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A qualitative comparison of general chemistry and advanced placement chemistry students' misconceptions regarding solution chemistry

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A QUALITATIVE COMPARISON OF GENERAL CHEMISTRY AND ADVANCED
PLACEMENT CHEMISTRY STUDENTS' MISCONCEPTIONS
REGARDING SOLUTION CHEMISTRY

An Abstract of a Thesis
Submitted
in Partial Fulfillment
of the Requirements for the Degree
Master of Arts

Megan J. Vandersee
University of Northern Iowa

December 2017

ABSTRACT

This study focused on identifying misconceptions which high school AP and collegiate general chemistry students hold with regards to solution chemistry topics and comparing the misconceptions held by each student group. Previous research has found that misconceptions can greatly impact students' understanding of material and have a negative impact on student learning. However, not all solution chemistry topics had been explored in previous research. In addition, it has been suggested that collegiate students have reached a higher level of cognitive development as they are older and more advanced in their studies. If this is the case, one could assume that the collegiate students would better able to comprehend complex chemistry topics and, therefore, hold onto fewer misconceptions over the course of classroom instruction.

AP Chemistry students from three different high schools ($n = 20$) and collegiate general chemistry students from one university ($n = 4$) participated in this qualitative study. Students were asked to complete an open-ended, researcher-developed Solution Chemistry Questionnaire (SCQ) both before and after instruction. The questions were based around solution chemistry topics that were introduced and discussed during classroom instruction at both the AP and collegiate level. Students were then selected through the process of maximum variation sampling, based upon their pre- and post-assessment responses. The selected students participated in a one-on-one semi-structured interview involving the same topics that were present in the SCQ. Misconceptions identified within all three phases of the study were used to determine trends and determine the overall results of the study. The five main categories which misconceptions

were coded to include: structure of molecules, polar v. non-polar substances, types of solutions, colligative properties, and types of salts.

The results of this study support the idea that collegiate chemistry students are more advanced in terms of their cognitive development, specifically with regards to complex chemistry concepts. Collegiate students displayed a more complex understanding of solution chemistry topics, even though misconceptions were identified within both populations. AP Chemistry students displayed a wider range of misconceptions, while the misconceptions of students at the collegiate level were more uniform and based around more complex chemistry concepts.

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This Study by: Megan Vandersee

Entitled: A Qualitative Comparison of General Chemistry and Advanced Placement
Chemistry Students' Misconceptions Regarding Solution Chemistry

has been approved as meeting the thesis requirement for the

Degree of Master of Arts

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CHAPTER 1

INTRODUCTION

When introducing new topics in the classroom, many teachers relate content to situations their students might encounter outside of the classroom as it allows the students to create personal connections between their past experiences and new content knowledge. Unfortunately, some students create these connections either before being introduced to the correct scientific understanding or before fully understanding the related scientific concepts which, in turn, can lead to the formation of a tightly held belief that acts as a roadblock to future learning and understanding. This complication can continue as students advance in their schooling and work to explain more complex scientific theories, often leading to an oversimplification and generalization of scientific concepts (Çepni, Taş, & Köse, 2006; Committee on Undergraduate Science Education, 1997). While using students' prior experiences can be very important when creating interest and introducing new concepts in the classroom, these same experiences can have an impact on students' ability to integrate their prior knowledge with correct scientific understanding (van den Broek & Kendeou, 2008). If prior experiences and student interpretation lead to ideas that are incorrect with regards to scientific understanding, these ideas are often referred to as either "misconceptions" or "alternative conceptions" (Çepni et al., 2006). For this research, we will exclusively use the term misconception.

Students hold many different misconceptions within the science discipline as humans are interacting with scientific phenomena on a regular basis. In addition, students are often introduced to scientific concepts in the classroom at an early age. By integrating

young students' inquisitiveness into academic experiences, teachers hope to create memorable experiences and provide students with scientific knowledge. However, this can often backfire as young students' brains are not ready to comprehend abstract and conceptual topics, such as chemistry, so early in their academic careers (Driver, Rushworth, Squire, & Wood-Robinson, 2005). Since the majority of chemistry concepts occur on the microscopic level, teachers often use replicas or other macroscopic examples to model the current understanding of chemical processes. While this often helps students understand the basic concept at that particular moment, it can also cause students to hold onto some of the inconsistencies or false assumptions that the model suggests (Gabel, 1999; Li & Li, 2008).

Coll and Treagust (2003) studied the age of students in relation to their understanding of a chemistry topics and it was determined that both collegiate and secondary students provided similar interpretations of the material; however, the collegiate students were able to provide greater detail in their descriptions. This ability to comprehend and apply larger amounts of information can be related to the students' level of cognitive development. The levels of cognitive development were originally proposed by Piaget as he essentially split individuals into four main groups based upon their ability (or inability) to perform particular mental tasks. Piaget originally suggested that students aged 11 to 15 years old are typically in the period of formal operations, meaning that students are able to deal with all types of problem (past, present, and future) and hypothesize how a change to one event may affect something else in the future (Kolodiy, 1975). However, a more recent study by Kolodiy found that many high school and

college students have yet to reach the formal operations level of cognitive development. Instead, students are typically in the period of concrete operations and are only able to apply their understanding of concepts to situations that are observable (Kolodiy, 1975). The fact that only some college students have developed mental functions that would be expected of those within the realm of formal operations suggests that the shift from stage three to four may occur near the time when students enter college for many, but there is a chance that some individuals will never reach the stage of formal operations. Seeing as some students do move into the stage of formal operations around the time they enter college, this would insinuate that there may be a difference in cognitive abilities between students enrolled in collegiate chemistry courses and AP Chemistry as a high school course. If students are unable to process information at a cognitive level that is necessary for a complete understanding of chemistry concepts, there would be a higher chance of incomplete knowledge or the formation of a misconception. These misconceptions can compound on one another and lead to even larger misconceptions as students progress through their academic careers. Only by identifying and challenging student misconceptions in the classroom can teachers provide an effective learning environment that encourages a complete and accurate understanding of chemistry concepts.

The purpose of this study is to identify, analyze, and compare misconceptions of high school chemistry students and general chemistry college students with regard to solution chemistry through the use of written, verbal, and pictorial means. This focus has been chosen for two essential reasons. First, there is much research on student misconceptions with regard to the particulate nature of matter and its relation to solution

chemistry, such as the process of dissolution, solubility of solids and gases, and types of solutions (Adadan & Savasci, 2012; Calik & Ayas, 2005; Calik, Ayas, & Coll, 2009; Pinarbasi & Canpolat, 2003; K. J. Smith & Metz, 1996). However, there is a lack of information regarding student misconceptions in other areas of solution chemistry. This study will focus not only on the concepts listed above but other conceptual aspects of solution chemistry, including factors affecting solubility, polarity and molecular interactions and colligative properties.

Second, this research will compare the misconceptions of students who are approaching the end of an Advanced Placement (AP) chemistry course in the high school setting with students enrolled in a general chemistry course at the collegiate level. This is significant as the governing body of the AP courses, the College Board, assumes that the students in the AP chemistry course have been exposed to chemistry concepts at the same level as students in a first-year, collegiate, general chemistry course (College Board, 2014). With it being the high school students' second full year of chemistry and the fact that they are more experienced with regards to chemistry topics such as the particulate nature of matter, one could make the assumption that these students will hold fewer misconceptions than high school age students in previous research. On the other hand, the allegedly higher cognitive development level of collegiate students compared to the AP students may mean that they are better able to comprehend the scientific concepts. The more advanced level of comprehension has been attributed to collegiate students' abilities to understand and correctly apply higher-level, academic vocabulary in the correct context. In addition, more experienced students have been shown to provide a greater

number of details when describing the science behind particular phenomena (Calyk, Ayas, & Ebenezer, 2005; Coll & Treagust, 2003). This study will look to determine if there are differences between the misconceptions that both AP students and collegiate students hold, in addition to comparing those misconceptions to those identified in previous studies.

CHAPTER 2

LITERATURE REVIEW

The Construction of Misconceptions

Misconceptions have been defined as an individual's interpretation of content that is different than what is currently accepted within the corresponding discipline. This incorrect interpretation not only will affect students' current understanding of information but can also set a precedent that will lead to future errors in understanding (J. P. Smith, diSessa, & Roschelle, 1993). Research into the formation and effect of misconceptions has become a central focus within the last few decades. Researchers suggest that individual students construct a unique knowledge base as they use their experiences to make sense of the world around them (Özmen, 2004). This overarching idea is often referred to as the constructivist theory and helps to explain an individual's conceptual framework. After creating this conceptual framework, each student is able to determine the importance of an idea and interpret new information in a way that makes sense to them (Garnett, Garnett, & Hackling, 1995). The idea of constructivism explains why there is such great variation in understanding as the meaning of experiences is subjective and based upon certain objects or ideas (Creswell, 2014). As students connect new experiences and their interactions with the natural world to their existing conceptual framework, they are constructing meanings that either relate to or explain their previous beliefs (Driver et al., 2005). However, in some cases, either students' prior interactions with the physical world or their interpretation of information leads them to generalize knowledge to better complement their understanding of more complicated topic. When

this generalization does not actually align with the current scientific understanding of a phenomena and is integrated into the student's long-term memory they, in turn, can create a misconception that is difficult to correct (J. P. Smith et al., 1993).

While it may seem that a straight forward approach to eliminating current misconceptions is to introduce students to the 'correct' way of thinking, theorists believe that these frameworks are often deeply rooted in personal beliefs that students have created to explain the world around them (Bodner, Klobuchar, & Geelan, 2001; Chakraborty & Mondal, 2012; Modell, Michael, & Wenderoth, 2005). For this reason, it can be quite difficult to elicit change in a conceptual framework and convince students to abandon their original beliefs. In fact, researchers suggest that a conceptual change is not an immediate switch from a personal way of thinking to the technical views that are commonly accepted by scientists. Instead, it is a gradual process in which students must acknowledge new ideas and then integrate them into their conceptual framework (Garnett et al., 1995). It is through this process that students begin to correct their way of thinking. However, teachers do not have the ability to correct a student's model for them. The student is the only one who can modify his/her own model and, even as the students gain knowledge and new understanding, the theories which students originally created while trying to make sense of the world around them are never completely forgotten (Modell et al., 2005).

In order to improve student understanding and address the formation of misconceptions, teachers and researchers must first understand why misconceptions are so prevalent in classrooms. One of the principal reasons for the research on student

learning is simply how intuitive misconceptions are and, therefore, how resistant they can be to change. Van den Broek and Kendeou (2008) suggest the resistance to conceptual change is due to the fact that misconceptions make sense to those who hold them and students are often committed to these ways of thinking since they explain how their personal experiences connect to the world around them. Recently, psychologists started to closely examine the idea of conceptual change and the manner in which teachers can help students to reach understandings that allow for future modifications of misconceptions. In order for an individual to go through this process of conceptual change, four specific conditions must be met: (1) the student must be unhappy with their current way of thinking, (2) there must be another, intelligible way of thinking that is apparent to the student, (3) this new way of thinking must be demonstrated/explained to the student in a way that makes sense to them, and (4) this new way of thinking should be useful and lead to further avenues of exploration for the student (Posner, Strike, Hewson, & Gertzog, 1982; van den Broek & Kendeou, 2008). Within Conceptual Change Theory, teachers do not have control over eliminating students' misconceptions, but instead, teachers should use supports such as textbooks, videos, animations, and lab experiences as a part of classroom instruction (Posner et al., 1982). It is through a combination of all of these resources that teachers guide students through correcting their understanding of everyday events.

Understanding Potential Sources of Misconceptions

While the goal of many researchers and teachers is to identify and address misconceptions, it is also important to focus on how to teach or introduce topics in the

classroom in a manner that could reduce the number of misconceptions (Özmen, 2004). Researchers have discussed a variety of strategies including discussions, demonstrations, scenarios that conflict with students' current understanding, and exchanges of ideas amongst teachers and students. In fact, the more opportunities teachers provide for students to take part in tasks that promote metacognition or reflection of personal understanding in the classroom, the more likely students will recreate their conceptual framework to include accurate scientific ideas (Garnett et al., 1995). Each of the strategies mentioned above allows students to not only work through new information in a personal manner but with peers as well. One form of constructivism is known as social constructivism. This form takes into account a student's collaboration with peers and other individuals in the classroom and recognizes that social interactions can play an important role in the learning process. Group-based activities encourage students to be more active in the learning process and work together to reach an understanding that mirrors scientists' previously agreed upon theories (Garnett et al., 1995).

A common source of confusion and, therefore, misconceptions are textbooks. Research shows that students working to understand material written in academic language above their comprehension level often leads to misconceptions and confusion for students (Sanger & Greenbowe, 1999; van den Broek & Kendeou, 2008). After considering the current structure of textbooks, researchers believe that more explicit connections between chemistry concepts and students' personal experiences will allow students to better internalize the material within in their conceptual framework (van den Broek & Kendeou, 2008). When the textbook is used as the sole source of information in

the classroom, the misconceptions and confusion associated with textbook use and academic language are further compounded. The terminology or method of explanation of a particular topic might vary from one author to another and, often, students exposed to a single source believe that one variation or definition is the only option. Consequently, textbook authors have been instructed to be wary of using oversimplifications and vague statements when creating their texts and, instead, encouraged to use many different examples and descriptions for each topic (Sanger & Greenbowe, 1999). Not only does this allow teachers to incorporate a wide variety of learning styles and strategies in the classroom, but it increases the chance that one of the examples could trigger a memory or experience for individual students in the classroom that will allow them to connect information to their conceptual framework. As discussed by Gabel (1999), learning is most effective when individuals connect new knowledge to information that is already stored in their memory bank.

While research is ongoing to address common misconceptions and determine the process by which they may form, researchers agree that students enter the classroom with preexisting beliefs that alter their understanding of future knowledge. (Calik et al., 2009; Gabel, 1999; Hamza & Wickman, 2008; Modell et al., 2005; Nakhleh, 1992; Schmidt, 1997). When considering specific sources of misconceptions in the field of science, many believe that they form as students try to memorize or oversimplify scientific concepts without understanding the real meaning of the material (Çepni et al., 2006). To further complicate matters, many concepts within the realm of science are abstract and hard to explain without using analogies or models – which at times confuses students further

(Gabel, 1999). Ultimately, these factors lead to various influences on a student's future learning, future understanding of conceptual information, and achievement in future classes (Çepni et al., 2006).

Researchers in Istanbul, Turkey, completed a study involving 16 and 17 year old chemistry students, where the instructional methods were limited to lecture-style teaching approaches, including definitions, calculations, graphs, and visual representations from chemistry textbooks (Adadan & Savasci, 2012). Adadan and Savasci determined that even when students had a basic understanding of the topic, they struggled to provide satisfactory responses when explaining details regarding the same scientific concepts. The College Board has emphasized the presence of scientific practices within the AP Chemistry curriculum by encouraging students and teachers to discover and use evidence to create hypotheses, test predictions, and explain natural phenomena as a regular part of the curriculum (College Board, 2014). When varying the experiences students have in the classroom (including lectures, labs, demonstrations, etc.), students are better able to create and share conceptions that more closely resemble the true scientific phenomenon (Adadan & Savasci, 2012; Garnett et al., 1995).

Misconceptions in Chemistry

Common misconceptions in chemistry first arise early in students' educational careers. Students are often introduced to abstract and conceptual topics at a young age, possibly before they are able to understand the complexity of the phenomena. This can lead to students developing their own ideas about these scientific concepts before a formal introduction to factual information in an academic setting (Driver et al., 2005). In

addition, many of the topics found within a chemistry curriculum at the high school level are abstract and require the use of models and analogies to further explain details of individual topics. While models and analogies are beneficial to student learning and comprehension, they are also detrimental to students who are unable to dissociate the model from what actually exists in reality (Gabel, 1999). In fact, many misconceptions stem from oversimplifying scientific concepts in order to introduce information at a level that more accurately represents the intellectual capacity of students in a particular classroom (Li & Li, 2008). Some misconceptions can be attributed to the age and maturity of the students, while others can be attributed to the scientific language and vocabulary that are often used by both textbooks and teachers in the classroom.

Introducing elementary students to complex scientific ideas and terminology requires a simplification of topics to accommodate the ability level of the students. There is a surprisingly large amount of chemistry material found in elementary textbooks due to the potential to relate many chemistry topics (such as states of matter) to a young student's everyday experiences (Gabel, 1999). While introducing topics at a young age can be beneficial in the construction of a conceptual framework, it can also hinder a student's understanding when teachers use words from their everyday language, such as heat or theory, to explain scientific phenomena where the words have very specific meanings (Özmen, 2004). Student understanding is also affected by the amount of time spent on each topic – the less time a student spends exploring a topic, the more likely a misconception will form and affect future learning experiences. This lack of understanding carries over to more advanced material as well, creating a vicious cycle of

learning, connecting and restructuring a conceptual framework that was incorrect from the very beginning (Nakhleh, 1992).

Nakhleh (1992) also explains the idea of restructuring conceptual ideas in science through elaborate cognitive structures. Within their personal structures, students have both concepts and propositions present. Propositions are simply declarative statements that relate to a particular concept, while concepts are a set of propositions that a person uses to develop a meaning regarding a particular topic. For instance, if discussing the concept of 'atomic structure,' a proposition could be 'an atom contains a nucleus' or 'electrons are not found in the nucleus of an atom.' Once multiple concepts have been created by a particular student, they can then be linked together in various ways to create the individual's conceptual framework.

When considering student misconceptions, the most important aspect of this conceptual framework is both where and how the students are gathering the information that eventually becomes a proposition. Nakhleh suggests that there are two sources: "public knowledge" and "informal prior knowledge." The public knowledge is material that is presented in classrooms while the informal prior knowledge represents understanding gained through their day to day experiences and personal interpretations of scientific terms. Misconceptions occur through the combination of both types of knowledge. If each student were to only have the public knowledge, everyone would start on the same page and teachers would be able to introduce material in a one-size-fits-all method of instruction. However, it is the differences in informal prior knowledge created

in each student's set of unique lived experiences that cause students to create their own interpretations of chemical concepts that differ from those the teacher has introduced.

While there are many different misconceptions in chemistry, there are a couple that are much more common than others at the secondary level. In fact, most of the misconceptions revealed through previous studies have been linked to a weak understanding of the current model of matter. An even more concerning revelation is that students are able to use scientific terminology in conversation, but when pressed to explain a particular term, they are unable to give a definition other than the memorized, technical version. This leads researchers to believe that student understanding of chemical topics often has little to no connection to their day to day lives (Nakhleh, 1992). One example of students' inability to explain the purpose behind chemical symbolism is the idea of balancing equations. Researchers asked groups of students to balance an equation and then diagram the respective reaction. Students were unable to complete the task and answer conceptual questions regarding the purpose of coefficients or how they affect the number of molecules in a reaction (Chakraborty & Mondal, 2012). Even though the students had a surface-level understanding of the process for completing the task, they were unable to use that knowledge to explain why scientists use coefficients in chemistry.

Identification of common misconceptions is vital to the success of students within their current courses, but also when students move on to subsequent science courses and encounter the same topics in the future. Even before discussing a concept in great depth, researchers suggest that teachers engage students in discussions regarding their prior

knowledge and experiences with the topic. Not every misconception can be addressed in the same manner and it is important that teachers give students the opportunity to verbalize their ideas as teachers attempt to identify misconceptions that students have previously established. It is through deep conversations that teachers have the greatest access to a student's conceptual framework (Özmen, 2004; Vosniadou, 1994). Teachers must be willing to communicate with the students to address any inconsistencies between the student's understanding and the proper scientific knowledge. In order to approach the corrections in a constructive manner, the teacher must emphasize that science is a discipline that relies heavily on the thinking process and that it is okay to have an incomplete or incorrect understanding of a topic, as long as the student takes the opportunity to learn from their mistakes and new experiences (Schmidt, 1997). It is the collection of a student's experiences and learning opportunities that will allow them to have the most complete and accurate conceptual understanding of chemistry possible.

Factors for Understanding the Particulate Nature of Matter

Some of the most prominent chemical misconceptions revolve around the idea of the particulate nature of matter. The particulate nature of matter is a scientifically accepted theory that models the structure, components, and characteristics of matter (Ayas, Ozmen, & Calik, 2010). Most often, teachers approach this theory in the classroom when discussing types of matter and phase changes, but there are many more advanced topics that require students to have a basic understanding of this theory as well, including solution chemistry. While there are many aspects of the particulate nature of matter students need to understand, de Vos and Verdonk (1996) argue that some

important factors include that gases are composed of particles evenly distributed within a container and that these gas particles are in motion at all times. In addition, gas particles do have the ability to react to form new substances, but typically there is just empty space between the particles themselves. While these five features may seem limiting, they can be used as a starting point for gauging student understanding of the particulate nature of matter. It has been shown that students are unable to grasp the more complex topics without a valid understanding of chemistry basics (Ayas et al., 2010; de Vos & Verdonk, 1996). The importance of these five statements in relation to student learning has been established, yet many students still demonstrate inconsistencies related to the particulate nature of matter through their work samples in various studies. For example, students often view matter as continuous instead of particulate, especially when considering solids and liquids, since these states have connections, or bonds, that students believe are holding the material together (Ayas et al., 2010). Even students who comprehend and internalize the idea that matter consists of particles often think atoms are small pieces of either a solid or liquid that are static, non-uniform, and lacking in cohesive forces (Driver et al., 2005).

Expanding upon the list provided by de Vos and Verdonk (1996), there are eight basic ideas that come together to make up a complete explanation of the particulate nature of matter. Ayas et al. (2010) summarizes these ideas as follows:

1. All matter consists of entities called particles. Individual particles are too small to be seen. They behave as hard, solid, perfectly elastic (except in chemical reactions) immutable objects. Their absolute dimensions are usually irrelevant.

2. Motion is a permanent feature of all particles...there is a direct relation between the temperature of an amount of matter and the average kinetic energy of its particles.
3. In a gas, particles are evenly distributed over space, the empty space between particles is much larger than the space occupied by the particles themselves.
4. Particles mutually attract each other, but the magnitude of the attraction decreases rapidly with distance.
5. In liquids and solids, the particles are much closer together than those in gases. Therefore, their mutual attraction is much larger...in liquids, the particles move from place to place within the fixed volume...
6. Different substances consist of different particles, but all particles of one substance are mutually identical...
7. In a chemical reaction, to make a distinction between molecules and atoms is necessary...
8. An atom consists of a nucleus with a positive electrical charge surrounded by a number of negatively charged electrons. Chemical bond formation as well as electrical current is described in terms of the mobility of electrons. (p. 168)

Ayas and fellow researchers consider these statements to be accurate descriptions, even if they do not all incorporate precise scientific terms and represent the material taught within science curricula at both the elementary and secondary levels. Most importantly, if a student is unable to grasp the first idea presented, the remaining seven have no basis for application. Therefore, it is no surprise that many students are confused and often have difficulty explaining chemical concepts using the ideas found within the statements above.

Multiple researchers have attributed the students' difficulty in comprehending the particulate nature of matter to a tendency to attach macroscopic properties to the microscopic world (Taber & Garcia-Franco, 2010; Yeziarski & Birk, 2006). For many students, what is in front of them is what truly exists and since macroscopic properties are often visible and easy to interact with, teachers tend to introduce the properties associated

with these objects first. However, this approach often leaves many students trying to explain microscopic properties and behaviors in terms of the macroscopic world, instead of the other way around. Especially at young ages, teachers should expect students to struggle to visualize the microscopic properties that are a part of the theory, which, in turn, enhances the disconnect between the two different levels of matter and leads students to incorrectly apply macroscopic properties to smaller units of study (Garnett et al., 1995). By failing to differentiate the macroscopic and microscopic levels of matter, students develop a fragmented view of chemistry that fails to explain both the *how* and *why* behind various chemical phenomena (Gabel, Samuel, & Hunn, 1987). This is an important distinction as research shows that the students who have a complete conceptual understanding of the particulate nature of matter are the ones who are able to visualize the chemical phenomena at an atomic and/or molecular level (Yeziarski & Birk, 2006). These students are able to create a solid foundation of chemical knowledge that they can later reference and build upon as they move forward in their sequence of science education.

Misconceptions in Solution Chemistry

A common application of the particulate nature of matter within many secondary chemistry classrooms is solution chemistry. A solution is scientifically understood to be a combination of two or more substances that has the same chemical composition throughout (Driver et al., 2005). The two substances are often referred to as the solute and solvent, with the solvent being the substance that dissolved the solute. One familiar example used in chemistry classrooms is a sugar solution. In this example, the sugar

would be the solute as it would be dissolved by the water, or the solvent. Contrary to the beliefs of many students, a solution is not required to consist of one solid and one liquid substance (Adadan & Savasci, 2012). Instead, one could have a combination of any of the three states of matter, as long as the two substances are equally distributed throughout the container. When considering the sugar and water example above, some students believe that the different types of particles are moving around each other but can still be separated through filtering or other methods, while other students believe that the sugar-water solution is a single entity since they are unable to physically see the separation between the two substances. While many students fit into one of these two belief systems, there is a large spectrum of beliefs, falling somewhere in between the two previously mentioned (Driver et al., 2005).

One common topic within solution chemistry is the idea of dissolution. Similar to the language components discussed previously, students hear the word *dissolve* in many different contexts before understanding the scientific meaning of the word. This can lead to misunderstandings or misinterpretations of the technical definition. In addition, students often fail to differentiate between the properties of a single atom or molecule, such as water, and the properties of a solution that contains both water and a second substance (Chakraborty & Mondal, 2012). While we can expect pure water to act in a particular way, those behaviors are typically altered when a second substance is introduced into the relationship. For instance, a common activity when discussing this concept in class is to place salt into water. In the case of the salt and most other ionic crystalline solids, the bonds within the substance break and the ions become individual

components within the solution. When researchers asked students to describe this process based upon their observations, students used key phrases, such as: it just goes, disappears, melts away, dissolves away, or it just turns into water (Driver et al., 2005). This shows that even when students have common experiences, such as watching salt dissolve in water, they do not always have consistent ways of explaining the phenomena in question. However, one should note that it is better for a student to have misconceptions or an underdeveloped conceptual framework than no experience with a topic at all (Taber & Garcia-Franco, 2010).

A second common topic in the realm of solution chemistry is concentration which is a measurement of the amount of solute compared to either the amount of solvent and/or the amount of solution present. Using this relationship, one can place solutions into one of three categories: unsaturated, saturated, or supersaturated (Brady & Senese, 2009). These categories range from having little to no solute to the point where more solute is present than can naturally be dissolved. The difference between this topic and many other chemistry concepts is the fact that there are little to no mathematical calculations needed. While some students are able to comprehend mathematical concepts quickly, there is often disconnect between the mathematical process and the conceptual meanings represented by numerical results (Pinarbasi & Canpolat, 2003). Pinarbasi and Canpolat (2003) demonstrated this within their interview questions when they asked students to define and identify the three different types of solutions. They found that students were able to correctly state the definitions of each solution type, but were unable to use that information to create pictorial representations of their solutions. These results supported

the theory that students are often using memorized definitions and mathematical algorithms to solve problems instead of learning the conceptual chemistry that explains the *how* and *why* behind chemical phenomena (K. J. Smith & Metz, 1996).

A third common topic in solution chemistry is colligative properties. Colligative properties of solution are properties that occur solely based upon the ratio of solute and solvent, rather than the identity of the substances. The behaviors associated with colligative properties are based upon the typical patterns of ideal solutions – ones that are pure and follow the predicted patterns. Chemists can explain any deviation from this norm by the presence of a new solute in the solution and the deviation will follow the pattern suggested in the name of these two properties. The colligative properties include freezing point depression, boiling point elevation, vapor pressure lowering, and osmotic pressure. For the purposes of this research, we will be focusing on the first two, which students are able to comprehend more easily as they can relate the information to their experiences outside of the classroom more often. Simply put, when adding solute to a solution, the boiling point rises and the freezing point lowers. In other words, more heat (or energy) must be added to the substance so that it can change from a liquid to a gaseous phase and less energy needs to be present when changing from the liquid to the solid state when compared to the phase changes of the pure solvent (Brady & Senese, 2009). This is the same thought process behind putting salt on the roads in the winter or adding antifreeze to radiator fluid. However, while students are often able to create a relationship between the salt placed on the street and this concept, students are unable to

differentiate between the properties of the solution as opposed to the properties of each of the pure substances (Chakraborty & Mondal, 2012).

Research Questions

Based upon the information and previous studies introduced above, the research questions addressed in this study focus on the topics of structure of molecules, polar v. non-polar substances, types of solutions, colligative properties, and types of salts within the larger conceptual idea of solution chemistry. With these topics in mind, the research questions include: (a) What are the misconceptions that high school students in Advanced Placement Chemistry hold with regards to topics in solution chemistry both before and after instruction?; (b) What are the misconceptions that college students enrolled in General Chemistry courses hold with regards to topics in solution chemistry both before and after instruction?; (c) How do the misconceptions held by students in each group compare?

Theoretical Framework

This research is approached through a practice that is often referred to as constructivism which refers to a learner's ability to assemble their own knowledge, or conceptual framework, based upon personal beliefs and experiences. Knowledge is not a static entity but is continually built and modified in order to integrate new information. In addition, constructivism suggests that knowledge cannot simply transfer directly from teacher to student but instead each individual will interpret the information differently (Bodner et al., 2001). Consequently, each individual has a unique knowledge base even though the information introduced to them may be the same (Gilbert & Watts, 1983). As

long as new ideas are viable, or able to fit into a student's current conceptual framework then, according to constructivist theory, learning can occur (Bodner, 2004; Bodner et al., 2001).

There are many variations of the constructivist theory; however, this research is focused around personal constructivism. Constructivism was introduced in great detail as a part of the *Construction of Misconceptions* section within the literature review. This is the belief that students use their interactions with the world around them to construct new meanings and integrate knowledge into their conceptual framework. Teachers can facilitate learning through constructivism by providing students with the opportunity to collaborate with other individuals while interacting with scientific phenomena (Driver et al., 2005). More specifically, constructivism emphasizes the idea that individuals construct knowledge in a way that meets their individual needs and understanding of a topic at a particular time. While the idea of constructivism typically focuses on the individual learner and private experiences, it also accounts for the fact that social interactions with classmates, teachers, etc. affect the learning process and an individual's conceptual framework as well (Bodner et al., 2001). Since it is impossible to ignore the social nature of education and the interactions students have with other individuals throughout their educational career, both the personal and social forms of constructivism will merge to form the framework of this particular study.

Constructivist theory is often linked to another common mechanism used to explain learning in the realm of science – conceptual change. It is through both the individual experiences and interactions with other students or teachers in the classroom

that students are able to process their understanding of a concept and make changes to their pre-existing conceptual framework (Bodner et al., 2001). Conceptual change is a theory of learning first introduced by Jean Piaget as he believed that individuals must be exposed to events that make them uneasy and forced to make accommodations in their understanding before true learning can occur (Piaget, 1966; Von Glasersfeld, 1989).

Learners are the only ones who can actually change their conceptual framework.

Vosniadou (1994) suggests that there are two forms of conceptual change. In the first form of conceptual change, enrichment, students simply add new information to their current framework as they supplement their current understanding based upon past experiences or lack thereof. In the second form, revision, the student has to reconstruct their entire framework to account for any new information that does not agree with their previous beliefs. Another common way to address the two forms of conceptual change is accommodation and assimilation, as these terms also relate to the process of scientific discovery. These terms are categorized based upon the amount of change that a student must make to their conceptual framework in order to have a complete and accurate understanding of scientific phenomenon. When students use their prior knowledge and concepts to relate to a new phenomenon, that is referred to as assimilation. The other variation, accommodation, occurs when a student's current concepts are inadequate and are unable to connect with new phenomena. Typically an accommodation requires a much more radical reorganization of a student's conceptual framework than assimilation (Posner et al., 1982). It is only when teachers recognize gradual adaptations in a student's

conceptual framework that teachers can also address, correct, or use the misconceptions as a method to ensure greater student understanding (Mayer, 2002).

As students reconstruct their conceptual framework, a teacher's goal is to help students reach a more complex, yet accurate, mental model. According to Vosniadou (2007), there are three types of mental models: intuitive, synthetic, and scientific models. These models help to explain how an individual's conceptions of a topic are or are not related to scientific ideas. At one end of the spectrum is the intuitive model which typically has no influence from science and is primarily based upon the phenomena that the individual would have experienced in their day to day lives. The other end of the spectrum is a scientific model; this level of a conceptual belief is usually obtained by educated adults as it completely agrees with scientific views. Vosniadou referred to the final type of conceptual model as synthetic as it is a combination of the two other types. Typically, the synthetic model would be most similar to what both teachers and researchers would refer to as misconceptions, or a misrepresentation of scientific beliefs, as students are combining their personal conceptions with a scientific model. However, there will be some instances where students' synthetic models do accurately portray the current scientific understanding. Data researchers will collect in this particular study are based upon this theory of conceptual change and the construction of student knowledge in the science classroom.

CHAPTER 3

METHODOLOGY

This study utilized a qualitative approach to allow students to express their individual thoughts and knowledge regarding solution chemistry. As this study is based upon the constructivist framework, it is believed that each student has their own experience and interpretation of the scientific concepts that were introduced within the solution chemistry unit. In order to capture each student's unique perspective, open-ended questionnaires and interviews are the main sources of evaluative data (Patton, 2002). This study included three distinct phases – pre-assessment, post-assessment, and semi-structured interviews. This approach was chosen as the researcher can complete each of these phases using techniques that constructivist teachers typically exhibit in the classroom. Specifically, the researcher used the four behaviors introduced by Driver (1989) in the data collection process: (1) always question students' answers, whether they are right or wrong; (2) insist that students explain any answers that they give; (3) don't allow students to use scientific terminology or specific equations without explaining their relationship to the current topic; and (4) encourage students to reflect on their own answers throughout the learning process. Through the application of these four behaviors, the researcher was able to determine not only the students' basic understanding of a concept but also the relationship of these ideas to their larger conceptual framework.

Participants

Participants within the AP Chemistry student group included junior and/or senior students who were currently enrolled in the AP Chemistry course at three different mid-

sized, suburban high schools in the Midwest. Each of these students completed at least one semester of AP Chemistry prior to the start of the study. In addition, the students also completed a full-year, high school chemistry course either one or two years prior to the current academic year as required by each of the three individual school districts. The participants in the collegiate general chemistry student group consisted of students enrolled in CHEM 1120 General Chemistry II at a mid-sized public University in the Midwest during the Spring 2017 semester. Each student enrolled in either the AP or collegiate course was invited to take part in the first two phases of this study; however, the researcher purposefully sampled the population for the interview phase based upon student responses and coding of the pre- and post-assessments. While all high school students were enrolled in the AP Chemistry course, they may have had different experiences with chemistry topics, depending on the school district they are enrolled in. However, the AP course does have an internationally mandated curriculum, which helped to regulate the chemistry topics students were exposed over the course of the school year. The researcher was not involved in teaching chemistry at the time of this study.

Materials

Participants were asked to complete a researcher-created Solution Chemistry Questionnaire (SCQ) (Appendix A) as a pre- and post-assessment to measure student understanding of basic solution chemistry topics and how those ideas changed after instruction. The SCQ contains seven open-ended questions which were formulated based upon common student misconceptions that were identified during the literature review process. This requires students to not only provide a basic answer to a question, but also

explain their reasoning behind their answer. The questions were designed to elicit responses that would demonstrate students' understanding within five different solution chemistry topics - structure of molecules, polar v. non-polar substances, types of solutions, colligative properties, and types of salts. Conceptually correct answers for the SCQ (Appendix B) were determined and recorded in advance of student completion to strengthen coding consistency during the data analysis process. The researcher, in conjunction with an AP Chemistry teacher and a UNI chemistry professor, created the SCQ to ensure the material and terminology on the assessment were comparable to the information taught in the classroom setting.

After completing the SCQ pre-assessment, classroom instruction, and the SCQ post-assessment, the researcher purposefully sampled consenting students to participate in a semi-structured, one-on-one interview. The interview was semi-structured in the sense that the researcher had pre-determined the general format and questions (Appendix C) to initiate various portions of the conversation, but students' thoughts and statements dictated the specific direction of the conversation during the interview. Interviews were based upon two different interview techniques. The first type – *interviews about instances* – involves a discussion of a specific phenomenon to encourage students to display their knowledge in relation to a real occurrence as opposed to just defining a concept. This approach includes creating or analyzing drawings in order to explain a particular concept as opposed to being directly asked to define a vocabulary term. The second type – *interviews about events* – involves students demonstrating or observing phenomena instead of just discussing or representing the phenomena in a pictorial

manner. This method could range from students engaging in a hands-on activity to demonstrate their knowledge to simply observing phenomena and describing how it relates to the larger realm of content knowledge (Taber & Garcia-Franco, 2010). The researcher used both interview approaches interchangeably throughout the interview as they provided students either with a demonstration or simple laboratory experiment to complete within each segment of the interview. The demonstrations were shown after students made their predictions and explained the reasoning behind their responses. After students provided their original answer to each question, the researcher probed students to either provide more information or consider another aspect of the same topic. If, during the interview, it appeared that the student was particularly stuck the researcher provided the student with a basic piece of information as a trigger and then asked the student to expand upon that idea based upon what they remembered.

During the introduction of the interview process, there was an emphasis on the idea that there are no right or wrong answers and the researcher was instead interested in their individual thought process. Since the researcher was working with older and more advanced students in this study, prior research suggests that an upfront explanation of the study will garner a sense of trust and cooperativeness between the researcher and interviewees. In addition, it was important for the researcher to maintain a neutral façade in regards to language and nonverbal responses to student ideas throughout the interview process so as not to sway a student's response or thought process (Osborne & Freyberg, 1985). After the completion of the interview process, the researcher used the SCQ and

statements made during the individual interviews to identify misconceptions that the students held before and after instruction.

Procedure

Pre-Assessment – Phase 1

The researcher asked all participants in both the AP Chemistry and CHEM 1120 courses to complete the SCQ assessment prior to the first day of the solution chemistry unit. As the assessment was administered via Qualtrics, the researcher directly distributed the SCQ assessment to the collegiate students via email, while the high school students were provided with the link to the survey as a part of their classroom instruction. This ensured that students had not yet received formal introduction to this material and that course instructors were not aware of which students chose to participate in the study. The parents/guardians of twenty high school students provided the researcher with the proper consent to allow their students' answers to be a part of this study. After collecting student responses, the researcher did not provide the specific results of this pre-assessment to the course instructors as a way to minimize any adaptations made to the typical course curriculum or instruction. Over the course of approximately two and half weeks, the instructors introduced their students to the topics found within the assessment in addition to many other aspects of solution chemistry. The instructors also provided students with the opportunity to participate in laboratory experiments, classroom activities and discussions, and teacher-led lectures regarding this material. The details of various activities and discussions likely varied between the AP and General Chemistry courses; however, the content covered should have remained consistent.

Post-Assessment – Phase 2

At the completion of the solution chemistry unit, it was originally intended that all the students who participated in phase 1 would be invited to complete the same SCQ assessment again. However, a small number of collegiate participants in phase 1 led to the decision to simply skip phase 2 and invite them to take part in the interview process in phase 3. This still allowed the researcher to collect data regarding the collegiate students' understanding both before and after direct instruction.

With the larger number of AP Chemistry participants in phase 1, all AP Chemistry students were invited to complete the same SCQ assessment again, using a new Qualtrics survey link. This assessment consists of the identical seven questions and, as a result, the researcher was able to use the results to determine whether the students' conceptions regarding solution chemistry changed due to the instruction they received in the classroom. In this phase, the researcher received consent from the parents/guardians to use the responses of nineteen AP Chemistry students. The researcher then identified any change in conceptions through the process of matching and reading each student's pre- and post-assessments and comparing responses for each question. This procedure helped to determine correlations between students' original thought process and potentially different answers given during the post-assessment. During this post-assessment, students were surveyed regarding their interest in participating in the interview process.

Interview – Phase 3

The methods for obtaining AP and collegiate chemistry participants were different in phase 3 as well due to the low collegiate student participation in phase 1. Collegiate students who completed the SCQ in phase 1 were contacted first and asked to participate in the interview process. After those interviews were scheduled, a Qualtrics interest questionnaire was sent out to all students enrolled in the CHEM 1120 General Chemistry II courses to solicit more volunteers to take part in the interview process.

Since AP students completed both the pre- and post-assessment SCQ, the results from these two assessments were linked and compared for the students who had received proper parental consent. Once the researcher had determined how AP students' conceptions had changed over the course of instruction, AP students who were willing to participate in the interview process were contacted once again. Using the students who were willing to participate, maximum variation sampling occurred in preparation for the interview process. Maximum variation sampling allowed the researcher to purposefully choose interviewees that represented a wide variation of responses present in the previous two phases (Patton, 2002). Seeing as the goal of this research was to determine the misconceptions that are present before and after instruction, it was important to interview AP students who represented a variety of SCQ outcomes. This includes students that had answered all questions correctly, students that had no answers correct, and other variations of correct/incorrect answers from both the SCQ pre- and post-assessments.

Through the processes outlined above, the researcher selected both AP Chemistry students and collegiate general chemistry students to take part in the interview process. In

order to obtain an accurate transcript of the events within each interview, LiveScribe technology was used. This pen is designed to record audio while also electronically tagging any information that may be written onto paper at the same time. This technology allowed the researcher to return to student drawings and representations after the interview and determine how the students' verbal descriptions related to their written expressions.

The interviews took place towards the end of the spring semester, after the students had moved onto a new unit of study in the chemistry classroom. As mentioned previously, the interviews were semi-structured to allow student conceptions to drive the conversations and to gather an in-depth view of the students' understanding of solution chemistry and its relationship to the particulate nature of matter. The interviews ranged in length from fourteen to twenty-six minutes, but most were approximately twenty minutes long. This variation in interview length can be attributed to the fact that students' responses to each of the questions determined how long the discussion for each specific question took. Segments of varying lengths occurred based upon the depth and the breadth of information provided by individual students. The students were interviewed at their respective course's location and compensated for their participation with a \$25 Amazon gift card. All data collection and recruitment methods were reviewed and approved by the University of Northern Iowa's Institutional Review Board (HP# 17-0114).

Data Analysis

The researcher developed the SCQ in conjunction with an AP Chemistry teacher and a UNI faculty member who teaches in the General Chemistry sequence to ensure the validity of the assessment in terms of content covered and the types of academic language used within the questions. In addition, the use of the SCQ pre-assessment, post-assessment, and open-ended interview questions allowed the researcher to triangulate results to ensure that student responses are valid and consistent throughout the study. After all the interviews were completed, the data were analyzed using qualitative analysis software and, as the researcher analyzed the students' responses to each of the questions, a coding system was developed. There was only one coder for this particular study, so intercoder reliability was not possible but, instead, the researcher established a codebook to ensure consistency of the definitions of each code throughout the duration of the project. This coding system allowed the researcher to identify common themes and then further develop an understanding of the relationships present amongst responses from different students, questions, and solution chemistry topics. The researcher also invited a fellow chemistry educator to review the codebook and various sections of data as a form of cross-checking at various times throughout the study.

The MAXQDA Analytics Pro 12 program was used to organize and aid in the analysis of qualitative data collected as a part of this study. Student responses collected as a part of both phases 1 and 2 from the SCQ pre- and post-assessments were imported from Qualtrics and student interview data (both the LiveScribe audio and notebook pages) were imported as well. From there, the interviews were transcribed by the

researcher and the images drawn by students were appropriately linked and inserted into the transcripts. The students were quite hesitant to use the pen unless directly asked to draw a picture or other visual representation. For this reason, very little pictorial data was collected during the interviews. The few images collected from each student were integrated into the text transcripts as supplemental material and the text-based transcript documents were solely used as the data set for phase 3 analysis of the student interviews. Each data set – AP pre-assessment, collegiate pre-assessment, AP post-assessment, AP interviews, and collegiate interviews – was analyzed separately.

The pre-assessments were analyzed first for each of the participant groups, followed by the post-assessments and then the interviews. Neither the pre- nor post-assessments were analyzed according to the developed coding system until all three phases of the study were complete. This helped to ensure that the analysis process was consistent and the intention of the codes did not change over the course of the study. The pre-assessments were first coded based upon which question the student was responding to so that all student responses to similar questions could be coded successively. This method was enacted to increase the reliability of results. As student responses were being separated by question type, any response such as “don’t know,” “no idea,” “not sure,” “?” etc. was placed into a code of “No Real Response” to ensure that it was not placed into a different coding category later in the analysis process. These responses did not provide any insight into a student’s understanding and would not help the researcher to come to any conclusions regarding student misconceptions or the research questions being investigated.

After this initial sorting of responses was complete, any incorrect or incomplete student responses were filed into one of five codes – types of salts, colligative properties, structure of molecules, polar v. non-polar, and types of solutions. These codes were created by the researcher to encompass the five topics in solution chemistry which were the focus of this study, again, based upon misconceptions that were uncovered within the literature review. This same coding process was then repeated for both post-assessments and interviews. Once the data from all three data sets were coded into the five overarching codes, the responses within each code were revisited and compared to one another to create subcodes. These subcodes focused in on specific aspects of chemistry that could affect a student's understanding of solution chemistry concepts. For example, within the code of 'Polar v. Non-polar,' the following subcodes were created: saturation, surface tension/intermolecular forces, basic explanation (layers, etc.), switch of polar and non-polar, solubility, and density. All of the codes and subcodes established during the data analysis are seen in Figure 1 below, and examples of student responses within each subcode are provided in Appendix D.

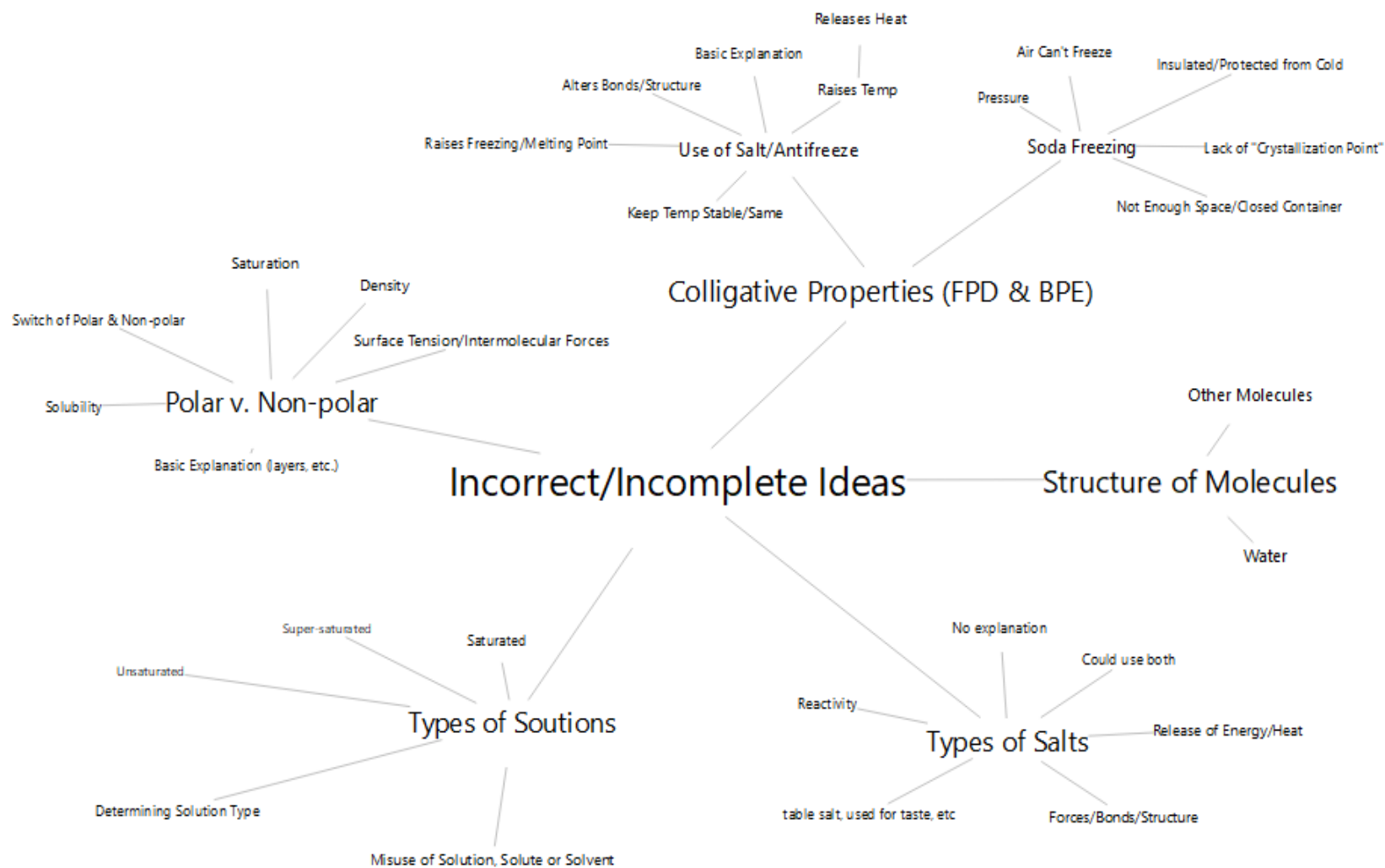


Figure 1 – Relationships between Codes and Subcodes Developed from Student Responses

CHAPTER 4

RESULTS

Participants

Within the two population groups – high school AP Chemistry students and collegiate general chemistry students – there were students who started the SCQ, but either did not finish the survey or did not provide consent for their responses to be used. Of the 49 high school students who completed the SCQ as a part of their AP Chemistry course, 19 of the students had proper consent (from both self and a parent/guardian) to allow their answers to be used as a part of the study. The collegiate population consisted of 132 students who were currently enrolled in the CHEM 1120 General Chemistry II course at a mid-sized public University in the Midwest. However, of the 132 students enrolled in the course, 23 students started the survey and only two fully completed the SCQ pre-assessment.

The reason for 21 potential college participants not fully completing the pre-assessment is not implicitly known; however, the length of the survey and the lack of instructor follow-up are two likely possibilities. Most of the collegiate students who began the survey made it through the initial background information but did not answer any of the seven chemistry content questions. The fact that the questions were all open-ended may have led to a perception that the survey was too much work and not worth the potential compensation, which did not come until Phase 3 of the study. During phase 3, four additional collegiate students responded to the interest survey, leading to a total of six interviews scheduled with collegiate students. When the interviews took place, two

students did not show up and the researcher was unable to get into contact with them to reschedule – this led to a total of four collegiate interviews being completed. The number of students participating in each phase of the study is outlined in Table 1.

Table 1

Number of Student Participants by Phase

Phase of Study	# of AP Students	# of Collegiate Students
Pre-Assessment (phase 1)	20	2
Post-Assessment (phase 2)	19	N/A
One-on-One Interview (phase 3)	5	4

Basic demographic information was collected from students during the SCQ pre- and/or post-assessment to associate pre- and post-assessment data for individual students. This demographic information included: first and last name, previous chemistry courses taken, and email (if interested in participating in the interview portion of the study).

Research Question #1 – Misconceptions of AP Chemistry Students

Structure of Molecules

There were no misconceptions identified regarding the structure of molecules within the SCQ pre- or post-assessment. This is most likely due to the students not being explicitly asked to describe or draw the structure of different molecules as a part of the SCQ question stem. However, during the more in-depth questioning and clarification

process of the one-on-one interviews, two different students misused scientific vocabulary terms when describing the structure of water and salt (sodium chloride – NaCl). One student incorrectly identified the undissolved salt at the bottom of their drawn

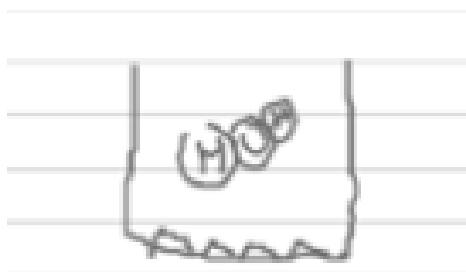


Figure 2 – AP Student Drawing with NaCl as ‘Precipitate’

beaker as a ‘precipitate’ (Figure 2). This may not be an unusual misconception because while a precipitate is a solid, it is by definition, a solid that deposits out of solution after the mixing of a second substance or change in temperature, not just a solid that did not dissolve and is resting on the bottom of the beaker (Britannica, 2014). A second student was attempting to describe the bent shape of a water molecule and tried to use the term ‘polarity’ in their explanation. This particular student identified that there would be negative and positive ends to the water molecule, but they incorrectly suggested that those ends would repel one another, increasing the polarity of the molecule and providing for the bent shape of water. However, opposite charges should attract one another and the difference of charges is not the reasoning behind the bent shape of a water molecule.

Polar v. Non-polar Substances

During the pre-assessment, the misconceptions which were identified included ideas such as: density, saturation, or the fact that the two substances just ‘don’t mix’.

These responses showed that the students had a very wide range and basic understanding of the difference between polar and non-polar substances (Table 2).

Table 2

Sample AP Student Responses Regarding Polar v. Non-polar Substances

<u>Phase of Study</u>	<u>Sample Student Responses</u>
Pre-Assessment	<ul style="list-style-type: none"> • When one attempts to combine oil and water, the water forms a layer on top of the oil. • Oil is not soluble in water • Water is less saturated than oil • Oil and water do not mix because the surface tension between the two substances repel each other. • The H⁺ ions and the OH⁻ ions present in water don't form compounds with the molecules present in the oil so the two liquids do not mix. • This is true because of the differing densities of the liquids. The water is less dense than the oil and the oil will settle to the bottom.
Post-Assessment	<ul style="list-style-type: none"> • Oil is supersaturated so and water isn't • Different intermolecular forces that repel one another • Oil can be a colloid (water-hating) which leads to the separation of oil and water instead of mixing. • Oil is polar and water is non-polar • They don't mix because they have different densities and different intermolecular forces that repel one another.
Interview	<ul style="list-style-type: none"> • I believe the water would end up on top

During the post-assessment, the students were providing explanations that were more complex in nature and were more accurate than those previously provided. Some of the misconceptions identified in the post-assessment included ideas such as polarity, intermolecular forces, a substance being “water hating,” and different elements being present in the structure of the substances. While these ideas are still inaccurate or

incomplete explanations, students were more accurate as there were less references to differences in density and more discussion regarding the structure of the molecules.

Based up upon these results and the lack of misconceptions identified during the interview, one can identify the students' shift to a more complete understanding of the differences between polar and non-polar substances.

Types of Solutions

This category included multiple questions regarding solutions and how to differentiate between the three different types – saturated, unsaturated, and super-saturated. Students were not only asked to explain the differences between the three types of solutions in terms of their definitions, but also to describe a process that would allow them to actively determine which type of solution was present in a provided beaker. The types of misconceptions that were identified in all three phases of the study were grouped into five categories – saturated, unsaturated, super-saturated, process to determine the type of solutions, and misuse of scientific vocabulary.

Student responses varied greatly as students worked to describe the difference between saturated, unsaturated, and super-saturated solutions in the pre-assessment. Some of the initial student misconceptions regarding the differentiation of the three types of solutions included statements regarding what type of substance is present and/or the structure of a substance within the solution. Sample student responses regarding saturated solutions are seen in Table 3.

Table 3

Sample AP Student Responses Regarding Types of Solutions

<u>Phase of Study</u>	<u>Sample Student Responses</u>
Pre-Assessment	<ul style="list-style-type: none"> • Saturated solution is a substance that has starch in it. • Saturated has bonds to hydrogen, but some (or at least one) of the bonds isn't to a hydrogen • Saturated solutions have a maximum concentration of something dissolved in something else • Saturated solutions have multiple types of molecules
Post-Assessment	<ul style="list-style-type: none"> • Saturated has some single and some multiple bonds • The cloudy solution is saturated
Interview	<ul style="list-style-type: none"> • Saturated, would be with water and salt...I believe it is equal amounts of water and salt • It is saturated because it doesn't look like there is anything in there and it just looks clear

With regards to super-saturated solutions, one student described it as a solution that is “more full” of water than other types of solutions. This answer is analogous to a saturated or super-saturated sponge, as that sponge would be over-filled or dripping with water. However, when comparing the responses provided in the post-assessment, the range of misconceptions was much narrower. The two main misconceptions identified were based on the structure of the molecules in the solution or how much of a substance has been dissolved into the solution. While taking part in the interview process, students exhibited similar misconceptions as those seen during the post-assessment. As students were probed further and asked to draw a representation of each type of solution, multiple students focused on the ratio between the number of water and salt molecules present in the solution as the main way to differentiate between the three types of solutions. Students suggested that a saturated solution would have a one-to-one ratio of water

molecules to salt molecules, an unsaturated solution would contain more water molecules than salt molecules, and a supersaturated solution would contain more salt molecules than water molecules (Figure 3).

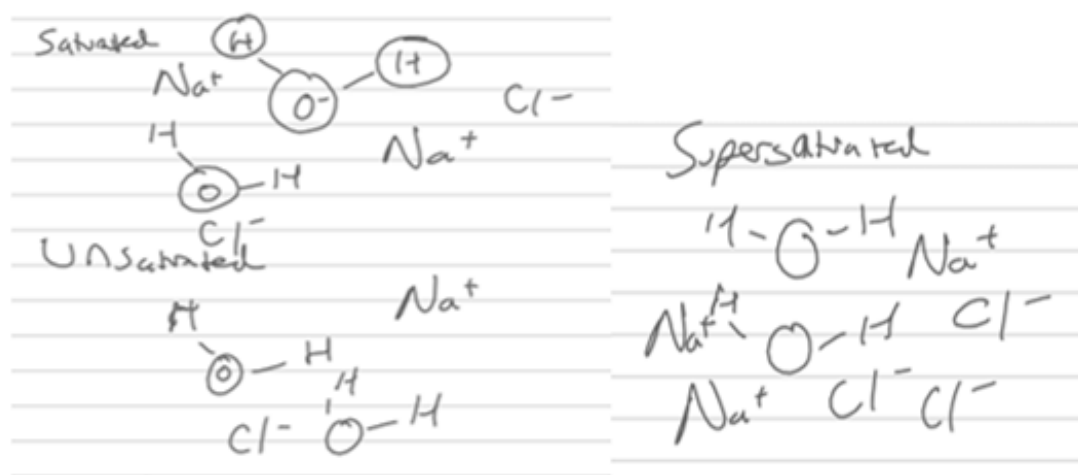


Figure 3 – AP Student Drawing of Saturated, Unsaturated and Supersaturated Solutions

With regards to determining the type of solution present in an unknown beaker, students had many suggestions regarding processes to follow both in the pre- and post-assessments. However, during the interview process, all but one student could accurately describe the process of adding a small amount of the solute to the solvent to see what would happen next. That one student suggested allowing the water to evaporate away and see how much of the solute was left behind. This suggestion was closer to the correct

interpretation than previous student responses. The pre-assessment and post-assessment responses can be seen in Table 4.

Table 4

Sample AP Student Responses Regarding a Lab Procedure to Determine Solution Type

<u>Phase of Study</u>	<u>Sample Student Responses</u>
Pre-Assessment	<ul style="list-style-type: none"> • Boil off/separate the solute and solvent and then calculate concentration • Add water to the solutions and see which is less dense • Cooking them with oil, and then eating them. Since the different amounts of starch would show the differences, you could tell which one is which. • You could compare an unknown solution to a measured proportional control and compare the appearances to tell if it's saturated or unsaturated. To be sure, you could also pick a colored substance to use. • React the solution and see what is left over. • Using two filters one normal and one that will drain less than the other put the solution through them.
Post-Assessment	<ul style="list-style-type: none"> • Heat, less saturation evaporates faster • Try to boil out the solutions - the supersaturated will boil out the quickest because the single bonds (and the intermolecular forces associated with them) are the weakest/easiest to break, and the unsaturated will boil out last/be the one remaining at the end. • If you can visibly tell the difference between two substances in a solution then it is unsaturated. If you can take a solution and evaporate the liquid and get a solid left behind then it is saturated.
Interview	<ul style="list-style-type: none"> • Like most things, if it were let's say salt dissolved in water, you could evaporate the water out and then you should have what was the solute left behind

The wide variety of answers within the pre-assessment correspond directly with the definitions that the students provided in the pre-assessment as well. For instance, a student that suggested the type of solution is based upon how much starch is present in

the solution also suggested that one could cook and then taste an unknown type of solution to determine which one it is. Similarly, the methods students suggested for determining the type of solution present in the post-assessment were related to the definitions of each solution type provided by the students. There was a smaller range of misconceptions present in this portion of the post-assessment. Just as was seen in the polar v. non-polar category, the explanations from the post-assessments and interviews were focused more upon understanding the molecular structure of substances than students' previous answers.

There were also some students who misused specific scientific vocabulary in both the pre- and post-assessments, as seen in other categories as well. The most commonly misused words within this section were 'solute,' 'solvent,' and 'solution'. However, without being able to clarify the students' intentions or explore their understanding in greater detail, the switching of these words could just be due to typing the wrong word by accident or due to the significant similarity in spelling and pronunciation between the three. While some students still held misconceptions after classroom instruction with regards to types of solutions, there is a distinguishable shift towards the correct thinking from the pre- to the post-assessment/interview as most of the misconceptions late in the study were due to either incomplete answers or over-simplification of a complex concept.

Colligative Properties

Three SCQ questions focused on colligative properties, specifically, how solutions are affected by pressure or how the freezing and boiling points of a solution differ from those of the solvent. One question – why doesn't a bottle of soda freeze until

you remove it from the freezer and take off the lid – was only addressed on the SCQ and not as a part of the interview process. During the pre-assessment, AP students attributed this phenomena to the misconceptions seen in Table 5.

Table 5

Sample AP Student Responses Regarding Pressure and Soda Bottle Freezing

<u>Phase of Study</u>	<u>Sample Student Responses</u>
Pre-Assessment	<ul style="list-style-type: none"> • The can around the soda keeps its heat inside and protects it from the cold for a while. However, once the soda is open and there is a gap in the can's protection, it freezes faster • In order for an object to crystallize, a single point around with the crystallization occurs must be present. Such a point does not exist in a bottle of soda, so in spite of the fact that the liquid reaches the freezing point, the liquid would not freeze until something occurs to create this single point • Because there isn't enough room for it to freeze • Something about pressure I think • The soda needs oxygen to be frozen without oxygen or any outside gas the soda is unable to freeze.
Post-Assessment	<ul style="list-style-type: none"> • The soda bottle cannot freeze • Liquids need a point to coalesce around to freeze. as such, a liquid in a soda bottle, as long as there are no points to coalesces around, will not freeze • The pressure with the lid on is high enough that it will keep the particles moving/preventing it from becoming solid and freezing • The closed off container creates a warmer atmosphere for the soda which makes it harder to freeze while an open container makes it easier to freeze. Also, it may have something to do with the space soda takes up in solid and liquid form

The first three misconceptions listed in Table 5 represent the most common misconceptions among the students and the most straightforward explanations. Many students have discussed within previous science courses that objects can act as insulators

to keep other objects warm and ‘protect’ it from the colder temperatures outside the object or, in this case, bottle. Also, students have often been introduced to the idea that water expands as it freezes, so it would not be surprising for them to attribute this characteristic to soda, another liquid, as well. During the post-assessment, very similar misconceptions were identified, as seen in Table 5. For instance, students still suggested that the soda can’t freeze because it is insulated, there is a lack of a crystallization point, and solid soda takes up more space than liquid soda. While the post-assessment explanations are still not accurate, the students did tend to provide more details in their responses, leading to more specific evidence of the students’ understanding. Also, there were two responses that were only identified in the post-assessment: (1) air molecules go into the bottle to make it freeze once it is opened, and (2) since the vapor pressure is higher when the lid is on, which keeps particles from freezing, the liquid can’t expand until the bottle is open.

The other two questions – why do we use salt on sidewalks and why do we use antifreeze in a car – both focused on how adding solute can affect the freezing and boiling points of a solution. Many of the responses in the pre-assessment were very basic explanations, as seen within the first five responses in Table 6. While some of these explanations are not wrong, they did not suggest that students had any scientific understanding of the processes occurring. Some scientific explanations were also provided by students, as seen in the last four pre-assessment responses in Table 6. However, in many cases, the scientific vocabulary students used did not pertain to the

topic at hand or it was used incorrectly to try to explain the change in freezing and boiling points.

Table 6

Sample AP Student Responses Regarding Changes in Freezing and Boiling Point

<u>Phase of Study</u>	<u>Sample Student Responses</u>
Pre-Assessment	<ul style="list-style-type: none"> • So that you can keep the car windshield clean without it fogging up • Antifreeze would be placed in the radiator of a car to undo freezing • The salt melts the ice • Salt causes the ice to melt • Salt absorbs water • The obvious answer is that it makes it less slippery because it can melt the ice due to the salt altering the bonds and form of the ice/water. • The salt raises the freezing point of the water by mixing with it, making it harder for it to turn into ice. The phenomena is the changing physical properties of mixtures. • Antifreeze is used to prevent the radiator from getting too hot or too cold, which can occur but the amount emitted from the reaction that runs the radiator - if there is not enough, it will be too cold, if there is too much, it will overheat. • Salt is placed on sidewalks because it reacts with the frozen water to release heat and melt ice. Salt reacts in an exothermic reaction to melt ice.
Post-Assessment	<ul style="list-style-type: none"> • It is placed because the bonding CaCl_2 has would break down the ice. The intermolecular forces is the reason it would break it down. The bonding works because of the molecules. • Salt helps facilitate the melting of ice because the polar salt and polar water want to stick together, so the solid dissolves. • Because it melts ice • Salt is placed on the sidewalks and roads during the winter because of the freezing point elevation phenomena. The salt raises the freezing point of the water so that it will stay in the liquid phase longer instead of freezing and creating ice. • It reacts with the ice to melt it. It creates an exothermic reaction releasing heat.
Interview	<ul style="list-style-type: none"> • I think it has more to do with the bonds to prevent what is already in your car from freezing so that you don't freeze your pipes • I think it is increases the melting point of water or ice...no, just of ice because it is melting. • I think it wants to break up water so that increases the temperature so that the ice will melt. It is more of heat in the terms of energy that it is providing. It is coming from the salt bonds breaking apart, which is releasing energy.

When coding both the responses from the post-assessments and interviews, common themes emerged, including the ideas of bonding, polarity, intermolecular forces, and the release of energy and/or heat as bonds break apart within the molecules. Again, these ideas can be identified as misconceptions but students showed a progression in their understanding as these responses illustrate a more complex understanding of chemistry topics. Another common mistake made by the students was reversing the affect that the solute would have on either the freezing or melting point. Many students suggested that the freezing/melting point would elevate (in other words the ice would form at warmer temperatures) or the boiling point would be depressed (water would start to boil at a lower temperature). This misconception was identified in both the post-assessments and the interviews, suggesting that it is potentially a common mistake amongst the AP chemistry students.

There were still a few student explanations that were basic (or did not provide evidence that the student possessed a scientific understanding of the phenomenon) coded within the post-assessments, but none in the interview process. This could be attributed to a couple of different things. First, when students are asked to write their responses, they are more likely to make their answers as short as possible. This approach could have led students to providing simple answers, even when they did possess a more complete understanding. Also, during the interview process, the researcher was able to ask probing questions to encourage students to provide more detail and clarify their understanding of the concepts being discussed.

Types of Salts

Within the questions coded to the category ‘Types of Salts,’ students were asked to consider what type of salts would be the best option for melting or preventing ice build-up during the winter. The two options provided to the students were NaCl (sodium chloride or table salt) and CaCl₂ (calcium chloride). In the pre-assessment, students with misconceptions focused on the amount of energy that is released when the bonds of the water molecule break and the differences in structure between NaCl and CaCl₂, as seen in Table 7. There were four students who had answers regarding NaCl being table salt as they believed that table salt cannot be used since it is for flavoring and would dissolve in the water too quickly.

Table 7

Sample AP Student Responses Regarding Types of Salts

<u>Phase of Study</u>	<u>Sample Student Responses</u>
Pre-Assessment	<ul style="list-style-type: none"> • Calcium chloride would work better because the energy released by breaking the ionic bond between the ions is greater than the energy released by sodium chloride. • CaCl_2 would be more effective because it is a more powerful salt. • CaCl_2 because NaCl is not as reactive, as it is safe for humans to consume. Therefore, as CaCl_2 is more reactive, it will be more effective. • Probably CaCl_2. Last time I checked no one was putting table salt on the sidewalks. • CaCl_2, my gut feeling. Also, NaCl is only table salt, and would not lower the freezing point of the water as much.
Post-Assessment	<ul style="list-style-type: none"> • CaCl_2 would work better to melt ice because it is a larger molecule and when it reacts with water molecules it produces heat • NaCl would. NaCl is an ionic compound therefore it would have a stronger bond so it would have more a higher impact on the water/ice. NaCl is also non-polar like water, like dissolves like, so the non-polar NaCl molecule will dissolve the non-polar water. • Whichever one is more polar cause it would then attract to the water molecule more. So possibly CaCl_2 because it is a bigger molecule? • The CaCl_2 salt works better because calcium has a lower melting point than sodium so the ice melts faster. • CaCl_2 would work better because it has a higher lattice energy and a stronger pull on the water molecules.
Interview	<ul style="list-style-type: none"> • I don't think it is due to the mass of them...I think part of it will have to do just with where the elements are on the periodic table and their strength. I don't want to say electronegativity, because I think it is something else. Ummm....more to do with where they are placed and the strength of those bonds. So I think that the NaCl has bonds that can break apart and release more energy than the CaCl_2 • Ok. Ummm...you know, I have never heard of people adding calcium chloride to sidewalks, so I am guessing that salt would be better...for some reason...ummmm...electronegativities...ionic bonds...stronger ionic bonds with bigger atoms, I believe...so, NaCl would have...it would more easily become ions, which would affect the melting point? I am guessing. • I think that NaCl would work better because it is more ionic and ionic bonds are the hardest ones to break apart.

Many of the same misconceptions were present within the post-assessment as well. However, instead of most incorrect responses focusing around the idea of NaCl being table salt, the students provided explanations based upon differences in the polarity and structure of the NaCl and CaCl₂ molecules. The three misconceptions identified during the interview process were a mixture of those seen in the pre- and post-assessments. However, the idea of electronegativity was introduced by the students for the first time as a part of the interview process. This suggests that the students are trying to explain why the bonds are different within NaCl and CaCl₂ as opposed to just stating that there is a difference between the two substances. This follows a similar pattern as seen in previous sections, while students may still hold conceptions that are not fully correct or complete, their understanding is developing and they are integrating new information into their pre-existing conceptual frameworks.

Summary

Overall, AP Chemistry students possessed misconceptions in all three stages of the study – pre-assessments, post-assessments, and interviews. However, students did seem to progress in their understanding of chemistry topics over the course of classroom instruction. Misconceptions identified within the pre-assessments were much more basic and did not contain as much scientific vocabulary or conceptual information as those identified within the post-assessments and interviews. While students may not have a perfect understanding of solution chemistry topics at the completion of the unit, their explanations were becoming more complex and scientific in nature.

Research Question #2 – Misconceptions of Collegiate General Chemistry Students

With only two responses for the SCQ pre-assessment within the collegiate population, it is much more difficult to fully grasp the shift in understanding of the college student population as a whole. However, there were still misconceptions that were identified during both the pre-assessment and interview phases of the study. The misconceptions that were uncovered during the interview process will provide a better view of the collegiate students' level of understanding with regards to solution chemistry after direct classroom instruction.

Structure of Molecules

There were no misconceptions identified regarding the structure of molecules in the student responses from the SCQ pre-assessment. Again, the SCQ did not directly ask students to draw or explain the structure of molecules as a part of their explanations. However, there were a couple of misconceptions identified during the interview process. One misconception was that water has a linear shape (when it is in fact bent) and that the linear shape would make it a polar molecule. Most linear shapes (such as the one drawn by the student in Figure 4) would be considered a non-polar molecule.



Figure 4 – Collegiate Student Drawing Representing the Incorrect Shape of Water

The second student held an entirely different misconception on drawing the water molecule. While the student identified water as H_2O , they explained that it was created with “a hydrogen and two oxygens...there are two oxygens for each hydrogen.” In actuality, water (H_2O) has two hydrogens and one oxygen. This misinterpretation of the number of atoms might be explained by the fact the molecular formula is read as ‘H two O’ and we typically read from left to right. In other words, there is a hydrogen and two oxygens. This misconception was carried throughout the entire interview, including in the student’s drawings of a water molecule (Figure 5).

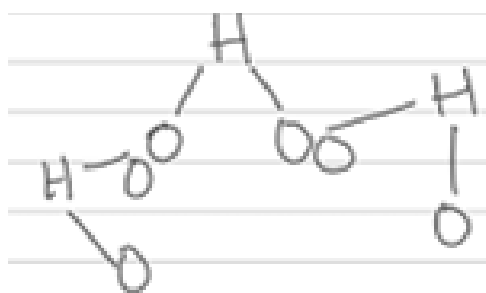


Figure 5 – Collegiate Student Drawing of Water with Incorrect Molecular Structure (HO_2)

Polar v. Non-polar Substances

No misconceptions were identified regarding the differences between polar and non-polar substances in the student responses from the SCQ pre-assessment. However, during the interviews, several misconceptions arose as students discussed the types and strengths of bonds that are present in either water or oil. One student suggested that oil and water stay separate in a beaker due to the very strong bonds between the oil and

water molecules and the fact that the already existing bonds are not breaking apart to reform new bonds. Therefore, this causes the two substances to be “separate but equal.” The other student suggested that it does not matter what type of bond (single, double, or triple) is present, a molecule would be polar just because it is linear. This explanation is very similar to the misconception identified within the *structure of molecules* code as well. The collegiate students did not demonstrate the misconceptions of polar/non-polar molecules being differentiated by density, solubility, or layers in either the pre-assessment or interviews as was seen with the AP students.

Types of Solutions

As mentioned previously, this category included multiple questions regarding solutions and how to differentiate between the three different types – saturated, unsaturated, and super-saturated. The misconceptions that were identified in either the pre-assessment or interview were grouped into five categories – saturated, unsaturated, super-saturated, misuse of scientific vocabulary, and process to determine the type of solutions. However, there were no instances of collegiate students misusing terms such as solution, solvent, and/or solute in either the pre-assessments or interviews.

Fewer misconceptions were identified for this code in the pre-assessment than during the interviews. However, with only four unique participants between the two stages, the *number* of misconceptions identified can be very misleading. In the pre-assessment, students focused on how much of a substance was present in the solution as a way of determining which type of solution was being discussed (Table 8).

Table 8

Sample Collegiate Responses Regarding Types of Solutions

<u>Phase of Study</u>	<u>Sample Student Responses</u>
Pre-Assessment	<ul style="list-style-type: none"> • Saturated should have high levels of a substance in solution • Unsaturated should have low or equal levels of each substance in the solution • Unsaturated is a mixture of water and oil • None dissolves = supersaturated • Saturated should have high levels of a substance in solution
Interview	<ul style="list-style-type: none"> • I guess if it were super-saturated, you would have to go by viscosity. And even, I guess, if it were at room temperature and it was super-saturated and you tried to add more, nothing would happen. You would have to re-heat it, I think, in order to get it to dissolve. • For saturated, if you have enough water...salt in the water...then you can get it to the point where you have little flakes at the bottom, you could say it is saturated because almost all of it dissociated but there is still a little bit left, meaning that you have enough H₂O to NaCl molecules • If you are putting a saturated solution...or as much as it can hold comfortably, I imagine that the salt would start to turn the water a little bit of a different color

While the definitions provided by the two students are not too far off from the correct understanding, the suggestion that oil must be the substance added to the solution is definitely a misconception. In addition, the same student suggested that one should be able to determine the type of solution solely based upon sight (Table 9). In other words, the color and the appearance of each solution type should be different. However, this is not the case as one would need to add more of the solute to the beaker and watch what happens to the solute to determine the type of solution.

Analysis of the interviews uncovered similar types of misconceptions. When students were asked to draw a molecular representation of the three solution types,

students focused in on the ratio of water and salt molecules in the solution – saturated had close to a one to one ratio, unsaturated had more water, and super-saturated had more of the solute than water molecules (Figure 6).

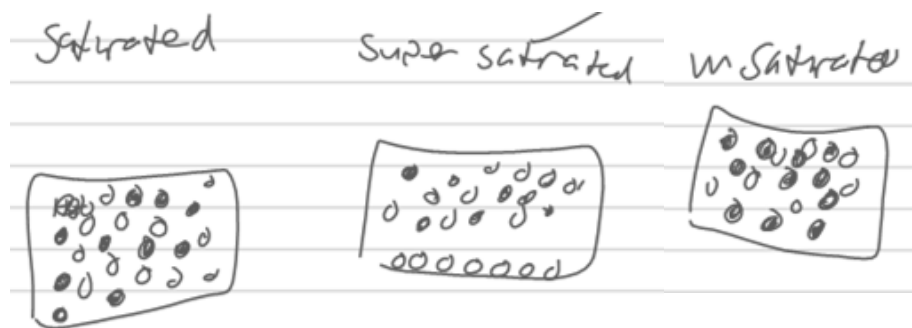


Figure 6 - Collegiate Student Drawing of Saturated, Supersaturated and Unsaturated Solutions

Unlike the pre-assessment, there was no mention of oil or other specific substances that must be present in any of the three types of solutions during the interview process. While students could describe the different types of solutions more accurately, there was still some confusion as to how to determine what type of a solution was present in a beaker with unknown contents (Table 9).

Table 9

Sample Collegiate Responses Regarding a Lab Procedure to Determine Solution Type

<u>Phase of Study</u>	<u>Sample Student Responses</u>
Pre-Assessment	<ul style="list-style-type: none"> You should be able to determine, based on the other two, by sight or by testing the level of each substance in a solution which is saturated and which is unsaturated (saturated should have high levels of a substance in solution, while unsaturated should have low or equal levels of each substance in the solution)
Interview	<ul style="list-style-type: none"> Depending on what the solute and solvent are, you might be able to tell if the color of the water changes or it looks a little bit cloudy, not if you could see individual particles, but...ummm....but like, if it just water and salt, um...I don't know. If it is super-saturated, you should be able to tell by the viscosity....I think. I don't know...the only super-saturated solution that I know is syrup. So it is very thick and...yea...between saturated and it is just right on the line of saturated and you can't see any excess particles, I don't know how you would tell that apart. Ok. You can actually boil all of the water out and then there will be a salt residue at the bottom. Now, I wouldn't know how to tell whether it was saturated or super-saturated or what was actually there. Umm....you could boil the water out, put it over a filter, and you could keep doing that cycle until it is basically just water by itself. But I wouldn't know how to tell if it was saturated, super-saturated, or unsaturated. The way that I would probably do that is by measuring....so salt has a certain pH so I would probably measure the pH level of the water in the room...Based upon the amount of salt, that is going to affect pH. Take measurements of the water in the room so that you can start with that as your baseline and then you can see what happens...you know, like take the pH of pure water and pure salt and if we can take them in solution, that will affect the pH a little bit...probably...

A couple of students again focused in on the idea of a difference in color or appearance as a way to differentiate the three types of solutions. These students suggested that salt would start to turn a saturated solution a slightly different color, while an unsaturated solution does not have enough of the solute so you would only find salt (or any other solute) in certain sections of the beaker so it would appear fairly clear. Lastly, a super-saturated solution would be more viscous and cloudier than the other two types.

There was also one misconception uncovered during the collegiate interviews that did not appear in any other stages of the study (Table 9). One student suggested that measuring the pH of the solution would help to determine which type was present. The student went on to explain that one could start with the pH of the pure water being used in the experiment and then slowly add salt and measure the pH repeatedly. One would continue this process until the pH of the new solution was the same as the pH of the unknown solution. Based on how much salt has been used to reach that pH value, one could determine if the solution was saturated, unsaturated, or super-saturated.

Colligative Properties

Three SCQ questions focused on colligative properties, specifically, how solutions are affected by pressure or freezing point depression/boiling point elevation. One question – why doesn't a bottle of soda freeze until you remove it from the freezer and take off the lid – was only addressed on the SCQ and not as a part of the interview process. During the pre-assessment, this phenomenon was attributed to a change in pressure by both students. One student simply stated that the pressure would change when the bottle was opened and some of the gases were able to escape. The other student suggested that the vapor pressure of the soda inside the bottle may be retaining heat, keeping the liquid from freezing. Since this topic was not covered as a part of the interview process, there is no post-instruction data available for the collegiate students.

The other two questions – why do we use salt on sidewalks and why do we use antifreeze in a car – both focused on how adding solute can affect the freezing and

boiling points of a solution. Within the pre-assessment, the misconceptions that were identified revolved around the concepts of heat and temperature (Table 10).

Table 10

Sample Collegiate Student Responses Regarding Changes in Freezing and Boiling Point

<u>Phase of Study</u>	<u>Sample Student Responses</u>
Pre-Assessment	<ul style="list-style-type: none"> • Antifreeze is used to keep the inside of the radiator at a certain temperature, regardless of the temperature outside of the radiator, so the car's temperature remains stable. • Salt raises the temp of the ice to make it unfreeze. • Salt, when it dissolves in water, generates heat from the intermolecular forces between the salt particles being broken apart, which will turn ice into water.
Interview	<ul style="list-style-type: none"> • When stuff freezes, the molecules don't move as much to make it solid. So maybe it is keeping the molecules moving so that they stay liquid. • We have ice on the sidewalk and we throw some salt on there. And let's say we are at 30 degrees...it would not have to get colder for that ice to reform. So that is why when it is super-cold in the winter, the ice on the roads doesn't work. You can't do that anymore...you can't...ummm...raise the ice's melting point to a point where it actually works. • To raise the melting point of ice...to melt the ice. It doesn't just melt the ice, it raises the melting point. • Antifreeze is doing the same type of thing that we do with salt, we are just trying to keep it at a buffered temperature so that it doesn't get to a freezing point, I believe.

Students incorrectly suggested that the addition of salt raises the temperature of the ice to make it unfreeze and that salt generates heat when the forces between salt molecules are broken apart, which can then turn ice into water. These misconceptions are likely based upon student's interactions with ice and melting in their day-to-day lives. With regards to

antifreeze, students are typically not familiar with the process that occurs within the radiator of a vehicle. One student suggested that antifreeze is used to keep the radiator at a consistent temperature, regardless of the temperature outside. While this is not necessarily the same approach as ice releasing heat to cause melting, it does suggest that students understand that antifreeze affects the properties of the radiator solution both at high and low temperatures.

Interview answers, however, shifted from misconceptions regarding changes in heat and temperature toward those regarding a change in the melting or freezing point of a solution. Answers that did mention the idea of heat and/or temperature included much more detailed explanations compared to the pre-assessment, including a description of how molecules were moving in the solution (faster/slower/etc.) before and after adding the salt or antifreeze to the solution. While there were some of the same misconceptions present, students were using chemistry concepts to explain why they thought that way, even if it did not pertain to this phenomenon. As mentioned previously, students were more likely to reveal misconceptions regarding the change in the freezing and/or melting points during the interview process. These students suggested that the melting point was being raised when the salt was added. This would mean that the ice was able to stay frozen longer, as it would have to be warmer outside for the ice to melt. This is the opposite of what is known to happen as a part of the freezing/melting point depression phenomenon. There were no misconceptions about how adding salt or antifreeze would alter the bonds or structure of molecules in either the pre-assessment or interviews of the college students.

Types of Salts

Within the questions coded to ‘Types of Salts,’ students were asked to consider what type of salts would be the best option for melting or preventing ice build-up during the winter. The two options provided to the students were NaCl (sodium chloride or table salt) and CaCl₂ (calcium chloride). In the pre-assessment, the only misconception identified was that NaCl would be the best salt due to its stronger intermolecular forces (Table 11).

Table 11

Sample Collegiate Student Responses Regarding Types of Salts

<u>Phase of Study</u>	<u>Sample Student Responses</u>
Pre-Assessment	<ul style="list-style-type: none"> NaCl, because it has stronger intermolecular forces, ion-dipole vs. dipole-dipole.
Interview	<ul style="list-style-type: none"> CaCl₂...ummm...yes. They are both going to dissociate in solution, but...I don't...I guess you could use CaCl₂. I don't know what that could change since they would both completely dissociate. It is the same chemical reaction with water, so...I don't know if NaCl is more abundant or easier to manufacture. I would say that you could use both. The NaCl would work better because it is a strong base...no, it is not a strong...base. But, I think it would work better, but I don't know why. I'm assuming that calcium chloride would work better only because it has a higher...it's a higher molar mass, but I don't actually know why...why one would be better than the other. Student: Well, so we just did the hydrolysis of solutions lab in chemistry. So, we did a bunch of those....so NaCl would be...neutral...what? No. I don't know. NaCl would be neutral because Na is part of a strong base and Cl is part of a strong acid, so it would be neutral. What was the other one? Interviewer: CaCl₂ - calcium chloride. Student: Those are both also part of strong...I don't know...they would both be neutral...I don't know. I feel like you can't just take a salt shaker outside...that doesn't work

One student suggested that NaCl has ion-dipole intermolecular forces, while the CaCl₂ has dipole-dipole intermolecular forces. In reality, NaCl and CaCl₂ would both have ion-dipole intermolecular forces as they are both ionic substances that are able to dissolve in water.

During the interviews, the misconceptions encompassed a much wider range of ideas. One student suggested that CaCl₂ must be the better salt because “you can’t just take a salt shaker outside, that doesn’t work!” And another student suggested that either type of salt would work the same as NaCl and CaCl₂ both dissociate in water and the same chemical reaction with water would be occurring. Nevertheless, most of the misconceptions identified were in regard to the structure of salt. This included the molar mass of the atoms and the relation of the salts to acids and bases. For instance, one student suggested that CaCl₂ would be best as it has a higher molar mass; however, the student was unable to explain how molar mass relates to the effectiveness of salt. Another student related the effectiveness of salt to its ability to dissociate and become a strong acid/base. The student stuck with their initial belief that NaCl would be the better salt, but was still a little confused as to how the salt interactions were related to acid and base interactions at the end of the conversation. This could possibly be attributed to the fact it was the current topic in their chemistry course and acid/base interactions were at the forefront of their current chemistry understanding. There were no misconceptions identified in either the collegiate pre-assessment or interviews that were coded into the categories of release of energy/heat, reactivity of the salt, or no explanation provided.

Summary

Overall, collegiate general chemistry students possessed misconceptions in both stages of the study – pre-assessments and interviews. It was much more complicated to determine the progression of these students' understanding of chemistry topics due to the low number of responses, specifically within the pre-assessment. However, it did appear that the misconceptions identified in the pre-assessments were more basic than those identified as a part of the interviews. The interviews uncovered misconceptions related to more complex chemistry topics, such as: bonding, intermolecular forces, and structure of molecules. In addition, it was noted by the researcher that many of the misconceptions identified during the interview process related directly to information presented between the end of the solution chemistry unit and the occurrence of the interviews. It is likely that these new topics were in the forefront of the collegiate students' minds during the interview process, which may have in turn influenced their responses. However, this is a caveat of all learning processes and while the students may not have had a perfect understanding of solution chemistry topics after completing the unit, it was apparent that the students were working to incorporate the information into their current conceptual framework.

Research Question #3 – Comparison of AP and Collegiate Misconceptions

As mentioned previously in the theoretical framework, Vosniadou (1994) has suggested that there are three types of mental models: intuitive, synthetic, and scientific models. These models can be used to explain how an individual's conceptions of a topic either are or are not related to accepted scientific ideas. The most basic level

understanding is categorized as an intuitive model since there is little to no scientific influence and the understanding is based mostly upon a student's personal experiences. The most complex and accurate level of understanding is known as the scientific model. This is the level obtained by individuals who models completely agree with current scientific views. The level in between these two is referred to as the synthetic model as it is typically a combination of personal experiences and scientific views. This synthetic model would be equivalent to what teachers and researchers refer to as a misconception.

Structure of Molecules

Overall, very few misconceptions were identified regarding the structure of molecules and those that were uncovered were very similar between the AP Chemistry and collegiate student populations. Instances where a student reversed the idea of polar and non-polar when discussing the structure of molecules occurred in both populations. For instance, one student suggested that water is polar due to its linear shape and another indicated that water is non-polar and oil is polar. One major misconception identified only in the collegiate population was the misidentification of the atoms found in water (two oxygen atoms and one hydrogen atom). As a whole in both populations, misconceptions regarding the structure of molecules were identified much more often as a part of the interviews compared to the written responses of the SCQ. This is likely due to the fact the researcher was able to ask students follow up questions to truly understand their explanations during the interview process. This allowed the researcher to make fewer assumptions about students' intentions when analyzing the results of the SCQ. Based on the data collected, it appears that students in both populations demonstrate

comparable levels of understanding regarding the structure of molecules, as based upon Vosniadou's levels of mental models.

Polar v. Non-polar Substances

The level of understanding of polar and non-polar substances is very different between the high school and collegiate populations. The collegiate students, even though misconceptions are present, exhibited a deeper understanding of polarity from the beginning. These students referenced the structure of molecules and the arrangement of atoms in their answers from the beginning, while the high school students began with a discussion of density to explain why polar and non-polar substances will not mix. Additionally, misconceptions identified during the collegiate interviews were due to simple reversal of the terms polar and non-polar by one student. Misconceptions within the high school student population were more widespread and wide ranging than those within the collegiate population. While the collegiate students did not demonstrate a complete and accurate understanding of polarity, it is clear that they are nearing Vosniadou's scientific model in their journey of conceptual development, while the high school students are just beginning to make their way from the intuitive to the synthetic model.

Types of Solutions

Two main topics discussed within the solutions code – defining the three types of solutions and using a laboratory procedure to determine which type of solution is present – further illustrated differences between the high school and collegiate populations. The collegiate students exhibited a deeper understanding of the three different types of

solutions starting in the pre-assessments. The AP Chemistry students provided a wide variety of answers in the pre-assessment to explain the different types of solutions, such as: how full a solution is of water or liquid, how many or what types of molecules are present (oxygen, starch, etc.), if a solution has been tampered with, or the types of bonds that are present in the solution. One misconception added by the collegiate students was the discussion of viscosity and how that would relate to different types. This information suggests that the AP Chemistry students demonstrate a much more basic understanding than the collegiate students and are likely performing within Vosniadou's level known as the intuitive model. With that being said, super-saturated solutions appeared to be the most confusing type of solution for all of the students. Many students in both populations struggled to define a super-saturated solution and how it related to the other two solution types. This was especially apparent during the interviews and suggests that the AP Chemistry and collegiate students' understanding may be more comparable after instruction than it was before.

Both student populations appeared to have a similar level of understanding both before and after instruction regarding the laboratory procedure used to differentiate between the three types of solution. Students in both populations suggested that the best way to determine the type of solution (saturated, unsaturated, super-saturated) present in a beaker was to either boil off or separate the solute and solvent to then calculate concentration, react the solution with another chemical and then see what is left over in the beaker, or to simply filter the solution. These suggestions all represent common laboratory procedures and are likely activities that students participated in as a part of

their chemistry experiences either at the high school or collegiate level, but are not applicable in this context. This suggests that all students were likely exhibiting a level of understanding that would correspond with Vosniadou's synthetic model both before and after instruction. Another similarity between the two groups was the belief that one can differentiate between levels of saturation in a solution based upon how they change colors or degrees of cloudiness. These misconceptions appeared in student responses before and after instruction, in both student groups. Based on these responses, it appears that AP Chemistry and collegiate students demonstrate comparable levels of understanding regarding methods used to differentiate between the three types of solutions and both population groups performed within Vosniadou's synthetic mental model with regards to explaining types of solutions.

Colligative Properties

The first question asked with regards to colligative properties – why doesn't a bottle of soda freeze until you remove it from the freezer and take off the lid – was only addressed on the SCQ and not as a part of the interview process. Because of this, the data collected only includes a pre-assessment for the collegiate students. During the pre-assessment, the two collegiate students attributed this phenomenon to a change in pressure. The AP Chemistry students did not focus on pressure in the pre-assessment. Instead, their misconceptions referred to the fact that the bottle insulates the liquid, there is no crystallization point present in the bottle, or that there is not enough space in the sealed bottle for the liquid to freeze. This suggests that they were operating within Vosniadou's intuitive model of understanding during the pre-assessment. However,

during the post-assessment some AP Chemistry students referenced a change of pressure, similar to the original explanations of the collegiate students. This suggests that the collegiate students were likely within the synthetic model of conceptual development in the pre-assessment and the AP Chemistry students approached that level of understanding in the post-assessment. Unfortunately, with no collegiate post-assessment data, the comparison between the two student populations cannot be made after instruction.

The other two questions – why do we use salt on sidewalks and why do we use antifreeze in a car – both focused on how adding solute can affect the freezing and boiling points of a solution. In the pre-assessment, a wider range of misconceptions was identified in the AP Chemistry population than in the collegiate population. Misconceptions ranged from salt altering the bonds or structure of water, raising the freezing/melting point of water to the release of heat due to the chemical reaction between salt and water. The misconceptions of collegiate students were focused on how the temperature would either rise or stay constant, depending on which student's response is considered. However, after completing the post-assessments and the interviews, the misconceptions identified between the two groups were much more similar. At least one student in both student populations used the idea of releasing heat or energy to explain why salt would be used to melt ice or discussed how the addition of antifreeze to a radiator would keep the temperature in the car's engine consistent. In addition, there were students in each group who reversed the explanation of the colligative properties (for example, students stating that the freezing/melting point would increase instead of decreasing). This suggests that while the collegiate students may have been further

along in their development before classroom instruction, the two groups seem to have similar types of misconceptions after instruction and, therefore, both populations were likely demonstrating a level of understanding typical of Vosniadou's synthetic model.

Types of Salts

When the students were asked to consider what type of salts would be the best option for melting or preventing ice build-up during the winter - NaCl (sodium chloride or table salt) or CaCl₂ (calcium chloride) – the AP Chemistry students focused on the reaction that was occurring between the salt and water, while the collegiate students focused on the structure of the molecule in all stages of the study. The AP Chemistry students discussed how one salt may be stronger or more reactive than another or even how the reaction between the salt and the water will release heat that, will in turn, melt the ice. These misconceptions, except for reactivity, were present in all three stages of the study. This illustrates that the AP Chemistry students held on to their misconceptions throughout their work with solution chemistry in the classroom.

On the other hand, the collegiate students did not mention the reactivity of different salts or the release of energy/heat due to a chemical reaction in either their pre-assessments or interviews. Instead, the collegiate students' focus was on the structure of the molecules, specifically the types of bonds and molecules present. Collegiate students also discussed the idea of strong acids and bases and the hydrolysis of water to explain the difference between using NaCl and CaCl₂ to melt ice. While this idea is incorrect, it shows that the collegiate students are connecting their ideas of solution chemistry with other chemistry concepts and continuing to alter their conceptual framework along the

way. The data collected suggests collegiate students had a more advanced conceptual framework with regards to comparing types of salts from the beginning to the end of this study. Collegiate students likely were approaching the scientific model of understanding, while the high school students began in the intuitive model and were starting to approach the synthetic model after instruction.

Summary

While there were distinct differences between the two groups and their levels of comprehension uncovered during this study, there were some similarities between the two student populations as well. In many cases, students in both populations did not necessarily provide details on why or how a certain phenomenon occurred during the pre- and post-assessments. For example, many students provided answers such as ‘salt melts the ice’ as opposed to explaining what was going on at a more detailed level. This could have been their attempt at providing quick answers to get through the survey faster or it could also suggest that the students did not have a detailed understanding of the underlying processes. In addition, students at both levels had instances where scientific vocabulary was misused or misrepresented in their explanations. The incorrect use of terms such as precipitate, solute, solvent, solution, saturated, or colloid could have affected the researcher’s interpretation of the student’s understanding and, in some cases, drastically altered the meaning of the explanation that the students provided.

Overall, the collegiate chemistry students displayed a more complex understanding of solution chemistry topics both before and after instruction even with the misconceptions that were identified. Misconceptions identified at the collegiate level

tended to revolve around the general idea of the structure of molecules (bonds, forces, interactions, etc.) and suggested a level of understanding that was at least equivalent to Vosniadou's synthetic model. AP Chemistry students displayed a very wide range of misconceptions and, more than once, held onto their misconceptions even after instruction. Generally speaking, it appears collegiate students were further advanced in their conceptual understanding of polar v. non-polar substances, defining the three types of solutions, and types of salts than the AP Chemistry students.

CHAPTER 5

DISCUSSION, RECOMMENDATIONS, AND CONCLUSION

Discussion

Previous research, specifically Coll and Treagust (2003), determined that both collegiate and secondary students provided similar interpretations of chemistry topics; however, the collegiate students were able to provide greater detail in their descriptions. This ability to comprehend and apply large amounts of information has been attributed to the college students' higher level of cognitive development. Piaget originally proposed the levels of cognitive development as he categorized individuals based upon their ability (or inability) to perform specific mental tasks. Recent studies have suggested that many high school and college students have yet to reach the formal operations stage, meaning that they are unable to hypothesize how a change to one event may affect something in the future. Instead, it is believed that these students are in the period of concrete operations and are only able to apply their understanding of concepts to situations that are observable (Kolodiy, 1975). If students are unable to process information at a cognitive level that is necessary for a complete understanding of chemistry concepts, there would be a higher chance of incomplete knowledge or the formation of a misconception.

Of even more interest to this study, it has been suggested that students may be transitioning between the concrete and formal operations as they approach the collegiate age. If this is the case, collegiate students would have a better ability to comprehend complex chemistry topics and relate the information to new scenarios. Through the analysis of both the AP high school and collegiate student data collected and the

misconceptions that were identified, the results supported this claim and three additional themes were exposed. These three themes were developed to explain the likely origin of students' misconceptions. These themes include: rote memorization, misuse of scientific vocabulary, and contamination due to other chemistry topics. This discussion will take a closer look at examples of student misconceptions that highlight each theme and how these themes may impact student learning.

Theme #1: Rote Memorization

One of the most discussed sources of misconceptions in the field of science is students memorizing information without developing a true understanding of the scientific concepts being discussed. This becomes an even more prominent source of misconceptions when students are asked to explain topics that often require instructors to use analogies or models when introducing the concepts (Çepni et al., 2006; Gabel, 1999). Many of the solution chemistry topics fall into this category as the chemical differences and interactions that are occurring are on the molecular level and cannot be observed directly by students.

Previous research has indicated that students are often able to use scientific terminology correctly in conversation, but are unable to provide anything other than a memorized definition when asked to explain their understanding further (Nakhleh, 1992). One example provided by Pinarbasi and Canpolat (2003) was when they asked students to define and draw a representation of the three types of solutions. They found that students were able to correctly state the definitions of each solution type, but the students were unable to use that information to create pictorial representations of their solutions.

This was not noticed within this particular study; in fact, students at both levels appeared to struggle with defining the three types of solutions during all phases of the study. When asked to draw a molecular representation, the students appeared to be confident in their drawings for both unsaturated and saturated solutions, with some slight hesitations while drawing the super-saturated solutions. This suggests that instructors in this study may have introduced students to more models or analogies than those in Pinarbasi and Canpolat's study. Since there was no control or knowledge of specific instructional methods instructors engaged in during this study, there is no direct evidence to support that claim.

However, this trend of providing a memorized response was identified in this study as there were both AP and collegiate students who reversed the explanation of the colligative properties. The fact that the students referred to it as a freezing point elevation or boiling point depression suggests that the students memorized the phrase and did not have a full understanding of what the concept represents. To say that adding salt would lead to a freezing point elevation is the same as saying that adding salt to the road or sidewalk would mean ice would form at higher temperatures than normal. That would be counterintuitive and should not make sense to the students when they fully explain the concept. These results supported the idea that students often memorize definitions and mathematical algorithms to solve problems, but fail to fully understand the chemistry that explains the *how* and *why* behind chemical phenomena (K. J. Smith & Metz, 1996).

It can be assumed that students at lower levels of cognitive development may need to memorize more information than those students who are able to fully

comprehend conceptual information and apply their knowledge to new scenarios. When a student's current concepts are inadequate and are unable to connect with new phenomena they must make an accommodation in order to integrate the information into their conceptual framework. However, when students at a higher level of cognitive development are introduced to new material, they can use their prior knowledge and concepts to relate to a new phenomenon through a process referred to as assimilation (Posner et al., 1982). Based upon the apparent memorization of material, the results of this study suggest that both the collegiate and high school students would possess a similar level of cognitive development as both populations memorized information incorrectly and were unable to relate their memorized material to the new situations they were provided.

Theme #2: Misuse of Scientific Vocabulary

As mentioned within the literature review, past research shows that a common source of misconceptions is the combination of everyday and scientific language (Sanger & Greenbowe, 1999; van den Broek & Kendeou, 2008). This is especially true when concepts are oversimplified or explained in vague statements to students as opposed to using many different examples and descriptions for each topic (Sanger & Greenbowe, 1999). It is also known that introducing younger students to complex scientific ideas and terminology requires a simplification of topics to accommodate the ability level of the students and this simplification can in turn hinder a student's understanding when teachers use words from everyday language to explain scientific phenomena (Özmen, 2004). These ideas were demonstrated within this study as well. The misconceptions

identified may have been established many years ago, but the students have not been made aware of the misconception nor have they been convinced to change their way of thinking since that time.

In this study, there were specific examples of students either misidentifying the meaning of specific vocabulary terms or creating a dual meaning for particular terms. For instance, the terms ‘precipitate’ and ‘colloid’ were used incorrectly by students. One AP Chemistry student incorrectly identified the undissolved salt at the bottom of their drawn beaker as a ‘precipitate,’ even though it was not a solid that had formed due to the mixing of two different solutions. This is an example of a student connecting two very different concepts that, while they may appear to look similar to a viewer, actually occur in a very different manner on the molecular level. Another AP Chemistry student used the term ‘colloid’ to describe a solution that is “water-hating”. The correct term that the student wanted to use in that case is ‘hydrophobic.’ Both terms were introduced to the students as a part of the concepts included in the solution chemistry unit, so it is likely that the student either simply switched the definitions of the two or perhaps had memorized the definitions to those two terms incorrectly.

An example of students creating a dual meaning would be the use of the phrase “melt the ice” when discussing why salt is added to sidewalks in the winter. The idea that the addition of salt will ‘melt the ice’ was a very common response for students at all levels, during all phases of the study. Stating that the salt would melt the ice is an implication that heat is being added to the ice in order to speed up the movement of the water particles, leading to the ice (in solid form) changing to liquid water. In reality, the

addition of salt to roads or sidewalks is to prevent the ice from forming by lowering the freezing point of the water. This would mean that the temperature outside must be colder than the normal freezing point (0°C) in order for ice to form. In turn, the students' use of the phrase 'melt the ice' led to many students in both student populations suggesting that the addition of salt must cause a release of heat or energy, which in turn would melt the ice. It is important to note that the phrase 'melt the ice' was not introduced by the researcher in the SCQ or one-on-one interviews – the phrase 'melt the ice' was always introduced by the student first.

This idea of ice melting is a phenomenon that students experience in their everyday lives. Whether students have observed ice being added to a warm drink, causing the ice to melt, or an ice cube being removed from the freezer and exposed to air at a warmer temperature, they will try to relate those experiences to their scientific explanations. In the other examples of ice melting, there is heat being added to the system, causing the ice to melt. This could be causing confusion for students as they try to determine how the salt acts like the warm drink or air that ice has been exposed to. For this reason, the students are trying to create a dual meaning for the phrase 'melt the ice.' Most students realize that salt is not hot and doesn't release heat, but they are unable to produce a different explanation, so they settle with and use the information with which they are already familiar. This creates two different meanings behind a singular phrase, which is recognized as the idea of a *dual conception* (Calik & Ayas, 2005).

Similar to the theme of rote memorization, it can be assumed that students exhibiting higher levels of cognitive development would be better able to use scientific

vocabulary in the correct context. These students would be able to assimilate new information into current knowledge from past experiences and, therefore, more accurately integrate new vocabulary into their existing conceptual framework. Based upon this assumption, collegiate students demonstrated a higher level of cognitive development as the majority of misused vocabulary terms were used incorrectly by the high school students. Since high school students were unable to use scientific vocabulary correctly in new situations, they are likely still in the concrete operations stage of cognitive development, while the collegiate students may have been in the formal operations stage.

Theme #3: Contamination due to Other Chemistry Topics

Many of the misconceptions identified within both the AP Chemistry and collegiate student populations were based around correct chemistry concepts, but concepts that were erroneously used to explain solution chemistry phenomenon. These instances included concepts that were introduced prior to the solution chemistry unit and topics that were introduced between the completion of the solution chemistry unit and the occurrence of the interviews.

For instance, AP Chemistry students relied on information they had learned about how liquids behave when crafting their answers regarding why soda only freezes when it is taken out of the freezer during the SCQ pre-assessment. This information was introduced to most of the AP Chemistry students (depending on which high school they attend) immediately prior to the SCQ pre-assessment and the start of the solution chemistry unit. In other words, students were applying their most updated conceptual framework to explain a phenomenon they were unfamiliar with, even though their

explanations were incorrect. However, during the SCQ post-assessment, the AP Chemistry students' misconceptions had more references to the gases and pressure present within the bottle. These misconceptions can be tied to information the AP students had been introduced to about six weeks prior to the unit and were similar to those that the collegiate students exhibited on the pre-assessment. This shows that the concept of osmotic pressure, which was introduced during the solution chemistry unit, may have brought forth students' previous interactions with pressure during their gases unit.

Another example of AP students using their preexisting conceptual framework to explain solution chemistry topics was in reference to the differentiation of polar and non-polar substances. There were multiple instances of students referencing density in their explanations of why polar and non-polar substances are not able to mix. While the students had not recently discussed density in terms of calculations (with mass and volume), most of the AP classes had just discussed how atoms are packed together within metallic solids. This would have led to a conversation about packing efficiency and how many atoms are able to fit in a particular region within various substances. The introduction to metallic solids and packing efficiency may have triggered students' previous interactions with the concept of density and brought forth correlating beliefs. One common density activity is the density column, a demonstration in which instructors place multiple liquids that will not mix with one another and have varying densities into one graduated cylinder. Through this demonstration, students are able to observe how liquids of different densities will stack on top of one another (Figure 7), similar to what



Figure 7 - Density Column
(Munchkins & Mayhem, 2013)

students believed would occur when mixing oil and water (the provided polar and non-polar substances). Even though density does not explain *why* oil and water do not mix, the students' previous experiences elicited responses that were based upon their current conceptual framework.

There was also an example of a student, during the interviews, using information they were introduced to after the completion of the solution chemistry unit to explain how to determine what type of solution was present in a beaker. In this case, the student had been introduced to the correct explanation but a more recent concept may have been in the forefront of their mind. In this particular case, the student used the procedure from an experiment regarding solubility and pH of a variety of salts to describe how you could use pH to determine if a solution was unsaturated, saturated, or supersaturated. The student correctly explained the procedure for the experiment, but applied it incorrectly as

a part of the provided scenario. This shows that students use both relevant and irrelevant information they have recently been introduced to as an anchor to explain an unfamiliar phenomenon. Students are often asked to anchor their explanations to prior experiences, as this is a fundamental concept within the theory of constructivism. However, this idea of anchoring can be problematic when students are unable to discern which prior experience is actually relevant to the new experience or information being presented. Students being unable to distinguish what information is relevant is likely related to students being at a lower level of cognitive development and not yet advanced enough in their thinking to apply the new situation to their preexisting ideas. Research has shown that the links students have established within their personal conceptual framework play an important role in their overall understanding of chemistry and their explanations of chemical phenomena (Garnett et al., 1995; Nakhleh, 1992).

Classroom Implications/Recommendations for Practice

The results of this study suggest important implications for the teaching of solution chemistry in both high school and collegiate classrooms. Instructors must be aware of how the three themes addressed within the discussion (rote memorization, misuse of scientific vocabulary, and contamination due to other chemistry topics) will affect student learning and comprehension regarding chemistry concepts based upon a student's level of cognitive development. It is well known that students build their conceptual framework as they are introduced to new concepts, but if those concepts are too complicated or abstract, students will be more likely to construct misconceptions within their personal framework (Garnett et al., 1995; J. P. Smith et al., 1993). Moving

forward, it is important that the misconceptions identified as a part of this study are addressed in not only high school and collegiate classrooms, but with all students in any level of chemistry. The shift from students' current views to new, more accurate views is a gradual process and requires patience from both the teacher and students. As a teacher, one must remember that students are not going to believe something just because it is introduced to them, especially when it is counterintuitive to their current mental model and pre-existing conceptual framework.

First, the results of this study should encourage instructors at both levels to provide various types of instruction to support student learning. This may include making available opportunities for students to experience new concepts in a hands-on manner, by using visual representations, or verbally communicating with instructors and fellow classmates regarding solution chemistry topics. It is important to realize that students will not reject an existing idea unless they have been provided with a sufficient reason for discarding it. Osborne and Freyberg (1985) suggest that a new idea must meet the following criteria before students will even consider its legitimacy. The new idea must be intelligible, it must be able to merge with other views the student already has, and it must be perceived as more advantageous to the student compared to their old viewpoint. This can be a very difficult hurdle for students as the scientific approach to a topic can often be much more complex than their original idea. In fact, it may even seem useless to the student. The authors go as far as to state that this is one of the central problems to learning science (Osborne & Freyberg, 1985). In this study, rote memorization of scientific topics was found to be one cause of student misconceptions. Therefore, instead

of asking students to memorize material, teachers must familiarize students to these new concepts in a methodical and meaningful way. Through these methods, instructors should support students' use of particle theory in the context of solution chemistry which, in turn, will help students to more accurately link these two concepts together. With a better understanding of particle theory and what is actually occurring at the submicroscopic level, students will rely less on rote memorization of concepts (Adadan & Savasci, 2012).

Second, instructors should be aware of the language they are using in the classroom and how that may affect student understanding. It is vital that instructors make the material relevant to the students and relate it to their individual lives as opposed to asking students to memorize material when introducing new topics. However, students often struggle to differentiate between the academic and personal contexts of the language across the many different types of connections that are often made (Osborne & Freyberg, 1985). In addition, instructors should be aware of terms that can easily be confused, such as what was seen in this study with solute, solvent, and solution. Students were able to explain the concept accurately but substituted an incorrect vocabulary term. By identifying this scenario early on, instructors can address student misconceptions before they become ingrained within a students' conceptual framework. The idea of everyday language and science concepts becoming intertwined will be reduced greatly if students are supported in their pursuit to build understanding of scientific vocabulary and, over time, students will then expand their ability to differentiate between common uses of language and the scientific definitions.

Third, instructors should consider their course sequencing and how the introduction of particular ideas may influence students' understanding of current and future chemistry concepts. In this study, there were multiple instances where students used descriptions of other chemistry concepts to explain solution chemistry topics. This contamination demonstrates how students will integrate new information into their conceptual framework in a way that makes sense to them and, in turn, possibly create misconceptions (Garnett et al., 1995). For instance, students incorrectly integrated concepts from past units into their explanations of solution chemistry topics on a fairly regular basis during the SCQ pre- and post-assessments, which should be of little surprise to many teachers and researchers. However, there were also examples (within the interview data) of students using information from units that occurred after the completion of the solution chemistry unit. This shows that instructors should be aware not only of how they intend for students to build knowledge from the start to the end of the course, but also to consider how the knowledge students have gained may be influenced by concepts introduced as a part of future units.

Limitations

Limitations of the study mainly revolved around the lack of collegiate students who participated in the SCQ Pre-Assessment as a part of phase 1 of the study. This, in turn, led to minimal data regarding collegiate students' understanding before instruction and the decision to not conduct a post-assessment. Instead, the one-on-one interviews were used to determine students' conceptions after instruction. With such a limited representation of college students, it is likely that collegiate students hold additional

misconceptions that were not detected during this process. Perhaps the collegiate students do share more misconceptions with AP Chemistry students than was determined during this study. For this reason, the comparison between collegiate and AP Chemistry students may be even more complex than this representation. In addition, these results should not be considered generalizable to all students at the high school and collegiate levels, but provide insight into the thought processes of the specific students in this study.

A couple of limitations also emerged regarding the methodology of this study. One limitation was the format of the SCQ and the types of student responses that the SCQ elicited. Since this was an open-ended assessment some students provided very short and simple answers that may not have fully demonstrated their true level of comprehension. This suggests that students may have possessed a deeper level of understanding than what was portrayed in their SCQ responses both before and after instruction. In addition, the students were not directly asked to draw molecular representations as part of the pre- or post-assessment. Similarly, the interview process allowed for the researcher to ask individual questions to clarify the students' understanding of particular topics. In turn, this led to the researcher provoking more detailed responses from both the collegiate and AP students during the third phase of the study. Students were asked to draw representations, expand upon their explanations, and describe why they believed something to be true. Based upon these limitations, it is possible that some of the students' misconceptions exposed during the interview process may have been present before instruction as well.

Recommendations for Future Research

There is a need for further research that continues to attend to the presence of misconceptions within the chemistry classroom, as well as additional methods that are beneficial when addressing misconceptions within the classroom, both on an individual and group basis. Further research regarding misconceptions within the collegiate student population would be especially important regarding student understanding before instruction due to the small number of participants in this study. It would be interesting to determine whether these results are reproducible in other locations or within a larger scale study. Based upon the results of this study, further questions to be considered include: (1) How do instructional methods affect the number and/or type of misconceptions students hold?; (2) How does course sequencing affect the number and/or types of misconceptions students hold?; (3) What instructional methods are best for addressing student misconceptions regarding solution chemistry in the classroom?; (4) How do misconceptions compare with regards to collegiate students who have taken AP Chemistry in high school versus collegiate students who have not taken AP Chemistry?

Conclusion

The purpose of this study was to determine the misconceptions that both AP Chemistry and collegiate general chemistry students hold with regards to solution chemistry topics both before and after instruction. The results of each group were then compared to determine any similarities and/or differences between the two populations. This comparison was chosen by the researcher as the AP Chemistry course is designed to mimic the experience of collegiate students enrolled in a first-year general chemistry

course, suggesting that the students should have a similar level of understanding of solution chemistry topics. The results of this study support the findings of previous studies while contributing to the overall body of knowledge regarding the relationships between the cognitive development of high school and collegiate students and their understanding of solution chemistry concepts (Adadan & Savasci, 2012; Calik & Ayas, 2005; Calik et al., 2009; Pinarbasi & Canpolat, 2003; K. J. Smith & Metz, 1996).

It was determined that collegiate chemistry students displayed a more complex understanding of solution chemistry topics both before and after instruction, even though misconceptions were identified within both populations. AP Chemistry students tended to display a wider range of misconceptions, while the misconceptions at the collegiate level were more uniform. In addition, the collegiate students' misconceptions were based around more complex chemistry concepts. This suggests that collegiate students are likely further along in Piaget's levels of cognitive development – approaching or within the formal operations stage – and exhibiting Vosniadou's scientific mental model more often than the high school students. Overall, the trend of collegiate students being further advanced in their conceptual understanding was directly observed with regards to polar v. non-polar substances, defining the three types of solutions, and types of salts than the AP Chemistry students.

These findings suggest that collegiate students are likely further advanced in their conceptual understanding of chemistry topics, specifically solution chemistry. Instructors should be aware of the differences within these two populations and the variety of misconceptions that have been identified as a part of this study. If a misconception was

identified within this study, it is very likely that other students would hold similar misconceptions as well. In addition, three major themes were identified as potential influences for students developing misconceptions, including: rote memorization, misuse of scientific vocabulary, and contamination due to other chemistry topics. This study suggests that these three themes should be taken into consideration by instructors of all levels when designing a chemistry course to encourage the highest levels of student understanding.

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4. Why would antifreeze be placed in the radiator of a car? Complete answers not only include the name of the phenomena represented, but also an explanation of how that phenomena relates directly to the situation provided.

5. Why is salt placed on the sidewalks and/or roads during the winter? Complete answers not only include the name of the phenomena represented, but also an explanation of how that phenomena relates directly to the situation provided.

6. Which salt would work better if placed on sidewalks/roads during the winter: NaCl or CaCl₂? Why?

7. If a soda bottle is placed in the freezer for a period of time it will not freeze. However, when it is taken out of the freezer and the lid is removed, the soda will freeze! Why does this happen?

APPENDIX B

SOLUTION CHEMISTRY QUESTIONNAIRE ANSWERS

1. Explain the difference between saturated, unsaturated, and supersaturated solutions.

Answer: Saturated = the maximum amount of solute has been dissolved in the solvent;

Unsaturated = more solute could still be dissolved;

Supersaturated = more solute is dissolved that should be possible for that temperature

2. Explain a simple laboratory procedure that is able to distinguish between saturated, unsaturated and supersaturated solutions.

Answer: Add one seed crystal of the solute...

- a. the unsaturated solution would dissolve the added crystal
- b. the saturated solution would not dissolve the crystal; the crystal would just settle to the bottom and remain undissolved
- c. the supersaturated solution would precipitate out LOTS of other crystals

3. Explain the reason behind the saying “oil and water don’t mix”. Why is this true? Complete answers not only include the name of the phenomena represented, but also an explanation of how that phenomena relates directly to the situation provided.

Answer: Oil is nonpolar and water is polar. Nonpolar and polar compounds are immiscible (don't mix) because the dipole-dipole forces in the polar molecules are too strong to be pulled apart by the LDFs that the nonpolar compounds could form with it. Polar substances can mix with other polar substances and non-polar substances can mix with other non-polar substances.

4. Why would antifreeze be placed in the radiator of a car? Complete answers not only include the name of the phenomena represented, but also an explanation of how that phenomena relates directly to the situation provided.

Answer: Antifreeze lowers the freezing point (freezing point depression) of the solution in the radiator AND increases the boiling point (boiling point elevation). Adding a nonvolatile solute increases the range of temperatures where the liquid phase can exist.

5. Why is salt placed on the sidewalks and/or roads during the winter? Complete answers not only include the name of the phenomena represented, but also an explanation of how that phenomena relates directly to the situation provided.

Answer: The salt lowers the freezing point so the water will not freeze as easily (freezing point depression). Lowering the freezing point prevents the formation of ice at the normal freezing point of water (32°F or 0°C). In other words, it would have to get even colder in order for the ice to form.

6. Which salt would work better if placed on sidewalks/roads during the winter: NaCl or CaCl₂? Why?

Answer: CaCl₂ would melt the ice better, since the van't Hoff factor is three, compared to two for NaCl. This makes the freezing point depression one and a half times greater for CaCl₂ versus NaCl. The van't Hoff factor is a measurement of the number of particles formed in a solution from one formula unit of solute, so CaCl₂ would dissolve into three particles (ions) while NaCl would dissolve into two particles (ions).

7. If a soda bottle is placed in the freezer for a period of time it will not freeze. However, when it is taken out of the freezer and the lid is removed, the soda will freeze! Why does this happen?

Answer: When the bottle is opened, some of the gases (carbon dioxide – CO₂) that was originally dissolved into the soda will escape out of the bottle. When the concentration (molality) of the CO₂ gas in the soda solution decreases, the freezing point is not depressed as much (so the soda will freeze more easily).

APPENDIX C

INTERVIEW GUIDE

Supplies:

Videos of each demo to show students during interviews

Interview Introduction:

Today we are going to be looking at a few phenomena that you have considered during your time in AP Chemistry this year. It is very important that you say whatever you believe to be true as we work through a few scenarios. There are **no** right or wrong answers, but I may be asking you to clarify some of the things that you say so that I have a better understanding of your beliefs. Also, the camera is on, but the purpose of the camera is so that I can reference things you have said later on. Just pretend that the camera isn't here and we are having a conversation about chemistry. Do you have any questions for me before we get started?

1. Beaker of Water (*have a beaker of just water sitting in front of the student*)

- To start us off, please draw for me what you would see if we were able to “zoom in” on one section of the water inside the beaker.
- Explain what you have drawn.
- *Ask student clarifying questions based upon their drawing.*
 - *What is this?*
 - *What is the relationship between these (particles)?*
 - *Are they moving? Or staying still?*

2. Addition of Salt (*use beaker of water and add a pinch of salt to the beaker*)

- Prediction: What would happen if I were to add salt to this beaker?
- Now that the salt has been added, please draw for me what you would see if we were able to “zoom in” on one section of the water inside the beaker.
- Explain what you have drawn.
- *Ask student clarifying questions based upon their drawing.*
 - *What is this?*
 - *Why is _____?*
 - *What happened to the salt?*
 - *What is the relationship between these (particles)?*
 - *Are they moving? Or staying still?*

3. Addition of Sand (*add a couple of pinches of sand to the same beaker*)

- Prediction: What would happen if I were to add sand to this beaker? Would it have the same response as the salt?
- Why do you believe that this would happen?

- What is the difference between sand and salt?
- What is the relationship between sand and water molecules? What about between salt and water molecules?

4. Unsaturated v. Saturated v. Supersaturated (*provide student with a beaker of salt/water solution and various supplies – which include: salt, spatula, sand, food coloring, etc.*)

- Can you describe the difference between an unsaturated, saturated, and supersaturated solution?
- Which type is this solution?
- How can you determine this? Please explain step-by-step what you would do.
- How do you know that it was a _____ solution? How would you have known if it was _____? What about _____?

5. Adding Oil to Water – “Like Dissolves Like” (*provide students with a beaker of water and a beaker of oil to be combined after the predictions have taken place*)

- What do you think will happen if you were to mix this beaker of oil and this beaker of water together? Why do you expect this to happen?
- Go ahead and mix the two together. Was your prediction correct?
- What phenomenon does this demonstrate?
- What is the explanation behind this phenomenon? Is there a difference in the structure of the liquids?

6. Adding Salt to Sidewalks (*hypothetical situation that all students can relate to and connects with the idea of Freezing Point Depression/Boiling Point Elevation*)

- When is salt typically placed on sidewalks and other surfaces? Why is this done?
- You say that it melts the ice, how does this happen? Is there heat involved? Is the salt hotter than the ice?
- What is this phenomenon typically known as?
- Can you think of another situation in which a similar phenomenon takes place?
 - Adding salt to water (boiling point elevation)
 - Adding antifreeze to a radiator to prevent the fluids from freezing
 - Adding coolant to a radiator to prevent the fluids from vaporizing
- What is the purpose of this action?
- Can you make a general statement regarding both the lowering and elevation of reactions within solutions?
 - *Question the students statement and work to pull apart their idea to understand the reasoning behind it and any general misconceptions they may have within this topic.*

APPENDIX D

SELECTED STUDENT RESPONSES

(organized by codes/subcodes)**Structure of Molecules:**

- *Water*
 - Water is made of H₂O so that is a hydrogen and two oxygens...there are two O's for each H...each O is attracted to the H because there are is a partial charge of positive and negative...but I forget which way
 - Water is just a simple, linear structure
- *Other Molecules*
 - The extra salt molecules would be separated from the H₂O molecules and they would be at the bottom like a precipitate

Polar v. Non-polar:

- *Saturation*
 - Oil and water don't mix because oil is saturated and cannot be mixed
 - Water is less saturated than oil
- *Surface Tension/Intermolecular Forces*
 - Oil and water do not mix because the surface tension between the two substances repel each other. Surface tension.
 - Different intermolecular forces that repel one another
- *Basic Explanations*
 - I believe the water would end up on top
 - Oil doesn't have the right elements/molecules to bond with the H₂O and mix.
- *Switch of Polar and Non-polar*
 - Oil is polar and water is non-polar
 - The onion salt could be a non-polar molecule and the water could be polar and they just don't dissociate because of their different...the way that the O to an H to an H...is a straight, linear shape while you could have a large carbon molecule for the onion that the polarity is pulling one direction majorly, right? And so that way it doesn't dissociate in the water.
- *Solubility*
 - This is true because one is soluble and the other is insoluble.
 - Oil is not soluble in water

- *Density*
 - o Oil and water do not mix because of their different densities
 - o This is true because the substances have different densities. Oil has a higher density so it "sinks" under the water and the water has a lower density so it will sit above the oil.

Types of Solutions:

- *Saturated*
 - o Saturated should have high levels of a substance in the solution
 - o Saturated solution is a substance that has starch in it.

- *Unsaturated*
 - o A mixture of water and oil
 - o Have low or equal levels of each substance in the solution

- *Super-saturated*
 - o Has as much solvent as it can handle
 - o None dissolves = super-saturated

- *Misuse of Solution, Solvent, and/or Solute*
 - o Unsaturated solution is when the solvent is fully dissolved and more solvent can be formed.
 - o Saturated is when a solution can be completely dissolved in a solution

- *Determining Type of Solution*
 - o You should be able to determine by sight
 - o React the solution and see what is left over.

Colligative Properties:

- *Soda Freezing*
 - o *Liquid is Insulated from the Cold*
 - The can around the soda keeps its heat inside and protects it from the cold for a while. However, once the soda is open and there is a gap in the can protection, it freezes faster.
 - It happens because the air on the outside is so much warmer and the inside so the inside freezes... the inside does not freeze in the fridge because the soda is not open to the cold air in the fridge?
 - o *Lack of Crystallization Point*
 - Liquids need a point to coalesce around to freeze. as such, a liquid in a soda bottle, as long as there are no points to coalesce around, will not freeze.
 - In order for an object to crystallize, a single point around with the crystallization occurs must be present. Such a point does not exist in a bottle of soda, so in spite of the fact that the liquid reaches the

freezing point, the liquid would not freeze until something occurs to create this single point.

- *Not Enough Space in the Container*
 - Because there isn't enough room for it to freeze
 - It may have something to do with the space soda takes up in solid and liquid form
- *Air Can't Freeze*
 - Because it is difficult for the air inside the bottle to freeze.
 - The soda needs oxygen to be frozen without oxygen or any outside gas the soda is unable to freeze.
- *Changes in Pressure*
 - The pressure with the lid on is high enough that it will keep the particles moving/preventing it from becoming solid and freezing.
 - Vapor pressure of the soda may be keeping in heat.
- *Use of Salt/Antifreeze*
 - *Altering Bonds/Structure*
 - The obvious answer is that it makes it less slippery because it can melt the ice due to the salt altering the bonds and form of the ice/water.
 - To try and melt the ice by the water bonding with the salt in a way.
 - *Raises Freezing/Melting Point*
 - Antifreeze raises the freezing point in the radiator
 - Salt is placed on the sidewalks and roads during the winter because of the freezing point elevation phenomena. The salt raises the freezing point of the water so that it will stay in the liquid phase longer instead of freezing and creating ice.
 - *Keeps Temperatures Stable/the Same*
 - Antifreeze is used to keep the radiator at a certain temperature, regardless of the temperature outside – it stays stable
 - Antifreeze would help regulate the temperature of the car
 - *Raises Temperature*
 - Salt raises the temperature of the ice to make it unfreeze
 - *Releases Heat*
 - Salt generates heat from the intermolecular forces between the salt particles being broken apart, which turns ice into water

- Salt is placed on the sidewalks to melt ice because when salt reacts with the ice it produces heat and melts the ice.
- *Basic Explanations*
 - Because salt somehow melts snow.
 - Add antifreeze so that you can keep the car windshield clean without it fogging up.

Types of Salts:

- *Could use Both Types*
 - I would say that you could use both types.
- *Release of Energy/Heat*
 - Calcium chloride would work better because the energy released by breaking the ionic bond between the Ions is greater than the energy released by sodium chloride.
 - CaCl_2 because the ions are bigger and the intermolecular forces are larger. In a reaction, this will release more heat because it has more energy.
- *Forces/Bonds/Structure*
 - NaCl because it has stronger intermolecular forces, ion-dipole vs. dipole-dipole.
 - NaCl would work better because it is an ionic compound. It will work better in breaking up and dissolving the molecules.
- *Reactivity of Salt*
 - CaCl_2 because NaCl is not as reactive, as it is safe for humans to consume. Therefore, as CaCl_2 is more reactive, it will be more effective.
 - CaCl_2 would work better because it has a higher lattice energy and a stronger pull on the water molecules.
- *NaCl is just Table Salt*
 - Probably CaCl_2 . Last time I checked no one was putting table salt on the sidewalks.
 - Sodium in NaCl would not break down ice because it is used for flavor. However, calcium is used for ice because it will break it down.
- *No Explanation*
 - I think the NaCl works better...well I know one of them will work better...
 - CaCl_2