ +Gain)</p>		<p>A pot sits on top of fire. Fire flickers and water in pot ripples. Shapes flying out of pot</p>	8	13	15	2
<p>T3-7 (Sat. WISE/ Sat. Proj/ +Gain)</p>		<p>Circles start at the bottom of a pot of water, break the surface of the water and then disappear</p>	8	18	20	7
<p>T3-2 (Unsat. WISE/ Sat. Proj/ -Gain)</p>		<p>Animation “flies” over to pot with water in it. Shapes start to fly out of pot (maybe bubbles) then molecules fly out of pot and separate</p>	14	20	18	6

Findings

Do student-generated computer animations enhance student conceptual understandings as suggested by Van Meter and Garner's (2005) Generative Theory of Drawing Construction (GTDC)?

The repeated measures ANOVA revealed no significant difference in gain scores across activity groups [$F(2,32) = 1.839, p=0.175$] suggesting little change in students' conceptual understanding. However, other qualitative and quantitative differences were noted among the groups. As indicated in Table 4.5, students who did well on both their project and WISE module questions did not vary much in their pre/post test scores (gain scores are shown in parentheses in Table 4.5). Although there were a limited number of students in each category, the table suggests that while there are some positive gains and negative gains in all categories, the Satisfactory WISE score/Unsatisfactory project score seems to be the second best group. Also, three of the students in Table 4.5 discussed molecules during their interview, but only one (C3-8) actually included molecules in his animation.

Student animations varied in detail and accuracy, yet several trends emerged. Most students only included macroscopic characteristics (i.e. the pot, water, and stove). Table 4.6 provides exemplars of what students talked about when asked what they were working on in their animations. A majority of the students (58%) only spoke of the technical/software aspects of the project during informal interviews. One student stated, I'm "trying to apply a spray and apply a snow effect to this cylinder...to imitate boiling water." When interviewed about the progress of their project, 75% of students with Satisfactory Project Scores talked only about the technical aspects of the project. Interestingly, 75% of students with

Table 4.5

*Project Scores vs. WISE scores**

		PROJECT SCORES	
		SATISFACTORY	INCOMPLETE / UNSATISFACTORY
WISE QUESTION SCORES	SATISFACTORY	C1-2 (0)	C4-11 (2)
		C3-8 (-1)	C1-10 (-1)
		T3-5 (0)	C1-16 (4)
		C1-18 (2)	T1-12 (-1)
			C1-11 (4)
	INCOMPLETE / UNSATISFACTORY	T3-4 (-2)	C4-14 (-5)
		C4-4 (5)	C4-2 (1)
		T3-2 (-2)	T4-6 (-1)
		T3-11 (-2)	C4-1 (-1)
		T4-7 (-1)	C3-11 (-3)
	C3-13 (-3)		

*Student codes are shown above with pre/posttest gains in (). “Satisfactory” scores are 10 and above.

“Unsatisfactory” scores are 6 and below.

Unsatisfactory Project Scores talked mostly about the content. This suggests that students spent a large amount of their time thinking about content instead of what needed to go into their animation. This further suggests that students may not have been secure in their conceptual understanding if they needed to discuss it.

Table 4.6

Exemplars of students describing key elements from the water boiling animation activity

Student	Quotation
C1-10	“Making bubbles move faster.”
C4-1	“So, first you get the water out of the faucet or whatever and then there’s the little guy. He’s making his way to the pot. He’s getting closer. Then he jumps it. And then there he is in the water. Then the water reaches the temperature and then starts to boil. Then steam comes and you put him in a little cup thingy. Then that’s the temperature at the end. It’s hot.”
C3-2	“Um, I’m gonna try to add some bubbles. Then I’m gonna add like a skillet pot to like make a scene with it.”
T3-7	“Um, I’m trying to do like a particle system right now. But I made a pot and I put some water in it, and I’m just trying to mess around, maybe put bubbles in it.”
T3-2	“I like the little, uh, circles in the pot that boiled when you clicked the temperature. As child...as childish, as like silly as it was, I kind of liked just clicking it.”

Every single student started with either the stove (even though the stove was not mentioned or required) or the pot, added water, and then began to add effects and details. Van Meter and Garner (2005) refer to this as *the selection of key elements* which are then organized and integrated. Figure 4.1 shows some of the changes made between Day 1 and

Day 2. This student (T1-5) started with a thermometer only at the end of the animation but then seems to have decided to add it throughout the animation. However, the red on the thermometer that might indicate a temperature change does not appear to change. The text does indicate a temperature change suggesting that the student knew the temperature should change and either did not know how or did not have time to change the levels on the thermometer in her animation. The text also indicates that the student does not understand the composition of the bubbles. She indicates that bubbles form, pop and then steam forms. This shows a lack of conceptual understanding regarding the composition of bubbles.

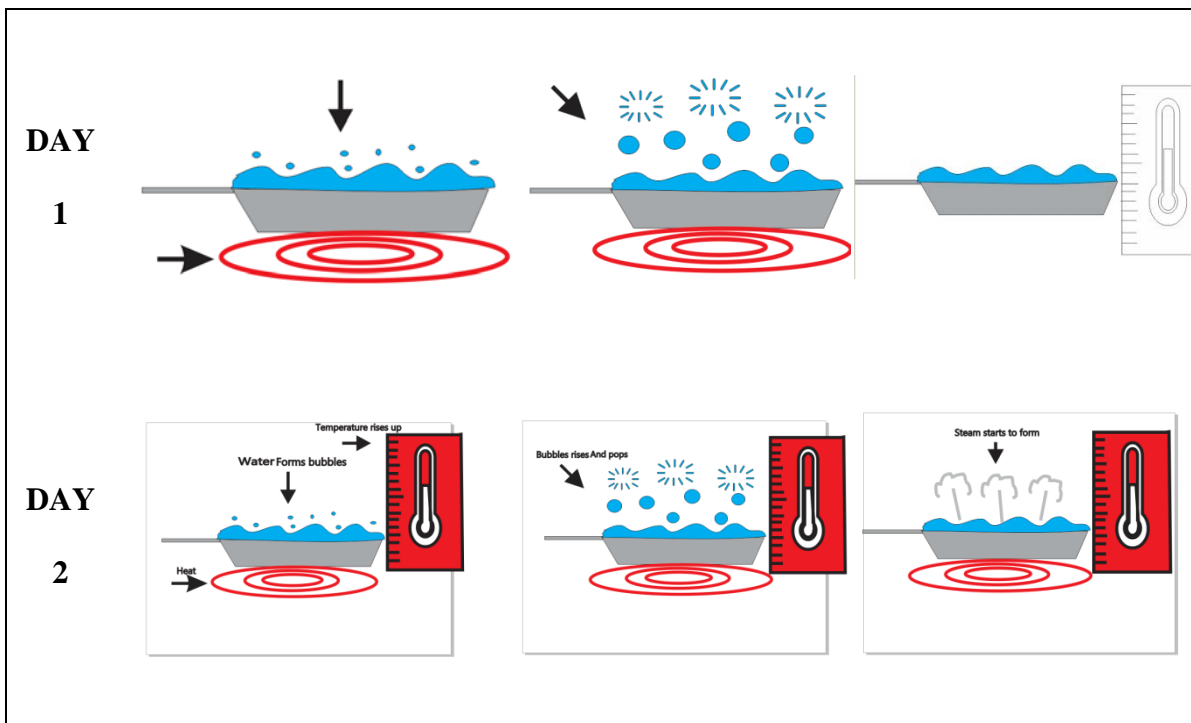


Figure 4.1. Examples of a student's (T1-5) work at the end of Day 1 and Day 2.

To what extent do student-generated animations relate to elements in the phase change learning progression and/or the provided text?

The students' animations were coded to identify which properties were present using the student project rubric (Albert, Wiebe, & Blanchard, 2012). The rubric identifies elements from the phase change learning progression (Stevens et al., 2010) such as the use of particles (shapes) to represent water in the gas and/or liquid phase. Students tended to focus on one level (macro- or micro-) or the other but rarely used both in a single animation. Of the 35 students in this study, 22.9% included molecules while 40% included shapes interpreted as particles. This suggests that many students were not thinking about water boiling at a molecular or particulate level despite every effort to encourage this level of thinking.

Students who constructed animations from supplied images, Group 1, did not show as much sophistication in their animations as those who created original animations (see C4-2 & T1-2 in Table 4.7). Table 4.8 shows that only one student in Group 1 used motion with regards to the molecules or particles displayed and that student only received a 1 out of 3 for motion suggesting an incomplete conception of molecular motion or an inability to properly animate it.

Table 4.7

Examples of researcher coding of student-generated animation data

Student	Group	SHAPE	PARTS	MOTION	SPEED	UPWARD MOTION	PROX-IMITY	TOTAL
C1-2	2**	2	1	1	1	2	1	8
C3-11	3**	1	0	3	1	3	0	8
C4-2	1*	1	1	1	2	2	1	8
T1-2	1*	1	1	0	0	2	1	5
T3-4	3**	2	2	2	2	2	1	11
T4-2	2**	0	0	0	0	0	0	0

* Students used supplied images to construct their animation.

** Students created original animations

Table 4.8 demonstrates that students in Group 3, those who created original animations and discussed them in groups, outperformed Groups 1 and 2 in most categories and overall score. The exceptions are PARTS and UPWARD MOTION for Group 1. Group 1 was given a folder containing pictures depicting pots, molecules, water, steam, and bubbles in various forms. The inclusion and PARTS and UPWARD MOTION for Group 1 translates into the use of molecules instead of particles (they were only given molecules) and bubbles moving upward, which were prevalent in the images they received.

Table 4.8

Summary of animation project rubric data by group

	SHAPE	PARTS	MOTION	SPEED	UPWARD MOTION	PROXI- MITY	PROJ TOTAL
Group 1							
Raw Sum*	7	8	1	1	21	6	
	N=9						
Group 1 Avg	0.78	0.89	0.11	0.11	2.33	0.67	5.33
Group 2							
Raw Sum*	15	10	10	8	20	11	
	N=14						
Group 2 Avg.	1.07	0.71	0.71	0.57	1.43	0.78	5.57
Group 3							
Raw Sum*	24	22	18	13	20	17	
	N=12						
Group 3 Avg.	2.00	1.83	1.5	1.08	1.67	1.42	9.92

*Raw sums are the sums of the total points each student received in the category. Maximum raw sum would be N*3 as each category has a maximum of 3 points per student.

Throughout both days of the water boiling animation activity, the researcher walked around the classroom and informally conducted semi-structured interviews, probing students' thinking about the structure of the activity and the use of animations, in general. Table 4.9 provides exemplars of these responses. Several commented that the animations in the WISE module prompted them to change something in their own animation (see C1-10 and T3-7 below).

Table 4.9

Exemplars of students describing their reaction to aspects of the water boiling animation activity

Student	Exemplars of student responses to researcher
C1-10	<p>Researcher: "Did any of the animations make you want to change anything in yours?"</p> <p>C1-10: "Yeah, 'cause they had it moving faster than mine did." (student referring to bubbles)</p>
T3-7	<p>Researcher: "Did [the WISE module] make you want to change anything in your animation?"</p> <p>T3-7: "Um, not yet but it may. I'm still just trying to make it look as realistic as I can."</p>

Does the process of students generating animations affect specific misconceptions?

Throughout the assignment, many students commented that they liked the assignment and/or the animations present in the WISE modules. One student said,

pictures would work but I think the animations work better...because you can see like what...like the animations give you more detail on what's going on...because a picture is just a still image and with the animation I can make things move and go through a process and more easier to understand.

In this assignment, students were asked to demonstrate the process of water boiling. The animations inherently force students to address the motion of objects such as bubbles, water, and molecules. Therefore, the results in Figure 4.2 suggest that conceptions related to motion and composition were most positively affected by the assignment. Also, students in Groups 2 and 3 created original animations and therefore were forced to think more carefully about the molecular composition of the elements they selected. Group 1 had a hard time turning their pictures into animations and used pre-existing pictures. Therefore, they were not forced to go through the same processes as Groups 2 and 3.

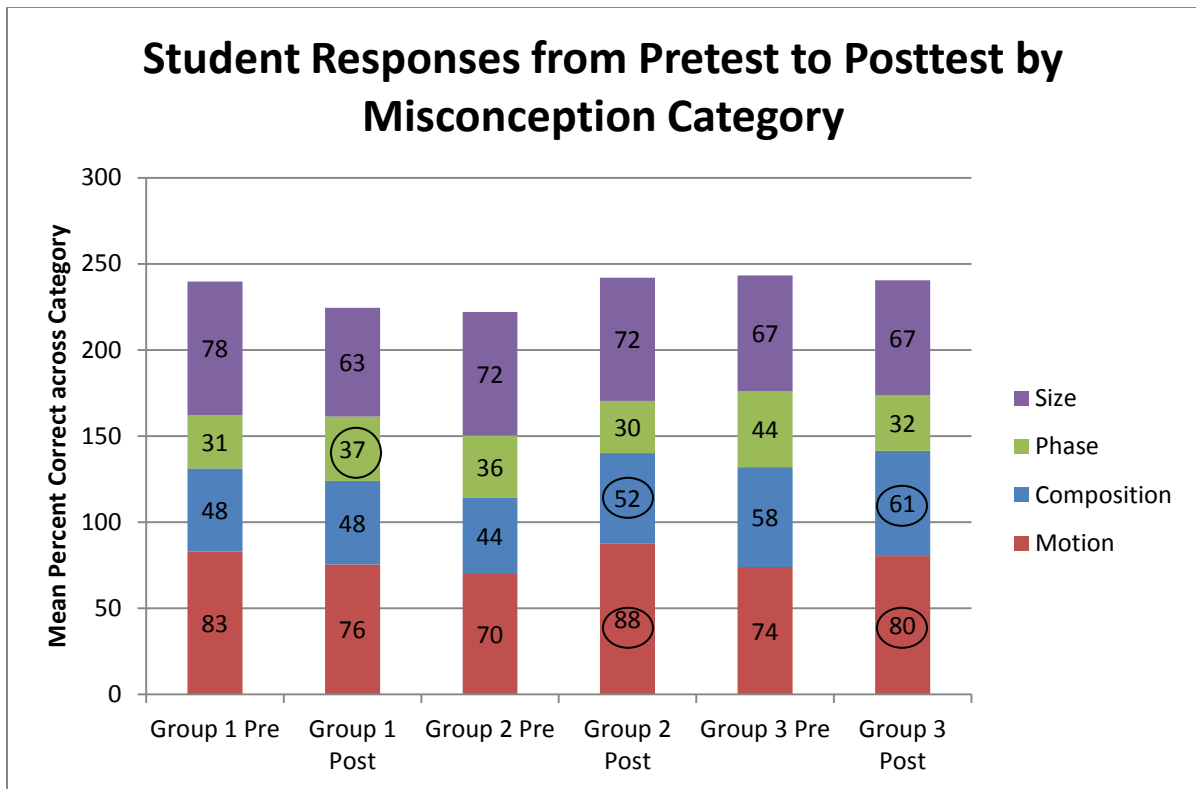


Figure 4.2. Pre-Posttest mean changes by type of misconception, in percentages.

Interestingly, there were two questions in which there was no change in any of the groups or overall. They were (Yeziarski & Birk, 2006):

A pot of water is placed on a hot stove. Small bubbles begin to appear at the bottom of the pot. The bubbles rise to the surface of the water and seem to pop or disappear.

What are the bubbles made of?

- A. heat
- B. oxygen or hydrogen
- C. air
- D. oxygen and hydrogen
- E. steam**

What is the approximate number of water (H₂O) molecules found in a single drop of water?

- A. 20 (2 x 10¹)
- B. 2000 (2 x 10³)
- C. 2,000,000 (2 x 10⁶ or 2 million)
- D. 200,000,000,000 (2 x 10¹¹ or 200 billion)
- E. 2,000,000,000,000,000,000,000 (2 x 10²¹)**

Although many students included bubbles in their animations, neither the text nor the WISE module explicitly discussed what is inside the bubbles. It simply discussed where they were formed (the bottom of the pot) and that they rose to the top, eventually breaking the surface. Therefore, of the 30 questions on the assessment, these questions demonstrated either the presence or absence of prior knowledge.

When students were asked if they learned anything from the provided text (see Appendix D) or from the WISE module, many students responded with a variety of things that they learned. One-fifth of students responded that they had not read the text yet and almost half stated that they already knew everything in the text and/or tutorial. However, several students, regardless of whether they thought they knew the material or not, responded with a variety of misconceptions (see Table 4.10).

Table 4.10

Exemplars of students' misconceptions or new conceptions from the water boiling animation activity

Student*	Quotation	Category
C1-10 (Group 2)	“Cause it’s heating it up. It’s at a high temperature so it’s gonna move faster than what I had.”	Motion
C4-1 (Group 1)	“Highest point of boiling water where the most water moves”	Phase
C3-2 (Group 3)	“Uh, I learned that the particles break up.”	Phase
T3-7 (Group 3)	“I didn’t know that the, um, the bubbles didn’t have like as much pressure as the outside area did.”	Phase
T3-2 (Group 3)	“Um, I learned that you cannot get hotter than boiling water. Like I thought that there was boiling and then you could still get higher.”	Phase

*The group assignment of the student is listed below the student’s ID.

Students, like the comment from C4-1 in Table 4.10, were most likely to refer to aspects of phase changes by talking about the changing temperature of the water or the evolution of bubbles. Many students commented that they did not previously understand the meaning of boiling point (see T3-2). However, most students understood that as the temperature rises, the particles/molecules move faster (see C1-10).

RESEARCHER: *Okay. Did you learn anything from the paper?*

T3-2 *Not really. Just that water boils and what happens when it does. I knew most of it.*

RESEARCHER: [laughing]

T3-2 *Well, I mean I knew...*

RESEARCHER: *Do you think this is easier in a program like 3D S Max or do you think...*

T3-2 *Oh yeah, totally.*

RESEARCHER: *...it would be easier.*

T3-2 *I like 3D S Max much, much more than most other animated programs we have, or just like straight up drawing. I like 3D S Max a lot better.*

RESEARCHER: *Do you think it's better to have an animator? Do you think you'd be better just to have a picture?*

T3-2 *Yeah. Animated. I like the vid...well, I'm pretty sure people learn better with videos. They just do better.*

RESEARCHER: *Why?*

T3-2 *I don't know. You don't have to just try and memorize a graphic. You can watch it happen instead of looking at arrows.*

This discussion between researcher and student validates many of the ideas floating around in the research. Many students learn concepts better through dynamic visualizations as

opposed to static visualizations, especially when the concept is dynamic. As the student suggests above, a picture may be worth a thousand words but an arrow in place of motion is not.

Discussion

Applying Van Meter and Garner's (2005) GTDC to student-generated computer animations

The findings indicate that while it is easy for students to mimic macroscopic characteristics in their animations, the animations mostly lack a connection between microscopic phenomena and the macroscopic level, as evidenced by only 22.9% of students including molecules in their animations. This is similar to what Margel, Eylon, and Scherz (2008) found in their study of middle school students in which only 23% of students retained a molecular view of materials after a three year program. For the molecular shapes, findings were consistent with O'Connor (1997), in that students used a variety of different models – for example, images/shapes they have seen in class via textbooks, class notes, etc. The simplistic animations rendered by students in this study may be indicative of the time and effort needed to use the computer software, requiring students to commit early to a single graphic solution in the visualization.

Van Meter and Garner (2005) clearly outline the psychological processes students experience while drawing, and the scaffolding needs of the student to make drawing more effective. Van Meter et al. (2006) varied the amount of scaffold students received by giving increasing levels of support to each of the four conditions (Control, Draw, Illustration, and Prompt). While the activity in this study did not vary the scaffolding students received (e.g. all students were supposed to complete the WISE module), findings indicate that supporting

students with starting images, as was done in Group 1, does not enhance their animations or understanding. Students in Group 1 did not have to cognitively engage in the selection of elements from the text as they were provided for them in the supplied digital folder in the form of .JPEG images. They selected from among the provided elements and then figured out how they went together.

Table 4.11 shows that there are students from each of the three groups in most categories but all of the students represented from Group 1 are in the Unsatisfactory/Incomplete category for Project Score. This suggests that it may have been more difficult for students in Group 1 to integrate the key elements in their animation. Group 1 students also had the lowest pretest mean (14.55) of the three groups.

The students' gains from pretest to posttest shown in parentheses in Table 4.11 show that students with Unsatisfactory/Incomplete WISE scores are more likely to have lower scores on their posttest. However, there are students who had Unsatisfactory scores who had gains in posttest scores, suggesting that students' prior knowledge may be a factor, or that not completing the WISE model or turning in a project could be simply a lack of motivation and not necessarily an indicator of student learning. Consistent with these findings, Cook, Wiebe, and Carter (2008) suggest that "the difference between high and low prior knowledge learners also reveals itself in how they distribute visual attention as they are viewing the representations" (p. 865). Applying this to student-generated animations would suggest that the students' lower prior knowledge may have been a contributing factor to their low project scores in Table 4.11.

Table 4.11

*Project Scores vs. WISE scores by group**

		PROJECT SCORES	
		SATISFACTORY	INCOMPLETE /UNSATISFACTORY
WISE QUESTION SCORES	SATISFACTORY	Group 2 -C1-2 (0) Group 3 -C3-8 (-1) Group 3 -T3-5 (0) Group 2 -C1-18 (2)	Group 1 - C4-11 (2) Group 2 - C1-10 (-1) Group 2 - C1-16 (4) Group 1 -T1-12 (-1) Group 2 - C1-11 (4)
	INCOMPLETE /UNSATISFACTORY	Group 3 -T3-4 (-2) Group 2 - C4-4 (5) Group 3 - T3-2 (-2) Group 3 - T3-11 (-2) Group 2 -T4-7 (-1)	Group 1 -C4-14 (-5) Group 1 -C4-2 (1) Group 2 -T4-6 (-1) Group 1 -C4-1 (-1) Group 3 -C3-11 (-3) Group 3 - C3-13 (-3)

*Student codes are shown above with pre/posttest gains in (). “Satisfactory” scores are 10 and above.

“Unsatisfactory” scores are 6 and below.

When asked about what they were doing, during informal interviews, students’ focus on technical aspects rather than conceptual statements may be explained by a difference in students’ content knowledge. When interviewed about the progress of their project, 75% of

students with Satisfactory Project Scores only talked about the technical aspects of the project while 75% of students with Unsatisfactory Project Scores talked mostly about the concepts. This may indicate the students who are more interested in or more savvy with the technology could perform well on this type of activity with other topics.

We found that our students used a bottom-up approach in creating their animations, starting with either a stove or a pot, rather than top-down, methods described by Kriz and Hegarty (2007) as the ways in which students process the information provided in animations. The order students use may be an affordance of the technology used or the order in which the concepts were presented in the text. In this study, the text provided to students required them to complete all the macroscopic properties (pot, water, steam) of the animation before adding the molecules, enabling students to complete the majority of the animation with familiar phenomena before thinking critically about the molecular phenomena. This was a limiting factor for the few students who ran out of time (due to missing class or other extenuating circumstances) who may have otherwise included molecules in their animation.

Consistent with the recursive nature of Van Meter and Garner's (2005) GTDC, students repeatedly moved between the text and their animation, selecting elements, organizing those elements, and integrating them into the overall animation. The changes that students made after viewing the WISE module are further evidence that some students edited their initial animations using this recursive process between text and the animation. Figure 4.1 shows that a student added thermometers to each slide of the animation. In the WISE module, one of the animations allowed the students to adjust the temperature on a thermometer and watch the effects on the molecules. This student may have added the

thermometer to her model, which she began the previous day, as a result of viewing this animation on Day 2.

Elements in animations

As students learn about the atomic-molecular theory, the concepts become increasingly complex and involve smaller parts (e.g. molecules versus particles) providing deeper understanding (Smith et al., 2006). Margel et al. (2008) used a curriculum with middle school students that began with macroscopic properties and then progressed to the particulate level and ultimately the molecular level. However, despite instruction at the molecular level, only 23% of students created drawings that reflected the molecular level. This study demonstrated similar results with only 22.9% (8 students of the 35) including some type of water molecule in their animation. On the other hand, 40% (14 students of the 35) used a shape (e.g. circle, star, triangle) to represent particles. Interestingly, 3 of the 9 students from Group 1 included molecules in their animations but none included particles. Indeed, particles were not included in the provided images but many students supplemented the provided images with their own drawings and therefore could have added particles. As a reminder, students in this study all were in high school and of the 35 students, 10 had completed physical science and 4 had completed chemistry. Therefore, it was expected that a higher percentage (>23%) of students would include molecules in their animation than the middle school students in Margel et al. (2008). However, the results seem to be the same. This may be indicative of the nature of the Sci Vis course (focus on realistic animations not science concepts).

In Table 4.7 and 4.8, PARTS and UPWARD MOTION are based on ideas in the Level 4 range of the phase change learning progression, suggesting that students with high

scores in these categories have deeper understanding of phase change and related concepts. Although PARTS do not occur to much extent in many of the animations, UPWARD MOTION does. However, the evidence for UPWARD MOTION was macroscopic. The molecular characteristics in the student animations ranged from molecules “in the water” to molecules moving from the liquid state to the gas state and dispersing into the air. Interestingly, two students (C4-1- Group 1 & C4-2 – Group 1) mentioned molecules during their interview, C4-2 referring to both molecules and particles on different days, but did not include any molecules/particles in their animations. It is possible that this is due in part to time constraints and lack of familiarity with the animation software.

Specific misconceptions

The findings provide some limited evidence that students who created original animations gained a better understanding of atomic/molecular motion and composition. Students, in general, tend to mimic macroscopic characteristics from the text in their animations; the real assessment is how they interpret the microscopic phenomena and join it with the macroscopic level (Stevens et al., 2010). Students in Group 1 made use of a magnifier convention to ‘zoom into’ the molecules. However, the molecules themselves were at varying degrees of proximity to each other in the liquid phase. Students in Group 2 and 3 overlaid the molecules onto the macroscopic water and air. These molecules were also different sizes and proximities to each other. This may represent an incomplete knowledge of the actual positioning and configuration of molecules in each phase and the affordances of the technology each group was using. Further, the mean score on the pre/posttest for Group 3 decreased. This group discussed in groups of 3 (representing high, medium, and low scores on the pretest) misconceptions that may possibly exist in their animations. This may have

exacerbated any misconceptions existing among the group members. According to Johnson and Stewart (2002), cooperative learning for the purpose of model evaluation can be successful or unsuccessful by a slight difference. They found that the unsuccessful groups only compared surface understandings instead of delving into deeper thinking. Also interesting to note, is that this group had the highest mean score on the pretest (17.11). There does seem to be an interesting juxtaposition between the trending of the scores that favor the students who created original animations. It could be that the effort required to create the computer animation spurred a more reflective, thoughtful model design process that encouraged deeper thinking about these atomic/molecular properties.

Finally, research (e.g. Wu & Shah, 2004) shows animations are useful in helping students understanding dynamic processes. Student T3-2 reiterates this in his conversation with the researcher when he suggests that animations are easier than trying to make sense of arrows. This is also consistent with the finding that the creation of animations evidence a positive change in questions related to motion.

Conclusion and Implications

The purpose of the study was to investigate whether student-generated visualizations enhance student progress along a phase change learning progression. The Scientific and Technical Visualization curriculum that provided a context for this study systematically trains students to use visualizations starting with basic two-dimensional pictures, moving to animations using pictures, and finally creating animations using the three-dimensional animation software. In this research on 35 high school students in two levels of Sci Vis classes, we found that students have a preference for the way in which they construct/create their animation. The students did not like starting with supplied pictures. Many students in

this group ignored the pictures and created their own images. Students also did not seem well equipped to combine the macroscopic and microscopic elements of the animation. The Group 1 students' program, CoreIDRAW® enabled them to more easily include a magnifier but students still did not consistently include molecules. Although the order in which atomic-molecular theory is taught may not change, there seems to be a need to better inform students as to how the levels (macroscopic and microscopic) connect. One suggestion supported by this and other studies (e.g. Harrison and Treagust, 2000) would be the principles set forth by the modeling learning progression (Schwarz et al., 2009), particularly the evaluation and prediction stages. Another suggestion may be having students work up to original animations by first completing animations with varying degrees of pre-set backgrounds or attributes (e.g. a beaker and magnifier already present and students add water, steam and molecules).

Van Meter, Aleksic, Schwartz, and Garner (2006) have shown that students produce higher quality drawings and demonstrate better understanding when they draw with support. Therefore, it stands to reason that teachers ought to be aware of these student needs. Resonant with Justi and van Driel's (2005) recommendation for teachers to have a better knowledge of models, we suggest that teachers be trained how to scaffold student drawing (animations) to maximize student understanding. We believe that the rubric developed for this study and the information gained on the scaffolding required for students to produce high quality drawings will be of use to teachers and teacher educators.

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APPENDICES

Appendix A: Glossary

Drawing - student created visualizations that are meant to look like the object (or idea) that they represent (Van Meter & Garner, 2005).

Model - abstract, simplified representations of a real phenomenon that helps to generate explanations and predictions (Harrison & Treagust, 2000).

Visualization – “a specific form of external representation that are intended to communicate information by using a visuo-spatial layout of this information and that are processed in the visual sensory system” (Scheiter et al., 2009, pp. 68-69).

Static – a form of visual representation displaying an individual image.

Dynamic – a form of visual representation displaying a series of images that give the appearance of movement and/or passage of time.

2-D – A physical or virtual representation displayed in two dimensions, such as on a piece of paper.

3-D – A physical or virtual representation that is displayed or created using three different dimensions.

APPENDIX B: Student Demographic Form

Name _____

Instructions: Please complete the following questions to the best of your knowledge.

1. Age: _____

2. Gender (circle one): Male Female

3. Grade: _____

4. School: _____

5. Teacher: _____

6. Current Science Class: _____

7. Previous high school science classes:

8. When did you take Scientific and Technical Visualizations I?

APPENDIX C: Pre/Posttest

Particulate Nature of Matter Assessment (ParNoMA)

****PLEASE DO NOT WRITE ON THIS TEST****

Instructions: Carefully read each question. Please mark either True or False on your answer sheet for each of the following questions #1-13

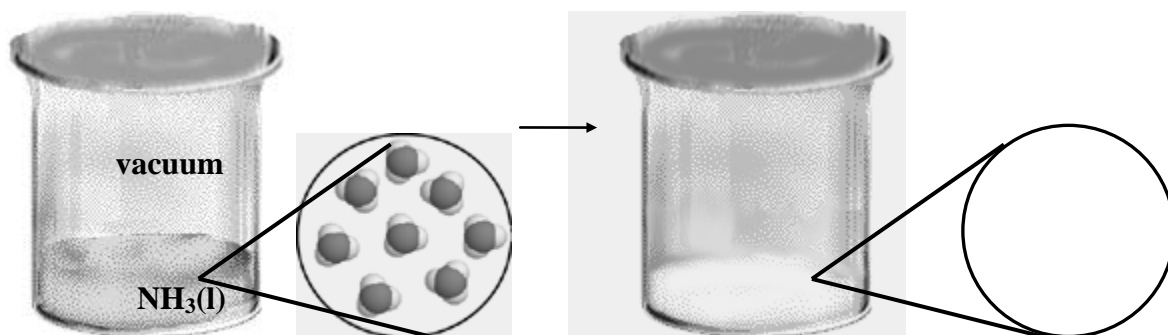
Statement	T or F
1. Molecules and atoms are always moving	
2. Molecules and atoms are all the same size	
3. Molecules in ice cream are very cold	
4. Molecules and atoms have mass and weight.	
5. Molecules can move at different speeds	
6. Only things you can see are made of molecules	
7. Molecules in a rock are not moving	
8. Two substances can be made of the same kinds of atoms but different kinds of molecules	
9. Two substances can be made of the same kinds of molecules but different kinds of atoms	
10. Molecules in liquids are always further apart than in solids	
11. Molecules in liquids move differently from molecules in solids	
12. Cells are kinds of molecules.	
13. There is empty space between the atoms and molecules of solids and liquids.	

Instructions: Carefully read each question. Choose the best answer for each one and mark your response on your answer sheet.

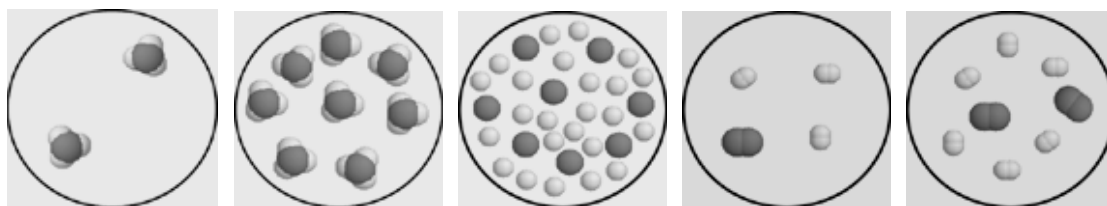
14. Which determines the speed of a molecule?
- A. its size
 - B. its energy
 - C. the amount of space it has to move in
 - D. all of the above
 - E. none of the above

15. A water molecule in the gas phase is _____ a water molecule in the solid phase.
- A. smaller than
 - B. lighter than
 - C. heavier than
 - D. larger than
 - E. the same weight as
16. What affects the shape of a water molecule?
- A. nothing
 - B. pressure
 - C. temperature
 - D. the phase it's in
 - E. the shape of its container
17. A pot of water is placed on a hot stove. Small bubbles begin to appear at the bottom of the pot. The bubbles rise to the surface of the water and seem to pop or disappear. What are the bubbles made of?
- F. heat
 - G. oxygen or hydrogen
 - H. air
 - I. oxygen and hydrogen
 - J. steam
18. The same pot of water described above in #17 begins to boil rapidly. A glass lid is placed on the pot and water droplets begin forming on the inside of the lid. What happened?
- A. The lid became sweaty.
 - B. Hydrogen and oxygen combined to form water.
 - C. Water from outside leaked into the pot.
 - D. Steam cools and water molecules moved closer together.
 - E. Steam combined with the air to wet the inside of the lid.
19. A wet dinner plate is left on the counter after it has been washed. After awhile it is dry. What happened to the water that didn't drip onto the counter?
- A. It goes into the air as very small bits of water.
 - B. It just dries up and no longer exists as anything.
 - C. It changes to carbon dioxide.
 - D. It goes into the plate.
 - E. It changes to oxygen and hydrogen in the air.

20. A sample of liquid ammonia (NH_3) is completely evaporated (changed to a gas) in a closed container as shown:



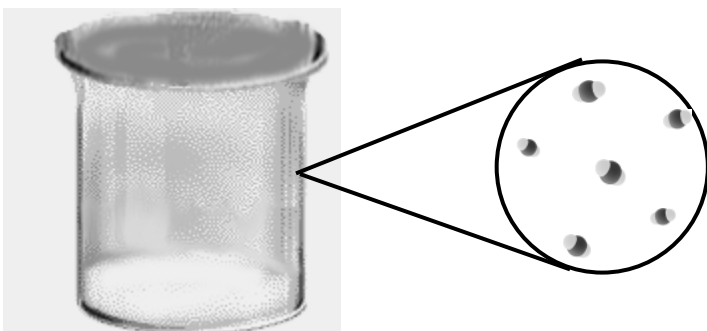
Which of the following diagrams best represents what you would “see” in the same area of the magnified view of the vapor?



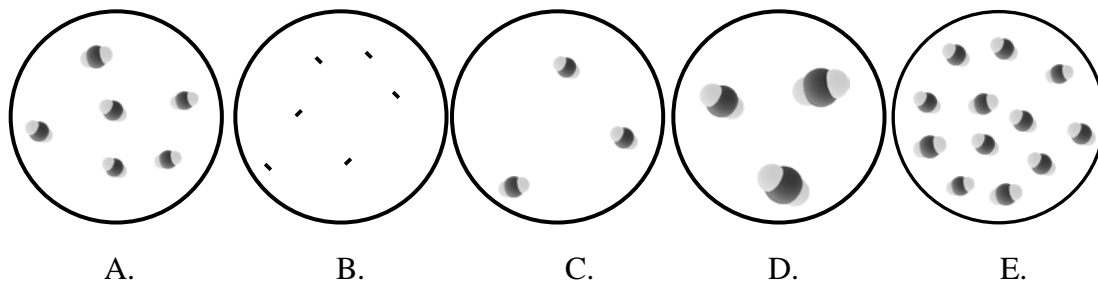
- A. B. C. D. E.

21. In a pure sample of oxygen gas, what exists between the oxygen molecules?
- A. matter
 - B. air
 - C. water vapor
 - D. nothing
 - E. atmosphere
22. What is the approximate number of water (H_2O) molecules found in a single drop of water?
- F. 20 (2×10^1)
 - G. 2000 (2×10^3)
 - H. 2,000,000 (2×10^6 or 2 million)
 - I. 200,000,000,000 (2×10^{11} or 200 billion)
 - J. 2,000,000,000,000,000,000,000 (2×10^{21})

23. A magnified view of a sample of carbon dioxide (CO_2) gas at a pressure of 1.0 atm is shown below.



Which of the following diagrams best describes what you would “see” in the same area at a reduced pressure of 0.5 atm?

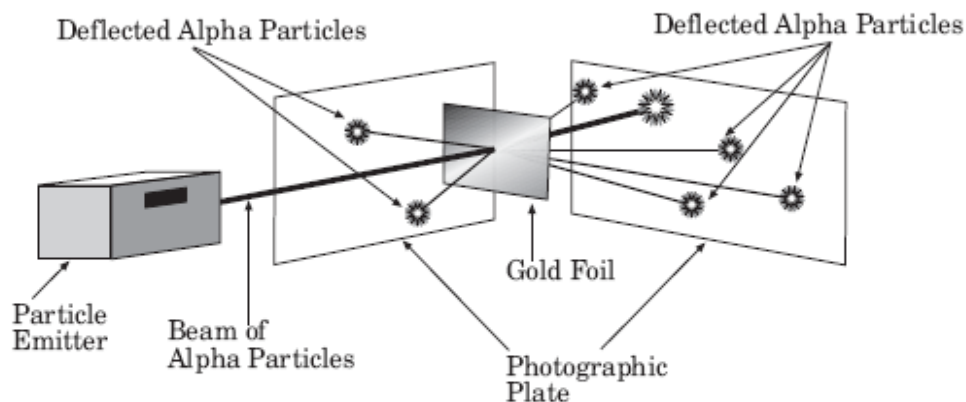


24. Which of the following statements is incorrect?
- F. Water molecules move at the same speed in the solid, liquid, and gaseous phases.
 - G. Water molecules move the fastest when they are in the gaseous phase.
 - H. Water molecules in the solid phase vibrate.
 - I. Water molecules in the liquid phase move faster than molecules in the solid phase.
 - J. Water molecules in solid phase are in the form of ice.
25. Which of the following statements is correct?
- A. Heat causes molecules to expand.
 - B. Molecular size depends on temperature.
 - C. Gases have mass and volume.
 - D. When a liquid changes to a gas, there is a decrease in mass.
 - E. Bonds within molecules are broken during melting.

26.

Ernest Rutherford performed a famous experiment in which he used a radioactive alpha particle source and aimed the particles at a thin sheet of gold foil. By studying photographic plates placed around the foil, he found that most particles passed straight through, some were deflected, and some reflected straight back. This discovery led him to make several important conclusions.

Rutherford's Experiment



Using the experimental setup, what conclusions about atoms were made by Rutherford?

- A An atom is mostly empty space, with a small, dense, positively-charged center.
- B Atoms are solid, dense, neutrally-charged particles.
- C Atoms are empty space except for randomly scattered negative particles.
- D An atom is mostly composed of a large, positively-charged energy cloud.

27.

Which *best* describes the current model of an atom?

- A a solid sphere with electrons and protons embedded
- B a solid sphere unique for everything that exists
- C a central nucleus containing protons and neutrons with electrons orbiting in levels of high probability
- D a central nucleus containing protons with electrons orbiting in specific paths

28. What happens when energy is removed from liquid water?

- A Molecules slow down, and more hydrogen bonds are formed.
- B Molecules slow down, and more hydrogen bonds are broken.
- C Molecules move faster, and more hydrogen bonds are formed.
- D Molecules move faster, and more hydrogen bonds are broken.

29. Object X and Object Y are made of the same material.
Object Y is twice as big as Object X (its volume is twice the volume of Object X).



- The mass of Object Y is:
- a. Twice the mass of Object X
 - b. The same as the mass of Object X
 - c. Half the mass of Object X
30. Which do you think is bigger, an atom or a speck of dust?
- a. They are the same size.
 - b. The atom is bigger.
 - c. The speck of dust is bigger.
 - d. I don't know.

Item Number	Source
1-13, 29, 30	Smith et al., 2006
14-25	Yeziarski & Birk, 2006
26-27	Physical Science EOC Released Item (NCDPI, 2010)
28	Chemistry EOC Released Item (NCDPI, 2010)

APPENDIX D: Text Provided to Students

As water boils, the water turns into steam (also known as water vapor or water gas.) You can probably watch this happen if you pay close attention when you boil your pot of water. First, the water begins to form bubbles at the bottom of the pot near the heating device. Then, the bubbles begin to rise until the bubbles begin to pop off the surface of the water and seemingly evaporate into the air. What's happening here?

As the energy from the heating device goes into heating the water, the water temperature rises. You'll notice this happening on your thermometer. But at a certain temperature, the heating energy goes only to turning the water into a gas. When that point is reached, your thermometer reading will not get any higher. At that point, all of the energy from the heating device is used to transform the water from its liquid state to its gaseous state (that's when you start seeing the bubbles form.) When you reach the point where the temperature of the water does not increase any further, you will have found the boiling point of your water. Interestingly enough, no matter how much longer you keep the pot of water boiling, it will get no hotter, because at this point all the energy from the heating device is being used to change the water into gas and not for increasing the temperature. Why is this?

As you heat up the water, you are breaking apart the liquid molecules so that it can turn into a gas. Bubbles are created in the water closest to the bottom of the pot first. But the pressure of the outside air will squash those bubbles at first because they don't have enough pressure inside them to stand up to the outside air pressure. As more energy goes into making those bubbles though, they will begin to be able to stand up to the outside air pressure. When they get to the point where they can stand up to the outside air pressure, you'll see massive bubbles coming off of your water, the temperature of your water will stay the same and your boiling point will be reached.

Adapted from: <http://www.ciese.org/curriculum/boilproj/background.html>

APPENDIX E: Questions in WISE Module

1. What happened to the marked molecule when you added heat to the model?
2. Define: Heat (thermal energy)
3. Define: Temperature (kinetic energy)
4. Define: Liquid water (molecules)
5. CHALLENGE: The concepts in this page were not directly discussed in the previous steps. Use your prior knowledge in defining them. Boiling (phase change)
6. Boiling point (temperature)
7. What happened to the molecule that was added NEAR the others? Explain why this happened by referring to intermolecular forces.
8. How would the motion of the molecules change if you could add heat (like in the first model you investigated)?
9. What is an "intermolecular force"? Give an example for such a force from the dynamic model of liquid.
10. How would the motion of the molecules in the liquid state change if you could cool the model down?
11. How would the motion of molecules in the gaseous state change if you could cool the model down?
12. Describe what happens to the gas molecules when pressed by a piston.
13. Why do bubbles of vapor rise to the surface when a liquid is boiling?
14. Based upon your previous answer, will it take longer to hard-boil an egg in the mountains than at sea level? Explain why or why not. Click the Panda icon for hints.

APPENDIX F: Rubric for WISE Module Questions

Question	Sample Responses		
	0	1	2
1. What happened to the marked molecule when you added heat to the model?	Don't know OR Blank	Faster OR Further	Moves faster and/or breaks bonds with the molecules around it. Moves further away from the other molecules.
2. Define: Heat (thermal energy)	Opposite of cold OR When something feels warm OR Blank	Thermal to kinetic OR Molecules move faster OR Change in temp	a. the energy transferred as a result of a difference in temperature b. thermal energy that is absorbed and converted to kinetic energy by the substance it is added to. c. therefore, the molecules move faster
3. Define: Temperature (kinetic energy)	What you have when you are sick OR Blank	the degree of hotness of a body, substance, or medium (Macroscopic description only)	the degree of hotness of a body, substance, or medium; the average kinetic energy of the atoms or molecules of a substance
4. Define: Liquid water (molecules)	Melted ice OR Blank OR Something you get out of the faucet	. a transparent, odorless, tasteless liquid OR definite volume but no definite shape (Macroscopic description only)	a. a transparent, odorless, tasteless liquid, a compound of hydrogen and oxygen , H ₂ O, freezing at 32°F or 0°C and boiling at 212°F or 100°C, b. definite volume but no definite shape

			c. molecules are bonded together but move fluid over each other (does not have to be all of these)
5. CHALLENGE: The concepts in this page were not directly discussed in the previous steps. Use your prior knowledge in defining them. Boiling (phase change)	Very hot OR Blank	to change from a liquid to a gaseous state, producing bubbles of gas that rise to the surface of the liquid, agitating it as they rise. (Macroscopic description only)	to change from a liquid to a gaseous state, producing bubbles of gas that rise to the surface of the liquid, agitating it as they rise. Molecules begin to move faster, breaking bonds between molecules by overcoming intermolecular forces and moving further away (does not have to be all of this but a good portion)
6. Boiling point (temperature)	When something gets hot and is thinking about boiling OR Blank	When water reaches 212°F (100°C) –or just before it does (The temperature only)	the temperature at which the vapor pressure of a liquid is equal to the pressure of the atmosphere on the liquid, equal to 212°F (100°C) for water at sea level.
7. What happened to the molecule that was added NEAR the others? Explain why this happened by referring to intermolecular forces.	Blank	Limited description/explanation OR Lack of explanation	The NEAR molecule was attracted to the other molecules and forms bonds with its neighboring molecules. Intermolecular forces depend on proximity and the closer the

			molecules, the greater the intermolecular forces acting on them. The FAR molecule is not affected by intermolecular forces and therefore remains unbounded.
8. How would the motion of the molecules change if you could add heat (like in the first model you investigated)?	It slows down OR Blank	Faster OR Farther OR Solid -> liquid	If we add heat to the model, we expect that the molecules will move faster and farther apart breaking some of the bonds. The solid would become a liquid.
9. What is an "intermolecular force"? Give an example for such a force from the dynamic model of liquid.	Irrelevant OR Blank	Intermolecular force is a force that exists between two molecules. (Answer with no example)	Intermolecular force is a force that exists between two molecules. The force (dotted line) between 2 blue balls in model. It causes the molecules to attract each other.
10. How would the motion of the molecules in the liquid state change if you could cool the model down?	It speeds up OR Blank	Liquid can become a solid (Macroscopic level only)	The molecules would move more slowly and move closer together. Liquid can become a solid
11. How would the motion of molecules in the gaseous state change if you could cool the model down?	It would speed up OR Blank	Gas -> liquid only	We expect that the molecules would slow down and move closer together in a defined area. Gas could become liquid
12. Describe what happens to the gas molecules when pressed by a piston.	Blank OR Don't know	They are compressed (move closer together)	The gas molecules are pushed down into a smaller area. They move closer

			together and begin to move slower. (Pressure is increased)
13. Why do bubbles of vapor rise to the surface when a liquid is boiling?	Heat rises OR Blank	They are made of gas (or something similarly brief)	The pressure of the vapor in the bubbles is less than that of the surrounding water and therefore rise to the surface. (The molecules in the bubbles are less dense than those in the surrounding water)
14. Based upon your previous answer, will it take longer to hard-boil an egg in the mountains than at sea level? Explain why or why not. Click the Panda icon for hints.	Blank OR No, it does not take longer	“Yes”, but No explanation OR “Yes”, Brief answer/explanation which may be incorrect	It takes longer because the boiling point of water is lower and therefore cooks an egg at a lower temperature which takes longer.

APPENDIX G: Rubric for Student Animation Projects

	Concept	0	1	2	3
BASIC STRUCTURE	Matter is made of particles (SHAPE)	No shapes are drawn	Water and gas represented by different shapes (indicating different particles)	Water OR gas represented by shapes but not both	Both water and gas represented by circles or other shape
	Particles are atoms and molecules (PARTS)	No shapes are drawn	Shapes are drawn but do not indicate atoms and/or molecules (Shapes do not have parts)	Hydrogen and oxygen are clearly discernible in water OR gas but not both	Hydrogen and oxygen are clearly discernible in both water and gas
ADDING HEAT –MO	Particles in constant random motion (MOTION)	No movement indicated	Shows particles in motion but they are all moving together (coordinated movement)	Shows particles in motion, they are moving on different paths (random) but only in one of the phases	Shows particles in motion, they are moving on different paths (random) in both phases
	Particle motion related to temperature (SPEED)	No movement indicated	Shows particles in motion but they are all moving at the same speed	Shows particles moving faster in one of the phases	Shows particles moving faster but distinctly in both phases (i.e. fast in liquid but faster in gas)
PHASE	Changes in the balance between kinetic and potential energy (UPWARD MOTION)	No gas bubbles	Bubbles appear at the bottom of the “pot” but nowhere else	Bubbles appear at the bottom of the “pot” and rise through the liquid water	Bubbles appear at the bottom of the “pot” and rise through the liquid water and then appear to break open at the surface

				and “disappear”
Concept	0	1	2	3
<p>“The temperature at the boiling point remains constant despite the continuous addition of energy. The added energy is used to overcome attractive forces between molecules of liquid during the liquid-to-gas change and is stored in the vapor as PE. (p.344)” (BOILING POINT)</p>	<p>No boiling point indicated or the temperature is shown as changing while the liquid is boiling</p>	<p>The boiling point is shown at some point during the animation</p>	<p>The temperature is shown increasing through the animation and stabilizes at the boiling point as the water begins to boil</p>	<p>The temperature is shown increasing through the animation and stabilizes at the boiling point as the water begins to boil. Once all the water has boiled and only gas remains, the temperature increases again</p>
<p>Interactions between particles in a liquid weaker than those in a solid; interactions between particles are negligible in a gas (PROXIMITY)</p>	<p>No particles shown</p>	<p>Particle proximity is the same regardless of phase</p>	<p>Liquid particles are close together (bonded) and seem to flow over one another OR Gas particles are far apart with little or no interaction</p>	<p>Liquid particles are close together (bonded) and seem to flow over one another AND Gas particles are far apart with little or no interaction</p>