A VYGOTSKIAN ANALYSIS OF PRESERVICE TEACHERS' CONCEPTIONS OF DISSOLVING AND DENSITY

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The purpose of this study was to examine the content knowledge of 64 elementary preservice teachers for the concepts of dissolving and density. Vygotsky's (1987) theory of concept development was used as a framework to categorize concepts and misconceptions resulting from evidences of preservice teacher knowledge including pre/post concept maps, writing artifacts, pre/post face-to-face interviews, examination results, and drawings.

Statistical significances were found for pre- and post-concept map scores for dissolving ($t = -5.773$, $p < 0.001$) and density ($t = -2.948$, $p = 0.005$). As measured using Cohen's *d* values, increases in mean scores showed a medium-large effect size for (dissolving) and a small effect size for density. The triangulated results using all data types revealed that preservice teachers held several robust misconceptions about dissolving including the explanation that dissolving is a breakdown of substances, a formation of mixtures, and/or involves chemical change. Most preservice teachers relied on concrete concepts (such as rate or solubility) to explain dissolving. With regard to density, preservice teachers held two robust misconceptions including confusing density with buoyancy to explain the phenomena of floating and sinking, and confusing density with heaviness, mass, and weight. Most preservice teachers gained one concept for density, the density algorithm.

Most preservice teachers who participated in this study demonstrated Vygotsky's notion of complex thinking and were unable to transform their thinking to the scientific conceptual level. That is, they were unable to articulate an understanding of either the process of dissolving or density that included a unified system of knowledge characterized as abstract, generalizable, and hierarchical. Results suggest the need to instruct preservice elementary science teachers about the particulate nature of matter, intermolecular forces, and the Archimedes' principle.

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I dedicate this dissertation to my father Ghazi who was displaced from his village of El-Kabri, Palestine in 1948 and sadly died in Arabia before seeing the completion of this dissertation. I also dedicate this dissertation to my mother Zeina who for 43 years has never stopped believing in me and for offering all that has enriched my life. The support both my parents and family has given me has been indispensable in enabling me to reach this goal. Lastly, all thanks are due to Allah for His protection and guidance.

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INTRODUCTION

Background of the Study

Since the 1980s, educational reformers in American schools have focused their efforts on science and mathematics education. However, inadequate preparation of American students in science and mathematics continues as evidenced by the low scores that American students have attained on national standardized tests (e.g., National Assessment of Educational Progress [NAEP]) and international standardized tests (e.g., Program for International Student Assessment [PISA] and Trends in International Mathematics and Science Study [TIMSS]). For this reason, teacher preparation programs must develop not only highly qualified but also highly effective teachers who enter classrooms well equipped with both content and pedagogical knowledge.

Statement of the Problem

The focus of this study was to assess prospective elementary teachers' conceptual understanding by identifying and categorizing scientific conceptions and misconceptions about dissolving and density. Vygotsky's (1987) theoretical constructs of concept formation and literature about concept mapping as a tool for identifying change in conceptual understanding (Novak, & Canas, 2008; Ruiz-Primo & Shavelson, 1996) were used to guide this study.

The study's aim, scope, and design were based on the results of a pilot study conducted in a semester prior to this study. In the pilot study, concept maps were used to investigate the conceptions and misconceptions of elementary preservice teachers about dissolving and density. The results from the pilot study helped to identify misconceptions and to modify and strengthen the instructional intervention.

Purpose of the Study

The purpose of the study was to examine preservice teachers' conceptual understanding about dissolving and density.

Research Questions

To examine preservice teachers' content knowledge in elementary science about dissolving and density, the following research questions were developed for this study:

$RQ_{1:}$ What conceptions do preservice elementary teachers have about the concept of dissolving as illustrated using concept maps, writing artifacts, interviews, examination questions, and drawings before and after instructional intervention?

$RQ_{2:}$ What conceptions do preservice elementary teachers have about the concept of density as illustrated using concept maps, writing artifacts, and interviews before and after instructional intervention?

Significance of the Study

College administrators and deans of teacher preparation programs have focused on addressing scientific content and pedagogical knowledge of preservice elementary teachers. Issues that college administrators often discuss include the nature and number of required courses taken and teachers' poor content knowledge in their subject areas (Appleton, 2006; Davis & Petish, 2005; Davis, Petish, & Smithey, 2006; Van Dijk & Kattmann, 2007). The significance of this study involved recognizing that many preservice teachers of elementary science have weak content knowledge in their subject areas and that many preservice teachers possess misconceptions about essential scientific concepts that they transfer to their students (Calik & Ayas, 2005). Accordingly, this study aimed to help preservice teachers identify and correct their misconceptions through an instructional intervention. For this purpose, concept maps, writing artifacts, and face-to-face interviews were used to identify and categorize preservice teachers' conceptions and misconceptions about dissolving and density according to Vygotsky's (1987) theory of concept formation and to develop an in-depth understanding about the nature of elementary preservice teachers' conceptual knowledge and how this knowledge might be used in the preparation of elementary teachers.

Appleton (2006) highlighted problems associated with the traditional preparation of preservice teachers. According to Appleton (2006), the challenge in traditional preparation of preservice teachers is the need to develop science content knowledge in a short period of time for preservice teachers who have missed the opportunity to acquire content knowledge in their high school education. To improve preservice teachers' learning, university administrators must design university programs for teacher education to address inadequacies of traditional systems of learning that promote empirical learning through the development of rote skills (e.g., calculation) or memorization of definitions to understand scientific concepts. The problem is compounded if preservice teachers miss this knowledge yet again during their college years. The implication is that preservice teachers will develop an enacted curriculum (Appleton, 2006), which they will take with them into their classrooms. The enacted curriculum may be filled with misconceptions not based on scientific constructs but derived instead from everyday experiences, and the teachers will present these knowledge errors to their students (Calik & Ayas, 2005). It is also most often these same misconceptions carried by teachers from their preservice college years that are then transmitted to the next generation of students. Therefore, this study was necessary to assess preservice teachers' conceptual knowledge about dissolving and density before and after an instructional intervention.

Definition of Terms

Complex concepts: Complex concepts contain individual elements of a scientific concept, elements that are connected to one another but are not based on unified association.

Conceptual change: Conceptual change is the process of learning or the product of learning. Since the 1980s, the most common idea about conceptual change is that students replace existing ideas with new ideas. Alternatively, a Vygotskian idea about conceptual change is that students build new knowledge on existing knowledge.

Diffuse concept: Derived from Vygotsky's (1986) Concept Development Theory, this is a Spontaneous II concept where a child can group one feature, allowing other traits to vary without bound.

Emerging concept: An emerging concept falls between an unscientific (everyday) concept and a scientific concept. Students who are developing emerging concepts are on their way to forming a scientific concept but have not yet arrived at that higher level of thinking.

Misconceptions: Misconceptions, also known as *naïve* or *alternative conceptions*, are concepts that are not scientifically based. As such, misconceptions are considered erroneous and are obstacles to conceptual change.

Preservice teachers: Participants in this research study, these are college undergraduate students enrolled in a teacher preparation program preparing to become school teachers.

Pseudo-concepts: Pseudo-concepts contain individual elements of a scientific concept, elements that are based on simple associations that contain internal contradictions, which distinguish them from scientific concepts.

Robust misconceptions: These are misconceptions that persist and are maintained by preservice teachers even after receiving instructional intervention.

Scientific concepts: Scientific concepts contain all of the individual elements of a scientific concept, elements that are underpinned and unified by a single association.

Spontaneous concepts: Spontaneous concepts are concepts built from generalizations through practical and everyday social interactions.

Total proposition accuracy score: Total proposition accuracy score is the sum total of the number of correct propositions on concept maps.

Weak misconceptions: These are misconceptions that are not present frequently in preservice teachers' responses, reduce significantly or are abandoned after receiving instructional intervention.

Limitations of the Study

There were several limitations for examining the content knowledge elementary preservice teachers held for dissolving and density:

- The sample population was a convenience sample (Marshall, 1996). The sample was chosen from 4 of 7 sections of elementary preservice teachers who enrolled in a science methods course during the 2011–2012 academic year. Each section was comprised of 19 to 24 participants.
- The sample size was large enough which helps in lessening random sampling error but was still considered limiting for generalization of the results of this study to a larger population.
- The topics studied in this research—dissolving and density—represented only two science topics from the many topics that preservice teachers might be required to teach. The two topics researched in this study were not meant to be used to evaluate the entire continuum of science topics that might be explored in further research. Preservice teachers might possess greater or fewer misconceptions in other topics of science.

- The two topics researched in this study were not represented as the most important topics that might be taught by elementary school teachers but were common topics included in science standards related to national and state standardized tests.
- The two topics researched in this study—dissolving and density—were two complex topics known to persist in the science curriculum through advanced studies at the college level.
- Teacher preparation programs might vary in their degree requirements for the preparation of elementary school teachers. For this reason, care should be taken when generalizing the results of this study to other teacher preparation programs.

Theoretical Framework of the Study

There were two theoretical frameworks for research about science education that were used to address conceptual change in students and to guide researchers:

The first theory, according to the *Handbook of Research on Science Education* (Abell & Lederman, 2007): Sociocultural theory, as advanced by Vygotsky (1987) was used, to reveal conceptual conflicts associated with the language and cultural differences thought to mediate social interactions between students and teachers.

The second theory, relied on concept mapping to measure conceptual change in preservice teachers' responses. It is based on the theory of concept mapping that is rooted in the learning psychology of Ausubel (1963) who distinguished between rote learning and meaningful learning. According to Novak and Canas (2008), meaningful learning requires the learning material to fulfill the three conditions of conceptual clarity, examples extending prior knowledge, and relevance or meaningfulness.

This study used an intervention to address preservice teachers' misconceptions about density and dissolving during instruction. This intervention was based on the sociocultural tradition of Vygotsky (1987) to understand and categorize preservice teachers' misconceptions. Vygotsky's (1987) theory of concept formation was used as the theoretical framework of this study. I chose Vygotsky's (1987) theoretical framework because it aligned with a constructivist view of science learning and was supported by the use of a constructivist tool, the 5E plan lesson model, for instructional intervention (Bybee, 1997).

Vygotsky's (1987) Theory of Concept Development

In Vygotsky's (1987) theory of concept development in children, children experience two critical periods of cognitive development when they are 3 and 7 years old. At age 3, children develop relationships with adults, and at age 7, children develop relationships linked to their own experiences. At age 7, children shift from internal focus to external focus as they develop relationships with people around them. Vygotsky (1987) called the period of cognitive development between ages 7 and 13 the *critical period*, which is the school-age period when children are moving toward adolescence. The critical period is also a time when children develop what Vygotsky (1987) called *internal speech*, which allows students to self-regulate and to appropriate or master concepts (Robbins, 2001). During the critical period, students address practical problem-solving activities, attain new levels of thinking (attention, perception, and memory), and reach a certain level of concept formation.

Researchers who use Vygotsky's (1987) theory of concept development seek to develop the *human consciousness*, which Vygotsky (1987) believed is a by-product of social interaction that children develop by using communication and other psychological tools, such as language, gesture, and sign. Children develop their sense of human consciousness first at the social level and later at the individual level, which is reversed from children's stages of development in

Piaget's (1923) developmental theory. Because Vygotsky (1987) believed that children develop human consciousness first at the social level, Vygotsky (1987) asserted that teachers play an important role in helping children facilitate their concept development.

According to Vygotsky's (1987) theory of concept development, teachers guide students to develop and understand their own thinking. To help students achieve human consciousness, researchers and teachers who have a Vygotskian (1987) understanding of classroom practices must take into account the relationships between the different stages of concept development. Vygotsky (1987) recommended the following process for teachers to use when encouraging concept development during classroom practices: explain concepts, place concepts in contexts, present problems, and listen to students' explanations of the concepts (Gredler & Shields, 2008). Vygotsky's (1986) phases and types of concept development are discussed next.

Vygotsky's (1986) Stages of Concept Development

According to Vygotsky (1986), children experience three phases in concept formation. In Phase I of children's concept development, children's conceptual understanding is in the form of syncretic images or heaps using subjective groupings. In Phase II, children think in complexes that are objective-concrete, perceptual factual groupings. During Phase III, children develop scientific conceptual understandings that are hierarchical and systematic. Table 1 summarizes and describes the different types, phases, and stages of concept development.

Table 1

Vygotsky's (1986) Three Types of Concept Development

Types	Phases	Stages	Description
Spontaneous I	Phase I: Syncretic images or heaps (subjective grouping)	Random	Child has no reason for grouping (e.g., child groups living and nonliving things together).
		Spatial	Child groups by physical proximity (e.g., child groups rock, leaf, and stick together because they are beside one another).
		Two-Step	Child uses a combination of physical proximity and random heaps for selecting members to create new heaps (e.g., child randomly groups living things and nonliving things next to one another and then begins to choose objects that are in close proximity to one another to add to the group, e.g., rock next to a leaf, next to a stem).
Spontaneous II	Phase II: Complexes (objective-concrete, perpetual-factual groupings)	Associative	Child groups based on similarity comparison to a nuclear object (e.g., child calls a cow a dog because child has a brown dog and calls a fox a dog because they are similar in shape).
		Collections	Child groups based on one similarity (e.g., child groups a beaker, flask, and graduated cylinder based on their practical operations.

(table continues)

Table 1 *(continued).*

Types	Phases	Stages	Description
		Chains	Child groups each member of a chain based on similarities, but not all members share the same similarity (e.g., child first groups a squirrel with a rabbit based on long teeth and then adds a deer to the group because the deer has a tail like the rabbit).
Spontaneous II, continued	Phase II, continued: Complexes (objective-concrete, perpetual-factual groupings)	Diffuse	Child groups one feature, allowing other traits to vary without bound (e.g., a goose makes a honking sound, so child calls it a car horn).
		Pseudo-concepts	Grouping seems externally similar to an abstract concept but is based on factual resemblance instead of abstract understanding (e.g., folk wisdom, common sense, everyday beliefs).
Scientific	Phase III: Scientific/True concepts (hierarchical and systematic)	Scientific/True concepts	Child groups through systematic organization, generality, voluntary control, and conscious awareness (e.g., generalizing density over multiple contexts).

Phase I. Syncretism involves the grouping of information using chance associations. According to Vygotsky (1986), Phase I of children's concept development involves the formation of heaps or syncretic images. In the random stage of Phase I, children group objects using chance associations involving trial and error and according to their visual fields and immediate perceptions. For instance, if children are asked to group a collection of objects that have different features, such as different shapes (triangles versus circles) or different colors, children may choose to gather objects with no specific shared features (random). In the spatial stage of Phase I, children may group objects that appear to be within close proximity to one another or *assemble heaps* by taking elements from different groups, or heaps, that they have already grouped. This stage of the first phase of concept development represents primitive, low-level thinking and is the stage during which children first begin to develop conceptual understanding. The final stage, the two-step stage, of the first phase of children's concept development involves the use of both random and spatial groupings.

Phase II. Vygotsky's (1986) theory of concept development explained that children move from Phase I to Phase II when they begin to use complex thinking and to identify concepts that "are concrete and factual rather than abstract and logical" (p. 113). The rules for complex thinking vary significantly from those of scientific concept formation. In complexes, some members of the set may be grouped with others, but all concepts are not grouped according to the same principle.

Complex thinking links concepts using patterns, similarities, differences, and features (Tuomi, 1998). For example, children might first label a canine as a dog and then label all four-legged creatures as dogs (Smagorinsky, Cook, & Johnson, 2003). In this phase of complex thinking, children organize elements according to existing bonds between objects (Yee, 2011). During Phase II of children's concept development, children form concrete groupings using factual bonds, representing how they organize elements into groups that provide the basis for later generalizations. These groupings are again concrete and factual rather than abstract and logical. Children mentally unite objects not only by their subjective impressions but also by bonds that actually exist between these objects, and when children are able to generate these mental bonds, they reach “a new achievement, in an ascent to a much higher level of thinking” (Vygotsky, 1986, p. 112). What distinguishes complexes from scientific concepts is explained by Vygotsky (1986) in the following quote: “While a scientific concept groups objects according to one attribute, the bonds relating the elements of a complex to the whole and to one another may be as diverse as the contacts and relations of the elements in reality” (p. 113). The five different stages of complex thinking that children experience in Phase II of concept development are described next.

Associative complexes. Associative complexes are a form of complex thinking through which children base the bonds they notice between a sample object and other objects. For example, children may call a cow a dog because of experiences with a brown dog, and children may call a fox a dog because the fox has a similar shape to the dog.

Collections complexes. Collections complexes are groups that children create according to one trait, grouping the objects based on the objects’ participation in the same practical operation. For example, children may group a beaker, a flask, and a graduated cylinder based on the practical operations of these objects.

Chain complexes. Forming chain complexes is children’s dynamic and consecutive way of joining individual links of concept development into a single chain. Children may begin to group objects into a chain using one criterion, such as shape, and then as children’s attentions shift to color, they may switch their groupings to allow objects with the same color to be included, which changes selection criteria for grouping.

Diffuse complexes. Diffuse complexes are yet another form of complex thinking that children use. Vygotsky (1986) explains diffuse complexes as being "characterized by the fluidity of the very attribute that unites the elements" (p. 117). For example, children may hear a goose make a honking noise. Later, the same children may hear a car horn and call the horn noise a goose because the sound of the car horn and the goose's honk are similar.

Pseudo-concept complexes. Pseudo-concepts are similar to scientific concepts but are not logical and abstract and do not follow the rules for scientific concept formation. Pseudo-concepts are important because they help children move from complexes to scientific concepts when adults provide vocabulary and ready-made generalizations that will hopefully lead children to form a scientific concept. Vygotsky (1986) reported that pseudo-concepts (transitions between complexes and concepts) predominate over all other complexes—associative complexes, collections complexes, chain complexes, and diffuse complexes—in the thinking of preschool children because children do not develop meanings for concepts on their own. Rather, adults instruct children in concept meanings. Consequently, children need adults to intervene and to help them form scientific concepts. However, simply telling children the meaning of a word does not necessarily translate into helping them form a scientific concept. For example, Kikas (2001) identified melting as a pseudo-concept used to describe erroneously the observed phenomena of dissolving. Melting is a term that children learn early in their lives. However, when dissolving salt and water, the salt is not melting; rather, the molecular compounds in salt are dissociating into their constituent ions (which is an example of a true scientific concept).

Pseudo-concepts are difficult to distinguish from true concepts because pseudo-concepts resemble true concepts: children use the same language and readymade generalizations, which adults provided, to describe both pseudo-concepts and true concepts. However, children in

Phase II of concept development cannot yet understand a concept abstractly and cannot yet generalize a concept to other contexts. As Vygotsky (1986) explained, the pseudo-concept "is a shadow of a [true] concept," or in other words, "there is a double nature to pseudo-concepts" (p. 122). Additionally, children in Phase II of concept development may be able to use scientific vocabulary to describe the meaning of a concept but may fail to comprehend the concept fully. Children can learn the meaning of a word, such as melting, but they can also erroneously apply it to a process such as dissolving which is unrelated to melting. Lastly, it is important to note that children are not the only people who use complexes to rationalize; both adolescents and adults use complexes, particularly pseudo-concept complexes, to rationalize.

In summary, there is no hierarchical organization of relationships between different traits of objects in complex thinking. All attributes of objects are functionally the same. Complexes are concrete and factual and do not follow the rules of scientific concept formation.

Phase III. Concepts (i.e., true or scientific concepts) are distinguished from complexes or groupings in that a single theme unifies the individual elements of a concept. Scientific concepts are abstract and logical, can be generalized, and follow rules. For example, the ability to generalize density over multiple contexts is a scientific concept. According to Vygotsky (1986), adults must instruct children to help them assign meaning and develop scientific concepts because children themselves do not assign meaning to true concepts. Instead, adults give meaning to true concepts for children. Over time, children ease into scientific conceptual understanding. Along the way, children use pseudo-concepts that act as conceptual bridges for transforming their thinking from complex to scientific.

Vygotsky (1986) distinguished between two types of concepts, each of which evolve under entirely different conditions. Spontaneous concepts are learned through cultural practice as the individual reflects on everyday experiences. Spontaneous concepts are learned in specific contexts and have limited generalization in new situations. For example, students in elementary science often use the words *vanish* and *disintegrate* to describe dissolving. This vocabulary represents commonsense words to describe dissolving, words that students derive from observations of everyday phenomena. However, students develop scientific concepts only through formal instruction in which word meanings and abstract categories dominate and restructure learning experiences. Adults attach meanings to words and vocabulary and provide experiences allowing children to understand the concepts represented by the words and vocabulary. Scientific concepts are grounded in general principles and can be applied to new situations (Smagorinsky et al., 2003).

Vygotsky (1986) argued that teachers need to participate actively in teaching scientific concepts because students can develop new interpretations of concepts based on interplay between teachers and students about spontaneous concepts. For example, understanding the concept of dissolving necessitates that students think abstractly at the micro-particle level. To think abstractly, students must develop a thorough understanding of the particulate nature of matter before they are able to understand the phenomena of dissolving. Understanding the particulate nature of matter is a learning experience that is considerably outside the experiences that students encounter in everyday life.

Furthermore, Vygotsky (1986) believed both spontaneous and scientific concepts exist in a dialectical relationship to one another. That is to say, spontaneous and scientific concepts develop in reverse directions and move toward one another as children develop intellectually. Scientific concepts develop from top down, and spontaneous concepts development from bottom up. How well teachers use vocabulary to connect concepts to scientific language will determine how effective instruction is for students within the zone of proximal development (ZPD; Vygotsky, 1986). Vygotsky (1986) defined ZPD as the conceptual distance between spontaneous and scientific concepts. According to Au (1992), "The two types of concepts follow different courses and play different roles in theory development" (p. 272), and there is a dialectic interaction between spontaneous and scientific concepts. Au (1992) argued that "'true concepts' emerge" as a result of this interaction (p. 272). Children must reach a certain level of concept development (prior knowledge) to grasp a scientific concept. Children's spontaneous concepts "are strong in what concerns the situational, empirical, and practical" (Vygotsky, 1986, p. 194). Downward conceptual movement of scientific concepts supplies the structure for the upward conceptual development of spontaneous concepts. For this reason, teachers must help students take their spontaneous concepts to a higher conceptual level because understanding scientific concepts is easier after students gain a thorough understanding of spontaneous concepts.

In summary, spontaneous concepts conceptually progress and transition into scientific concepts as meaning becomes more systematized and logical (Robbins, 2001). Because of the reverse development of spontaneous and scientific concepts, spontaneous and scientific concepts form polar opposites of one another (ZPD). Children require certain levels of conceptual development of spontaneous concepts before they can acquire related scientific concepts. Ideally, formal instruction will developmentally position scientific concepts just ahead (or upward) of spontaneous concepts (within ZPD). As children develop conceptually, higher levels of word meanings are governed by the law of equivalence of concepts in which "any concept can be formulated in terms of other concepts in a countless number of ways" and that "generalizations are built upon all the generalizations that came before them" (Vygotsky, 1986, p. 199).

Emerging Concepts

Akerson (2005) used the term coping strategies (Harlen, 1997) to describe the methods that enable elementary teachers to teach science whether or not they are comfortable with their content knowledge. These coping strategies could include teaching as little of the subject as possible, relying on texts or step-by-step work cards, or avoiding all but the simplest hands-on activities. On the other hand, Appleton (2006) discussed how relying on activities that work can be used by novice teachers in elementary school. Activities could, in this sense, mask lack of content knowledge for elementary teachers who generally have poor backgrounds in subject areas of science. Activities can function as coping strategies that help elementary teachers teach content with which they are not adequately familiar.

The argument put forth through the findings of this research study is that when preservice teachers do not have content knowledge, they substitute this knowledge with coping strategies derived from the lesson activity itself. An example of a substitute coping strategy is using rate to describe dissolving rather than recognizing that rate contains factors that influence the dissolving process but that do not define dissolving itself. A second coping strategy for lack of content knowledge is memorizing a formula from the lesson and using it to define a concept. For example, a preservice teacher uses the density formula to define density rather than to develop the conceptual understanding that density is a property of matter and as such cannot be defined by an algorithmic formula alone. An additional coping strategy for lack of content knowledge entails using experimental procedural information in place of concepts. In this coping strategy, the preservice teacher borrows from the procedural steps found in the lesson activity and uses them in place of the instructed concepts. Williams (1998) found that some students use procedural information on their concept maps in place of concepts. As an example, students in middle school tended to report on mechanical data such as stirring or heating to describe dissolving (Prieto, Blanco, & Rodriguez, 1989).

In addition, Clement and Brown (1989) introduced the phrase *anchoring concepts*, which they defined as an intuitive structure of knowledge that is in rough agreement with accepted physical theory. As such, anchoring concepts are formulated by preservice teachers and not by scientific understanding. Clement and Brown (1989) defined intuitive to mean concrete, not abstract, and developed by students themselves and not through adults' instruction; Clement and Brown also conditioned the anchoring concept knowledge to be one that is not simply memorized or rote.

All three examples cited above and identified by this research effort—using rate, density formula, and experimental procedural information—represent coping strategies that mask lack of scientific content knowledge. Thus, they do not represent unscientific concepts but will be referred to in this research project as emerging concepts. In a Vygotskian sense, they represent knowledge that exists within the students' zone of proximal development and might eventually be developed into scientific conceptual understanding with teacher instruction.

Concept Mapping

Concept mapping was developed in 1972 by Novak's research group at Cornell University as a means to measure and understand changes in children's knowledge of science (Novak & Musonda, 1991). Concept mapping began when Novak's research group investigated the meaningful learning theory advanced by Ausubel in 1963 (Moon, Hoffman, Novak, & Canas, 2011; Novak, 2010). The psychological foundation of concept mapping is based on how children learn concepts from birth to age 3, during which time they begin to recognize regularities and identify labels or symbols for these regularities using the process of discovery learning (Macnamara, 1982).

Concept mapping provides a method to uncover learners' prior content knowledge, which can inform instructional designs and can be used to measure conceptual change. Constructing knowledge through concept mapping facilitates storage of new concepts in working memory and future recall of concepts for problem-solving activities. Some research evidence seems to suggest that content mapping may also improve students' acquisition of new concepts and knowledge because of how the brain organizes information in a hierarchical structure. Therefore, learning strategies such as content mapping that mimic the hierarchical structure of how the brain organizes information enhance the learning capabilities of students (Bransford, Brown, & Cocking, 1999).

Concept mapping represents a tool that teachers can use to investigate how students construct concepts because concept mapping reveals relationships among concepts. Concept mapping creates what Gredler and Shields (2008) called propositional networks, which are conceptualizations of knowledge that are stored in long-term memory. Finally, concept mapping offers the added benefit that it positively affects learning. Hadwin and Winne (1996) identified three strategies for conceptual development that positively affect student achievement: concept mapping, self-questioning, and monitoring time spent in courses. Hadwin and Winne agreed with Novak, Gowin, and Johansen (1983) that concept mapping can result in higher achievement with regard to student learning. Therefore, concept mapping offers a diagnostic tool that can be used for pre-instructional and assessment purposes to identify students' conceptions and misconceptions (Novak & Canas, 2008).

Additionally, concept mapping can be used as evidence of knowledge in terms of hierarchical arrangement, interconnections, and quality of the system. Based on this evidence, concept maps explicate the levels of complexity of students' thinking to reflect students' higher order thinking (Novak & Canas, 2008). If the concept map analysis is followed by students' providing written responses or an interview, follow up with students can be used to probe and clarify students' thoughts by looking at the quality of the students' responses and can help ensure the validity of a researcher's interpretations of students' responses (Borda, Burgess, DeKalb, & Morgan, 2009). As a result, researchers can use concept mapping and interviews to reveal the extent to which preservice teachers reorganize their own knowledge structures.

Novak and Canas (2008) attributed the importance of concept mapping to its power to facilitate meaningful, as opposed to rote, learning. Concept mapping helps teachers scaffold and learners organize conceptual information into structured templates composed of superordinate, subordinate, and coordinate knowledge. These templates are stored in learners' working memories and facilitate interplay between working and long-term memory, allowing students to store knowledge for longer periods of time and eventually to formulate concepts in terms of other concepts in many ways.

Brooks and Shell (2006) support Novak's and Canas's (2008) ideas about using concept mapping for cognitive purposes by suggesting that experts tend to *chunk* (Miller, 1956) information in their long-term memories. Highly motivated experts who chunk information display powerful problem-solving skills when they encounter problem-solving situations. In familiar situations, experts' prior knowledge and experience allows them to tap into long-term memories and to use problem-solving skills to chunk information. However, depending on the extent to which students' concepts are refined due to instruction, concept mapping for students may or may not be similar to how experts chunk information.

In summary, this research effort aimed to contribute to the improvement of the overall quality of preparation for elementary preservice teachers. Recognizing the gap in the research literature for more studies investigating scientific misconceptions held by preservice elementary teachers, the two research questions guiding this study focused on common misconceptions held by preservice teachers on the two concepts of dissolving and density. By using concept maps, written responses, and interviews, preservice teachers' conceptual understanding and misconceptions were identified and categorized using Vygotsky's (1987) theory of concept formation. The interviews also helped me identify preservice teachers' pseudo-concepts, which often masquerade as scientific concepts because of preservice teachers' use of adult language and ready-made generalizations provided by instructors.

CHAPTER 2

LITERATURE REVIEW

Introduction

There is a gap in the research literature for how preservice teachers understand the science concepts they teach. This study examined the conceptual knowledge of elementary preservice teachers about dissolving and density both before and after an instructional intervention using pre-concept and post-concept maps. The theoretical framework for this study was based on Vygotsky's (1987) theory of concept development and Novak's theory of concept mapping.

The literature review provides a historical narrative of understanding conceptual development and details the use of instructional interventions and various assessment tools to promote conceptual change. In this literature review, first an overview of research about misconceptions is presented. Next, how other researchers have used Vygotsky's (1987) theory of concept development to examine preservice teachers' content knowledge and to explore conceptual change and how other researchers have applied Vygotsky's (1987) theory of concept development to categorize misconceptions are presented. The literature review includes research about concept mapping and how other researchers have used concept maps as evaluation tools to assess conceptual understanding. Lastly, the literature review in Chapter 2 concludes with a discussion of misconceptions about dissolving and density.

Research about Misconceptions

Overview of Research About Misconceptions of Elementary Preservice Teachers

During the 1970s, most research about preservice elementary teachers focused on the content that elementary preservice teachers should receive as part of their training in teacher preparation programs. The research focus eventually shifted during the late 1980s to pedagogy and how preservice teachers should deliver content to their students (Duitt, 1993). The dominant mode of instruction driving this shift from content to pedagogy and the process of teaching for preservice teachers were based on constructivism. During this shift, researchers in science education for preservice teachers began to focus on identifying misconceptions of preservice teachers.

Though some research about sources of preservice teachers' misconceptions is available, little research specifically focuses on science misconceptions among preservice teachers of elementary science (Calik, Ayas, & Coll, 2007). More research is needed to develop ways of identifying and eliminating common misconceptions of science teachers, especially of science teachers at the elementary level. The hope is to develop meaningful ways to recognize the misconceptions preservice teachers hold and to address these misconceptions through adequate strategies in teacher instruction at the preservice level.

In their review of misconceptions research, Settlage and Goldtone (2007) agreed that more research is needed about elementary science misconceptions of preservice teachers. They suggested that future research topics into this problem include (a) how misconceptions, cognition, and pedagogy are related; (b) how some concepts become misconceptions; and (c) why misconceptions affect the teaching of science.

Vygotsky's (1986) Method for Understanding Concept Formation, Conceptual Change, and Misconceptions

Vygotsky's (1987) theory of concept development argued that children develop spontaneous understanding of everyday concepts through interactions with objects in everyday life. Vygotsky (1986) called these everyday understandings spontaneous concepts. However, children do not assign meaning to spontaneous concepts without the aid of adults. Children only develop meaning through social interaction and communication with adults. Consequently, social activity mediates conceptual development. Vygotsky's (1986) theory is the opposite of Piaget's interiorization process, which revolved around individual activity mediating social development. Interiorization, according to Piaget (1923), means that individuals' internal cognitive development (i.e., internal thinking) can allow them to construct their knowledge away from their social setting, thus setting them free from their environment.

However, Vygotsky believed that the learned word was both cognitively as well as socially mediated. Hence, children's cognitively primitive understandings are derived from spontaneous conceptualization, but only afford children knowledge in the form of concrete, lower cognitive levels of understanding. To reach higher cognitive levels of abstract thinking, children need interaction with adults who act as mediators of children's learning and who assign meaning to concepts for children. Adults communicate with children using psychological tools such as gestures, language, sign systems, mnemonics techniques, and decision-making systems to help children develop meaning and conceptual understanding (Berger, 2005).

Vygotsky explained that concepts authoritatively handed down to children by adults (e.g., teachers) are nonspontaneous, scientific concepts. Children develop knowledge of new concepts from developing spontaneous or everyday concepts that are dialectically added to the scientific concepts taught by teachers through school instruction (Engestrom, Pasanen, Toiviainen, & Haavisto, 2006). In other words, students develop concepts from spontaneous everyday concepts as well as from scientific concepts given to them by classroom teachers. This dialectical method for concept formation necessarily involves teachers who actively interact with students in their classrooms because the interplay between spontaneous and scientific concepts helps students form and develop conceptual understanding.

In the theory of construct of concept formation, Vygotsky (1986) reasserted that children derive concepts from combining spontaneous concepts from everyday experience and scientific concepts from instruction they receive in school (Engestrom et al., 2006). Vygotsky (1986) argued that researchers should examine how students derive spontaneous concepts both from concrete experiences with everyday life and from scientific concepts, which are abstract and taught by adults during formal instruction using readymade generalizations and vocabulary. When teachers do not help students develop spontaneous concepts, then the gap between spontaneous and scientific concepts is too large, so the bridge of instruction between the concepts is weak. When instruction in concepts is weak, students develop misconceptions or alternative views that are erroneous and that interfere with their understanding of scientific concepts. Vygotsky (1986) defined alternative views or misconceptions that students may possess as complexes or pseudo-concepts (Smagorinsky et al., 2003).

In addition to emphasizing the importance of both spontaneous and scientific concepts, Vygotsky (1986) argued the teachers' role was to address students' misconceptions. Based on teachers' important roles in students' conceptual development, Vygotsky (1986) stated that adequate preservice teacher instruction is critical for teachers to create learning experiences that appropriately facilitate students' conceptual development. The goal for teachers is: (a) to position instruction slightly ahead of what students can do without assistance (i.e., ZPD), (b) to realize that the affinity between spontaneous and scientific concepts develops verbally, and (c) to realize that during each stage of conceptual development, new generalizations are built upon prior generalizations from previous stages. The central idea of Vygotsky's (1986) theory is that preservice teachers will become mediators of learning; therefore, the quality of content knowledge that preservice teachers will deliver to students is of paramount importance. The content knowledge of preservice teachers must be sufficient for them to scaffold learning experiences, building on the spontaneous concepts that they have derived from everyday experiences to arrive at nonspontaneous concepts, the stage of conceptual development in which scientific understanding occurs. Instructors must be able to identify students' misconceptions and to intervene and lead students to develop desired scientific concepts.

Concept Mapping as an Evaluation Tool

The earliest use of concept maps to assess students' conceptual understanding began in 1972 (Novak & Musonda, 1991). Novak and Canas (2008) stated that concept maps are powerful tools for evaluation and instruction because concept maps force students to arrange new concepts in an organized and structured manner. Hierarchical structures of concept maps resemble the way in which human brains organize and structure new information in working memories, information that will eventually be stored in long-term memories (Novak & Canas, 2008). Novak and Canas pointed to the important fact that creating concept maps forces students to demonstrate the complexity of their knowledge, which may include both higher-order and lower-order thinking.

Consequently, over the last two decades researchers have explored using concept maps in different ways: as a tool to evaluate student conceptual understanding, as a valid assessment tool in general by comparing them to conventional test scores, for use in the classroom to enhance student conceptual understanding, or as a tool for identifying misconceptions held by students and preservice teachers.

Many researchers have supported using concept maps as evaluation tools to test students' conceptual understanding (Francisco, Nakhleh, Nurrenbern, & Miller, 2002; Novak, Gowin, & Johansen, 1983; Ruíz-Primo, 2000; Ruíz-Primo & Shavelson, 1996; Vanides, Yin, Tomita, & Ruíz-Primo, 2005). For example, Ruíz-Primo (2000) discussed using concept maps to measure student achievement in science and to define mastery of concepts for three types of knowledge: propositional knowledge (knowing what a concept is), procedural knowledge (knowing how a concept works), and strategic knowledge (knowing how a concept is applied and in what context it is used).

Indeed, some researchers decipher differences in academic achievement for students by utilizing concept maps. Markham, Mintzes, and Jones (1994) found that concept map scores differed between advanced biology students and beginning non-science major students and that concept map scores for advanced biology students were more complex than were those for beginning non-science major biology students. Similarly, Wilson (1994) found that students who were high achievers in chemistry produced better scores for complex concept maps than did students who were low achievers in chemistry. Acton, Johnson, and Goldsmith (1994) found a similar result in physics, with higher mean scores for concept maps constructed by experts compared to lower mean scores for concept maps constructed by novices.

Moreover, researchers examined how concept map scores compared to conventional test scores in measuring student understanding and found agreement between the two. Stoddart, Abrams, Gasper, and Canaday (2000) reported that scores from concept maps were correlated to scores from conventional tests when the two tools were compared based on required application of knowledge (as opposed to recall of knowledge) on open-ended, student-directed tasks. Hoz, Bowman, and Chacham (1997) found similar results when they analyzed scores of 14 students who used concept maps and conventional tests in a geomorphology course. Construct validity for concept maps was confirmed when the scores from concept maps were compared to scores from conventional tests, yielding a moderate positive correlation. Similarly, Liu and Hinchey

(1993) found high to moderate construct validity between scores from concept maps and conventional tests used in two classes of seventh-grade science.

Next, concept maps were investigated for their role in enhancing students' conceptual understanding in the classroom. In their study of student achievement in eighth-grade ecology and genetics, Esiobu and Soyibo (1995) found that the experimental group using concept and Vee maps scored better compared to a control group. Gouli, Gogulou, and Grigoriadou (2003) examined the use of concept maps as a tool for assessment in conjunction with other tools of formative and summative assessment and reported positive changes for student conceptual understanding. Gouli et al. (2003) developed a coherent and integrated framework for assessment purposes, a framework based on concept mapping as the main tool to assess students' prior knowledge, to measure students' conceptual change during instruction, and to score students' overall conceptual understanding after instruction. Gouli et al. (2003) concluded that concept maps are valid tools to assess prior knowledge, to identify misconceptions, to measure conceptual change, and to increase overall knowledge of a subject. These findings further affirm the validity of using concept maps to identify and evaluate students' misconceptions.

In her 2-year study, Mason (1992) examined the use of concept maps with preservice teachers in science education and found that preservice teachers had declarative content knowledge but lacked conceptual understanding. After participating in Mason's study, teachers began to use concept maps to help students understand relationships among concepts that were being learned in isolation. Finally, Francisco et al. (2002) reported favorably about using concept maps as an assessment tool. In their study of undergraduate chemistry students' understanding of solution chemistry, Francisco et al. concluded that concept maps are an excellent alternative educational tool as well as a good evaluation tool for professors and teaching assistants desiring to understand students' conceptualizations and misconceptions of chemistry concepts.

Cognitive Rationale of Using Concept Mapping

Cognitive psychologists have determined that structure is the essence of knowledge (Anderson, 1984). Organizing knowledge in a structured way is what distinguishes experts from novices. Experts have extensive domain knowledge that novices lack, and experts organize this knowledge in a structured way not used by novices (Chi, Glaser, & Farr, 1988). Researchers have observed significant differences in student scores on concept maps depending on whether or not students are advanced in the subject matter (Markham et al., 1994; Wilson, 1994). Consequently, concept maps can provide students with a means to organize their conceptual understanding in structured ways, much as experts do in real life, to increase conceptual understanding.

Constructing and Scoring Concept Maps

In this section of the literature review, the different designs and types of concept maps available to researchers and teachers are presented. The discussion also describes how concept maps can be scored. This section of the literature review concludes by discussing literature about various issues of validity and reliability in concept mapping.

Developing a concept map is a two-step process: constructing the concept map and scoring the concept map. Scoring concept maps can vary widely. Novak and Gowin (1984) developed a standard method to score concept maps, a method based on the four aspects of proposition scoring: number of propositions scored, cross-links, accuracy of propositions, and comparison of similarities between concept maps for experts and novices.

The construct of concept maps can be one of two types: S-concept maps and C-concept maps (Yin, Vanides, Ruíz-Primo, Ayala, & Shavelson, 2005). In an S-concept map, students are provided with linking phrases; in a C-concept map, students must provide their own linking phrases. Yin et al. (2005) recommended C-concept maps instead of S-concept maps because C-concept maps provide more information about students' partial knowledge, tend to produce more complexly structured concept maps and faster student propositions, and allow students to show more of what they know than do S-concept maps. Yin et al. based their recommendation on results from research about students using S-concept maps followed by C-concept maps (SC group) and students who started with C-concept maps and then used S-concept maps (CS group). Mean scores for the SC group increased, but mean scores of the CS group decreased. These results show that students demonstrated a format effect as they switched from one technique to another. Yin et al. also noted an increase in mean scores for students per occasion (i.e., number of administered times): Students' mean scores increased on the second time they used concept maps, when students were required to construct their concept maps whether they belonged to the SC or the CS group.

Yin et al. (2005) scored concept maps using both quantitative and qualitative techniques. For the quantitative technique, Yin et al. determined total proposition accuracy and scored each individual proposition using a scale of 0 to 3 (with 3 being the highest score). For the qualitative technique, Yin et al. evaluated the proposition choice and the complexity of the structures of the concept maps using the following descriptions: linear, circular, hub or spoke, tree, and network. Figure 1 illustrates these five structures of concept maps. According to Kinchin (2000), analyzing students' concept map constructions qualitatively may reveal misconceptions or lack of connections in-between topic areas and may provide evidence of conceptual change taking place.

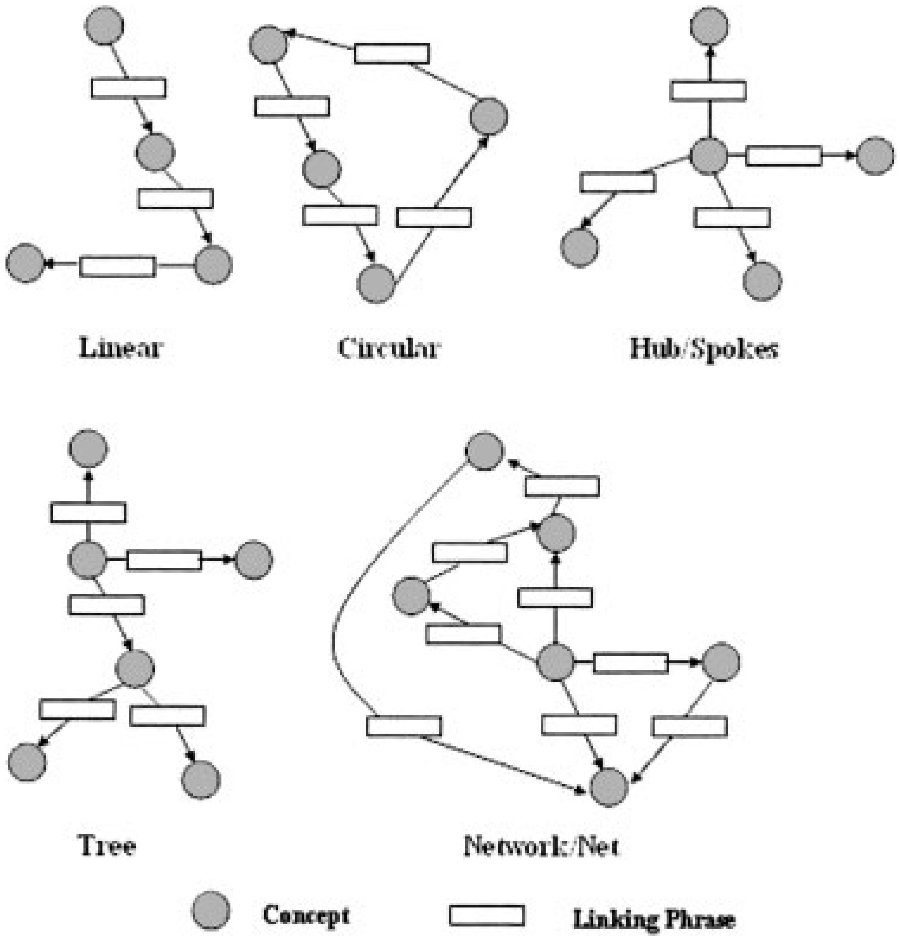


Figure 1. Different types of concept maps and varying geometrical structures as used with permission from Yin et al. (2005, pp. 166-184).

How to Construct a Concept Map

A typical concept map is comprised of nodes (circles) in which students place important concepts and connecting lines labeled with linking words to show relationships that connect different concepts. A node connected by a labeled line connected to another node is called a proposition (Yin et al., 2005). The proposition accuracy score (Type I) is the total sum on a 5-point scale of the accuracy of each proposition in students' concept maps. The 5-point scale is based on the following qualitative phrases: *accurate excellent* (5), *accurate good* (4), *accurate poor* (3), *don't care* (2), and *inaccurate* (1). The convergence score (Type II) is the proportion of accurate propositions out of the total possible valid propositions in the master map observed in students' concept maps. The salience score (Type III) is the proportion of valid propositions out of all the propositions observed in students' concept maps.

Research Findings for Validity and Reliability of Concept Mapping

Ruíz-Primo (2000) found that research results about validity of concept maps were not conclusive across all studies she examined. One way to check validity of concept maps is to compare results from concept maps to results from multiple-choice tests. After Ruíz-Primo compared results from the two types of evaluation tools, she concluded that the results across studies examined were not conclusive and depended on the concept mapping technique used. The reliability score examined for studies comparing the fill-in-the-node technique and multiple-choice scores reported was 0.75 on average, while the reliability score calculated by Ruiz-Primo was 0.37. Though results for correlations between construct-a-map technique and multiple-choice scores were reported in the literature to range from -0.02 to 0.34, they were found by Ruiz-Primo to be 0.5, when results were averaged across studies using the convergence scoring method.

Despite the fact that her results were inconclusive, Ruíz-Primo (2000) determined that teachers can still use concept maps as effective evaluation tools. Ruíz-Primo pointed to five advantages related to the use of concept maps:

1. Teachers can train students to construct concept maps in a short period of time with limited practice.
2. Raters do not introduce error variability into the scores (across studies, the inter-rater reliability on convergence score averaged .96).
3. The sampling variability from one random sample of concepts to another affords equivalent map scores when the concept map domain is specified.

4. The high magnitude of relative (.91) and absolute (.91) coefficients, as averaged across types of scores and studies, suggested that teachers can consistently rank students' scores on concept maps relative to one another, which can provide a reasonable estimate of students' levels of performance independently of how well their classmates performed.

5. The convergence score—the proportion of valid propositions in students' maps out of the total possible propositions in the criterion map—seems to better reflect systematic differences in students' connected understanding and is the most effort- and time-efficient indicator of students' understanding.

Furthermore, McClure, Sonak, and Suen (1999) found that the scoring method can influence the reliability of the concept map. McClure et al. (1999) and Novak and Gowin (1984) compared three methods for scoring concept maps: holistic, structural, and relational. In both studies, the most reliable method to score concept maps is in relation to a master map based on a 3-point criterion. This method is reliable (high *g*-coefficients of 0.76), valid ($r = 0.608$), and statistically significant ($p < .001$) when compared to similar scores for master maps. This method also requires only a short amount of time for complete scoring (1-5 minutes). McClure et al. and Novak and Gowin recommended the relational method as the method of choice for scoring concept maps because relational scoring offers reliability, validity, and efficiency.

As evaluation tools, concept maps are a means to evaluate students' organization of declarative knowledge. The two basic types of concept maps are high-directed concept maps in which instructors provide a lot of information and low-directed concept maps in which students provide most of the information (Ruíz-Primo, 2000). Ruíz-Primo (2000) recommended using low-directed concept maps because low-directed concept maps result in more information about students' knowledge in the particular domain and in better understanding of the connections students use to understand concepts.

Validity issues. In their work on validity, Ruíz-Primo and Shavelson (1996) discussed three types of validity issues for using concept maps as evaluation tools: content validity, concurrent validity, and construct validity. Researchers may check content validity by using expert maps and concurrent validity by measuring concept map scores against scores from measures with previously established validity, such as conventional test scores (e.g., standardized chemistry tests, Advanced Placement chemistry tests, etc.). However, researchers often do not consider construct validity, so more studies are needed to accumulate correlations that fit an expected pattern and that establish construct validity.

Ruíz-Primo (2000) and Ruíz-Primo and Shavelson (1996) examined many studies about the reliability of concept maps as evaluation tools and found varying results. These researchers cautioned that other researchers should be careful choosing which type of reliability scores to report because they found inter-reliability ratings of concepts tends to be high at 0.80, suggesting a need for re-test reliability. Also, Stoddart et al. (2000) found similar results to those found by Ruíz-Primo (2000) and Ruíz-Primo and Shavelson (1996) regarding the issue of reliability for concept maps. Ruíz-Primo (2000) and Ruíz-Primo and Shavelson (1996) reported high Cronbach's α values (0.76-0.90) for inter-reliability and high Cohen kappa measures (0.70-0.86) for inter-rater agreement in the concept maps used in their studies. Moreover, Wallace and Mintzes (1990) reported positive findings on measures of instructional sensitivity. They observed improvements in student scores on concept maps when comparing scores before and after instruction.

Yin and Shavelson (2008) examined how teachers use the two types of concept maps: S-concept maps (students provided with linking phrases) and C-concept maps (students create their own linking phrases). Yin and Shavelson applied G-theory to both types of concept maps and reported a larger *G* coefficient for C-concept maps than for S-concept maps. Yin and Shavelson (2008) concluded that if teachers administer the maps for only one occasion, C-concept maps are more valid, but S-concept maps are more reliable. To achieve higher reliability for C-concept maps, Yin and Shavelson proposed increasing the number of required propositions to 30 if there would be only one occasion to administer concept maps. Increasing the number of required propositions raises the generalizability coefficient of C-concept maps to 0.80, which is closer to the generalizability coefficient of S-concept maps. If there is more than one occasion to administer concept maps, then the number of propositions can be reduced to 18.

Yin and Shavelson (2008) cited advantages of using of S-concept maps for large-scale testing because of the S-concept map's ability to be scored more efficiently and with greater ease. For example, researchers can use computer programs that score students' concept maps against an expert concept map (Klein, Chung, Osmundson, Herl, & O'Neil, 2001). S-concept maps are more efficient and more reliable than C-concept maps, but S-concept maps have lower validity (Yin & Shavelson, 2008). A good analogy is S-concept maps are to multiple-choice exams as C-concept maps are to essay exams. Yin and Shavelson (2008) referred to C-concept maps as the gold standard of concept maps (Ruíz-Primo, Schultz, Li, & Shavelson, 2001).

To conclude this section, reliability and validity vary according to the type of map constructed. A researcher may opt to use two or three methods of scoring concept maps in conjunction with one another to judge validity and reliability of competing methods or to triangulate data. Using a low-directed, concept-mapping task with a C-concept map offers high validity while S-concept maps offer high reliability.

Conceptions and Misconceptions About Dissolving and Density

Dissolving

Scientifically accepted conceptions about dissolving and solutions. The process of making a solution occurs when a solute (usually a lower quantity of a solid substance) dissolves in a solvent (usually a greater quantity of a liquid substance). Dissolving is a physical, rather than chemical, change. The underlying scientific understanding of the concept of dissolving in solutions comes from thermodynamics and an understanding of chemically weak intermolecular forces that govern the solute and solvent particles at a particulate level (Brown, LeMay, & Bursten, 2006). The process of dissolving begins when enough energy of enthalpy is invested into the system (which can be facilitated through stirring or heating) to break intermolecular forces (also known as van der Waals forces) of solute-solute as well as solvent-solvent particles. These van der Waals forces are weak intermolecular forces of three types: dipole-dipole forces, London dispersion forces, and hydrogen bonding forces. These forces result from the polarizability of the compounds.

From a thermodynamics point of view, when a substance dissolves, the energy of enthalpy gained from intermolecular forces interacting between solute-solvent particles is more favorable than those between solute-solute and solvent-solvent particles on their own for dissolving to occur. During the process of dissolving, the original intermolecular forces are broken and new intermolecular forces form between solute and solvent particles in the newly formed solution. If the conditions are not thermodynamically favorable, more energy would need to be pumped into the system to favor intermolecular forces of solute-solvent particles so that dissolving of the solute could occur.

Misconceptions about dissolving and solutions. Research about misconceptions in chemistry began in the 1980s (Nakhleh, 1992). Misconceptions associated with understanding the concept of dissolving are shown in Table 2. Piaget and Inhelder (1941; 1974) found several misconceptions related to dissolving that depend on children's developmental stages. Students in prekindergarten and kindergarten explain dissolving as disappearance. Students in elementary school describe dissolving as liquefaction, and students in high school describe dissolving as breaking or pushing larger particles into pieces. In her study of children's conceptions of dissolving, Kikas (2001) used research literature to summarize major misconceptions associated with dissolving, including dissolving means melting, dissolving means breaking down substances, dissolving means disappearing, and dissolving means liquefaction. Calik, Ayas, and Ebenezer (2005) conducted a two-decade review of research studies on solution chemistry that suggested students confuse solution chemistry with nonrelated concepts, prefer to explain solution chemistry in everyday language, and lack submicroscopic explanations.

Table 2 provides the opportunity to identify a common thread in the literature findings. The major misconceptions exhibited by students and preservice teachers alike stem from lack of understanding first of the nature and role of intermolecular forces (Calik, 2005; Devetak, Vogrinc, & Glazar, 2009; Kind, 2004; Nakhleh, 1992; Taber, 1993) and second of the particulate nature of matter (Calik, Ayas, & Ebenezer, 2005; Devetak et al., 2009; Nakhleh, 1992). In the case of preservice teachers, the literature about dissolving misconceptions revealed that students and preservice teachers share the same types of misconceptions about dissolving (Calik & Ayas, 2005). In addition, preservice teachers transfer their misconceptions to their students (Calik & Ayas, 2005).

Table 2

Common Conceptions and Misconceptions Found in Research Literature about the Concept of Dissolving

Description of Dissolving	Researcher(s), Year
Kindergarten Students	
Melting.	Kikas, 2001
Disappearing.	Kikas, 2001
Elementary Students	
Melting.	Driver, 1985
Disappearing.	Driver, 1985
Middle School Students	
Molecules break down into individual atoms during a change of state.	Abell & DeBoer, 2008; Prieto et al., 1989
Melting.	Calik 2005; Calik & Ayas, 2005; Prieto et al., 1989
Disappearing.	Calik & Ayas, 2005; Longden, Black, & Solomon , 1991; Prieto et al., 1989
Dissolving is related to acidity.	Calik & Ayas, 2005
Lack understanding of hydrogen bonding and intermolecular forces.	Calik, 2005; Kind, 2004
Relate dissolving to surface area of solute.	Calik, 2005
Relate dissolving to changes in pressure.	Calik, 2005

(table continues)

Table 2 (*continued).*

Description of Dissolving	Researcher(s), Year
High School Students	
Disappearing.	Nusirjan & Fensham, 1987; Prieto et al., 1989
Molecules break down into individual atoms during a change of state.	Prieto et al., 1989; Nusirjan & Fensham, 1987
Involves a chemical reaction between solute and solvent.	Barker, 1995; Ebenezer & Erickson, 1996; Kind, 2004; Nusirjan & Fensham, 1987
Lack understanding of hydrogen bonding and intermolecular forces.	Calik, 2005; Kind, 2004; Taber, 1993
Have difficulty describing ionic bonding.	Taber, 1993
Melting	Calik, 2005; Ebenezer & Erickson, 1996; Othman, Treagust, & Chandrasegaran, 2008; Prieto et al.,
Relate the concept of dissolving to an unrelated concept such as density.	Ebenezer & Erickson, 1996
Small pockets of air in water are driven out by a solute that occupies those spaces.	Ebenezer & Erickson, 1996
Some substances don't dissolve because they can't find sufficient space in the dissolving medium.	Ebenezer & Erickson, 1996
Size of the solute must be small enough to dissolve in the solvent.	Ebenezer & Erickson, 1996
Solutes must have "special" properties to dissolve in a solvent.	Ebenezer & Erickson, 1996
Relate dissolving to surface area of solute.	Calik, 2005
Relate dissolving to changes in pressure.	Calik, 2005

(table continues)

Table 2 (*continued).*

Description of Dissolving	Researcher(s), Year
High School Students, continued	
Sugar only dissolves when stirred because stirring causes crystals to break into smaller particles that will spread in the water and can no longer be seen.	Othman et al., 2008
Sugar when dissolved fills the air spaces in water.	Othman et al., 2008
Preservice Elementary School Teachers	
Melting	Calik et al., 2007; Valandis, 2000
Solutes (like sugar) will sink to the bottom because they are heavier than water.	Valandis, 2000
Involves a chemical change or chemical reaction.	Calik et al., 2007; Valandis, 2000
Solid grains break up into "smaller and invisible grains."	Valandis, 2000
Teachers exhibit perceptual rather than conceptual knowledge of dissolving.	Valandis, 2000
Relate dissolving to surface area of solute.	Calik et al., 2007
Preservice Middle School Teachers	
Believe dissolving is melting.	Calik & Ayas, 2005
Believe dissolving is related to acidity.	Calik & Ayas, 2005
Believe dissolving means disappearing.	Calik & Ayas, 2005

From a Vygotskian perspective, these misconceptions about dissolving seem to come from alternative views held by students and preservice teachers alike and are based on spontaneous understanding of what takes place when a substance dissolves. Researchers have attributed some of these misunderstandings, specifically that dissolving means disappearing or that dissolving is melting, to what Vygotsky (1986) called complex thinking. Both misconceptions are derived from life experiences that are not grounded in scientific theory.

Using Vygotsky's concept development theory, some of these misconceptions are identified as pseudo-concepts. Kikas (2001) found that children may use pseudo-concepts to explain the concept of dissolving. Using Vygotsky’s (1986) understanding of pseudo-concepts to mean scientific words taken from adults but used in the wrong sense, Kikas found that when children use the words *dissolving* or *melting*, children allude to totally different ideas from the scientific meaning of the words. A teacher’s meaning for dissolving is the spread of solute particles in the solvent; for children, dissolving may mean that sugar combines with water to form a new substance. When children are asked to provide an explanation of a concept, they are either unable to do so or apt to provide the wrong answer.

Hence, in addressing these misconceptions, Ebenezer and Erickson (1996) found that to help students develop correct understanding about the concept of dissolving, instructors must take into account three factors. First, instructors must consider how students’ everyday knowledge affects their understanding of the process of dissolving and how students rely on what they see to explain the phenomenon of dissolving. Observing sugar dissolving into water does not mean that the sugar has become liquid or has melted. Second, students’ preexisting understanding about the properties of matter at the macroscopic as well as microscopic level must be accurate. Students tend to believe that matter, although made of particles, that these particles are just tiny pieces of matter that retain the original properties of the bulk matter piece. Finally, students do not always correctly and appropriately interpret and use their instructors' scientific language. Preservice teachers share these same difficulties as their students. For example, an instructor uses the word *particle* to describe atoms, but some students mistake the definition of particle to mean granules of solute. Valandis (2000) explained this as a result of preservice teachers' tendency to describe perceptual knowledge rather than conceptual knowledge about dissolving.

Lastly, it is noteworthy to observe that the research findings suggest that misconceptions can be developmental, yet also resistant to instruction. Nakhleh, Samarapungavan, and Saglam (2005) reported that middle school students will generally have views closer to scientific views than will elementary students. Middle school students begin to understand phenomena at the micro level, but elementary school students generally observe phenomena at the macro level.

Calik (2005) conducted a cross-age study of students in Grades 7, 8, 9, and 10 for four test items and found that the percentage of misconceptions about dissolving decreased by Grade 9 (except for one test item) but increased again by Grade 10. Calik concluded that misconceptions are stored in the long-term memory, can lead to new misconceptions, and can interfere with later learning. Also, Calik noted that misconceptions can be resistant to instruction.

Density

Scientifically accepted conceptions about density. Density is a physical property of matter that is intensive. Unlike extensive properties of matter, density does not depend on the amount of matter involved. In contrast, mass or volume are extensive properties of matter and depend on the amount of matter involved. Density has derived *Le Système international d'unités* (SI) units (in metric units these are expressed as g/mL or g/cm^3) and can be thought of conceptually as two-dimensional, meaning that density is dependent on the two physical entities of mass and volume. Algorithmically, density is a proportional or fractional relationship expressed in the formula that divides mass by volume and depends on the ratio of mass of an object to its volume: $d = m / v$.

When considering density, one must think of mass and volume simultaneously and in proportion to one another and assume that the two substances involved do not react chemically. How is the mass of the object related to its volume? An example would be in considering the relationship that governs density to volume and density to mass. Increasing the mass of an object but holding the volume constant would result in an increase in density. Alternatively, increasing the volume of an object but holding the mass constant would result in a decrease in density (Brown et al., 2006).

Buoyancy is what determines whether an object will float and is related to density by Archimedes' principle. An object's floating depends on the density of the fluid, the shape of the object, and the volume of fluid displaced (which is equal to the volume of the object). As such, buoyancy can be defined as the upward force that opposes the weight of an object immersed in a fluid and is equal to the weight of the displaced fluid. According to Archimedes, a body immersed in a fluid is buoyed up with a force equal to the weight of the displaced fluid (Graf, 2004).

Misconceptions about density. Common misconceptions related to density include confusing density with mass, heaviness, and weight and confusing density with buoyancy to explain the phenomena of sinking and floating. Students who are in Grades K-12 tend to confuse density with heaviness, believing heavier objects are more dense and less heavy objects are less dense (Krnel, Watson, & Glazar, 1998; Smith, Carey, & Wiser, 1985; Smith, Maclin, Grosslight, & Davis, 1997; Smith, Snir, & Grosslight, 1992). Also, students and preservice teachers alike have difficulty relating density to buoyancy to explain sinking and floating or misunderstanding that weight alone is what determines an object's ability to sink or float (Penner & Klahr, 1996; Stepans, Dyche, & Beiswenger, 1988; Tasdere & Ercan, 2011). Preservice teachers have difficulty recognizing density as a property of matter (Dawkins, Dickerson, McKinnet, & Butler, 2008). Indeed, the most common misconception related to density is confusing density with the concept of heaviness, mass, or weight.

Children's misconceptions about density seem to begin with early confusion about density and heaviness, which develops between the ages of 5 and 7; however, children can differentiate between the two concepts by age 8 or 9 (Smith et al., 1985). At age 9 or 10, children begin to relate the density of one material to that of another (Driver, Rushworth, & Wood-Robinson, 2006). Hewson (1986) investigated knowledge of density and found that some students aged 14 to 22 years relate density of material to denseness in the packing of particles.

Rowell, Dawson, and Lyndon (1990) conducted an experimental study of 11-year-old students who were measuring volume using the water-displacement method and reported that over 80% of students (n = 60) had misconceptions about volume that could present serious difficulties in developing a conceptual understanding of density. Rowell et al. stated that 35% of students used the false notion that heavier objects would result in more volume, thus displacing a greater amount of water. Krnel et al. (1998) revealed that students may confuse less dense objects as being lighter. However, Kloos, Fisher, and Van Orden (2010) argued that misconceptions about density do not come from students confusing heaviness and density.

Misconceptions about density come from limitations of the task and the structuring of the task that affect students' abilities to distinguish heaviness and density (Kloos et al., 2010). Table

3 summarizes the major misconceptions associated with understanding the concept of density.

Table 3

Common Conceptions and Misconceptions Found in Research Literature about the Concept of Density

Description of Density	Researcher(s), Year
Preschool/Elementary Students	
Relate density to buoyancy; however, weight and volume interfere in understanding how the two concepts relate.	Kohn, 1993
Confuse weight and density.	Krnel et al., 1998
Children below age 5 do not have the density concept articulated. At age 5 to 7, children do not differentiate density and weight. Differentiation of the two concepts of density and weight occur at age 8 to 9. Confuse density and weight in second grade but not in fourth grade.	Smith et al., 1985
Believe weight alone determines an object's ability to sink or float.	Penner & Klahr, 1996
Middle School Students	
May stop confusing density and weight by sixth grade.	Smith et al., 1985
Confuse density and weight.	Krnel et al., 1998; Smith et al., 1997; Smith et al., 1992
Can differentiate density and weight with intervention. Are able to setup the density calculation correctly and provide correct density unit label.	Smith et al., 1997
Believe that an object's buoyancy is equal its weight.	Tasdere & Ercan, 2011
Believe weight alone determines an object's ability to sink or float.	Penner & Klahr, 1996
Have misconceptions about volume that make it difficult to understand density.	Krnel et al., 1998
Exhibit difficulty in relating density to buoyancy.	Tasdere & Ercan, 2011
High School Students	
Relate concentration to density.	Heyworth, 1999
Relate density to packing of particles but inadequately or incompletely explain the phenomenon because their conceptions about mass and volume depend on their conceptions about arrangement, concentration, and the mass of particles.	Hewson, 1986

(table continues)

Table 3*(continued).*

Description of Density	Researcher(s), Year
Adults	
Relate density to buoyancy; however, weight and volume interfere in understanding how the two concepts relate.	Kohn, 1993
Preservice Elementary School Teachers	
Teach students about density based on poor comprehension of factors that influence sinking and floating, including relating density to buoyancy.	Stepans et al., 1988
Believe heavy objects sink.	Greenwood, 1996; Stepans et al., 1988
Have only rudimentary understanding of floating and sinking and can predict what sinks and what floats but can't explain why.	Greenwood, 1996
Preservice Middle School Teachers	
Exhibit difficulty in relating density to buoyancy.	Dawkins et al., 2008
Have difficulty recognizing density as a property of a substance.	Dawkins et al., 2008
Teach students in middle school and high school to focus on memorizing the definition of density and using the algorithm d = m / v.	Dawkins et al., 2008
Relate density to sinking and floating in that less dense objects will float while denser objects will sink.	Dawkins et al., 2008

Misconceptions about density are complicated by the fact that density simultaneously involves the relationship between the two concepts of mass and volume. One cannot examine the density of an object without first examining both the meaning of mass and volume and how the two are related to one another. Students struggle with distinguishing how mass and volume differ and with how the two concepts of mass and volume are interrelated with the concept of density (Dawkins et al., 2008; Hapkiewicz, 1992). Moreover, Dawkins et al. (2008) studied preservice teachers and found that preservice teachers may have discrete understanding of individual elements of science content but may have not connected those elements in a way that makes sense to them. Dawkins et al. concluded that in general, students do not understand scientific relationships because teachers do not completely understand scientific relationships. To bring about conceptual change for both students and teachers, Dawkins et al. suggested that teachers help students recognize why they have difficulty with relationships in science, facilitate improvements in students' understandings regarding mathematical models and what they mean conceptually, and provide students with effective pedagogical strategies to address scientific relationships (Dawkins et al., 2008).

Students require some algorithmic knowledge and conceptual development to understand density. Density as a scientific concept is more complicated because of its two-dimensional nature involving both mass and volume and requires more algorithmic understanding (mainly understanding proportions or fractions) than does a one-dimensionality concept, such as volume or mass on its own. To illustrate the difference in algorithmic understanding required to comprehend a two-dimensional versus a one-dimensional scientific concept, consider the example of the small piece of metal with the same density as a large piece of metal. Although the size of each piece of metal is different, each piece still has the same density. The two differently sized pieces of metal have the same density because of the ratio of the volume (size) and the mass of the objects. To understand this concept completely, a student must consider how the two pieces are related to each other and how proportionality changes in this relationship. If both volume and mass are reduced in proportion to one another, then density will stay constant. On the other hand, if either volume or mass is reduced without holding one variable constant, then density will change.

Density is also used to describe how objects float or sink, resulting in an additional element that is necessary to understand density: the concept of buoyancy. Kohn (1993) found that students as young as 4 years of age have some conception of density that allows them to make predictions about buoyancy. However, just like adults, children incorrectly report that heavier objects sink and lighter objects float. The interference comes from difficulty in understanding the related concepts of volume and weight. In addition, Smith et al. (1985) reported that students differentiated the concept of density from weight between the ages of 8 and 9. According to Smith el al. (1985), children do not have an understanding of density below age 5 and still cannot differentiate density from weight between the ages of 5 and 7. Kohn (1993) concluded that although children who are 4 years old do not have a formal proportional understanding of density, they do have a common sense understanding that density is what matters in an object's buoyancy.

In summary, Kohn (1993) believed that children understand that density influences an object's buoyancy as early as age 4 but also confuse the influence of weight on whether an object could sink or float. Smith et al. (1985) reported that confusion between the concepts of density and weight is generally not a problem for children who are between ages 8 and 9. If preservice teachers are confusing density, weight, and buoyancy, then they seem to exhibit the same misconceptions about density as are children who are below 8 years old.

CHAPTER 3

METHODOLOGY

Research Design

Marshall (1996) argued that choosing between quantitative or qualitative research methodology should be based on the research questions of the study. The aim of the quantitative approach is to test the predetermined hypothesis and to produce generalizable results; the objective is to answer “what” questions. The aim of qualitative research, by contrast, is to provide illumination and understanding of the complex psychosocial issues involved and is concerned with transferability; the objective of qualitative research is to answer “how” questions. This research project used a mixed-methodology approach. The quantitative approach was used to compare the scores of preservice teachers’ pre/post concept maps, while the qualitative approach involved a thematic approach to analyze the misconception and conception identified in the preservice teachers’ concept maps, writing artifacts, and interviews as part of gaining an in-depth understanding of the preservice teachers’ responses.

The data collection method involved was a methodological triangulation approach (see Table 4). Triangulation is used to enhance the credibility of qualitative analysis. It is a cross examination or a checking of results. According to Denzin (2006), methodological triangulation involves using more than one method to gather data, such as interviews, observations, questionnaires, and documents. This approach to investigating complex human behavior provides researchers with a fuller and richer understanding by studying phenomena and behavior from more than one standpoint (Cohn, Manion, & Morrison, 2000).

The descriptive research approach will involve categorization and triangulation of preservice teachers’ conceptions and misconceptions based on data analysis of interview themes, preservice teachers’ scores on pre-concept and post-concept maps, writing artifacts from preservice teachers' submitted answers to the two administered lessons, answers to midterm questions, and drawings on the final examination.

For the quantitative analysis, this study utilized a pre-experimental research design: the one-group, pretest-posttest design. The population of this study was a nonrandom convenience sample of preservice teachers who completed concept maps before and after instruction using the 5E Model for teaching selected science concepts in teaching courses conveying elementary science methods. The independent variable was the instruction in selected science concepts using the 5E model, and the dependent variable was students' understanding of selected science concepts as measured by preservice teachers' concept maps. Prior to the pretest, preservice teachers who participated in this study received training in the construction of concept maps as a block of instruction about concept mapping. The participants demonstrated their new knowledge about concept mapping by producing at least one concept map. The instructors provided feedback to each preservice teacher about his or her map prior to implementing the study.

A mean comparison of the scores of pre-concept and post-concept maps was conducted using a paired sample *t*-test using SPSS® version 20.0 to determine whether statistically significant differences in mean scores resulted from the instructional intervention. Analysis of data included preservice teachers' responses to concept maps, interviews, writing artifacts, midterm responses, and drawings to identify emerging themes and to categorize common conceptions and misconceptions held by preservice teachers. A pilot study was conducted during the fall semester of 2011, and the results of the pilot study were used to improve the research design. Consequently, the data collected for this study were gathered in the spring semester of 2012.

Table 4

Components of Research Design

Evidence of Teacher Knowledge	Method of Analysis	
Lesson artifacts	Thematic analysis using Vygotsky's concept development constructs	
Pre/Post concept map	Total number of correct propositions	Classification of concepts and thematic analysis
Pre/Post interviews	Thematic analysis using Vygotsky's concept development constructs	
Drawings	Thematic analysis using Vygotsky's concept development constructs	

Lastly, this research study included an instructional intervention that addressed common misconceptions about dissolving and density of solids, liquids, and gases (see Appendices A and B). The instructional intervention used in this study was based on the 5E model developed by Bybee (1997) and incorporated inquiry-based constructivist methods for teaching scientific concepts using Bruner's (1960) ideas about discovery learning, Ausubel's theories about meaningful learning (1963), and Vygotsky's (1987) ideas about social constructivist learning.

Dissolving Lesson

For the dissolving lesson of this study, preservice teachers were first engaged with the concept of dissolving by watching a video of mercury and gold dissolution. The video was followed with a discussion about the concept of dissolving. Preservice teachers were asked to explain concepts from the discussion, and additional information was further discussed through direct instruction. Teachers related dissolving to real-world processes (e.g., cooking, bone density, etc.), and finally, preservice teachers submitted their responses to the evaluation portion of the lesson.

During the dissolving lesson of this study, preservice teachers engaged in learning experiences related to a number of concepts. These concepts were the following: (a) The process of making a solution occurs when a solute (usually a lower quantity of a solid substance) dissolves in a solvent (usually a greater quantity of a liquid substance); (b) A solution is a special type of mixture, which is homogeneous; (c) Solutions display optical clarity; (d) Dissolving is a physical, rather than chemical, change/reaction, so no new substances are formed; (e) The process of dissolving begins when enough energy of enthalpy is invested into the system to break intermolecular forces (also known as van der Waals forces) of solute-solute as well as solvent-solvent particles; (f) The process of dissolving can be facilitated through powdering, stirring, heating, pressure, or concentrating; (g) A hydration shell forms around the solute; and (h) The process of dissolving is reversible using evaporation or distillation.

Density Lesson

For the density lesson in this study, a 3-hour instructional intervention was provided that used 6-pound and 12-pound bowling balls to represent a discrepant event, density blocks, layers of liquids, and a computer simulation for air density. Preservice teachers were formally assessed during the learning experience, and the learning activities were followed with debriefing activities. A number of questions were preplanned and included questions intended to gauge algorithmic understanding of the relationships governing proportions and of the interrelationships between volume and mass in the concept of density to underscore the need to understand the two-dimensional conceptual feature of density.

Sample Population

Participants included 64 preservice elementary and three middle-school teachers enrolled in teacher preparation classes in science methods at a large university in the southwest region of the United States. The preservice elementary teachers who participated in this study were in their final semesters of coursework prior to the preservice teaching semester. All participants met requirements for admission to teacher education, which included a minimum grade point average of 2.75 and minimum scores on standardized tests (SAT, ACT, THEA, TAKS). The minimum degree plan requirements included 12 semester credit hours of science (four courses), which could be selected from biological sciences, chemistry, physics, geology, or astronomy. This study analyzed transcripts from coursework taken by the preservice elementary teachers.

The proposed experimental group for the pilot study included three sections of elementary preservice teachers enrolled in three methods classes, which resulted in a population size of 67 teachers. Data for the pilot study were collected from three sections of a science methods course during Spring 2012.

Researchers have suggested different sample numbers of participants for qualitative triangulation of data collected during interviews. Creswell (1998) suggested 20 to 30 participants per group, depending on saturation of themes. Sandelowski (1995) suggested 30 to 50 participants per group, depending on saturation of themes.

Informed Consent

I requested and received approval to conduct this research from the independent review board (IRB) of the university hosting this study. Preservice teachers' identities were concealed. All data collected during the study, including concept maps, writing artifacts, videos, video transcripts, and interview data, were kept in a secure place.

Instrumentation

The following instruments were used in this study: pre-concept and post-concept maps, writing artifacts (preservice teachers' responses to evaluative portions of lesson plans, responses to midterm questions, and drawings on the final examinations), and face-to-face interviews. The concept maps were low-directed concept maps that relied on preservice teachers providing their own lists of key concepts and linking phrases for making their own concept maps (Ruíz-Primo, 2000). The concept maps were scored by four science education experts using a consensus model to create a cooperative dynamic (i.e., more than one scorer was involved) and to help make the best possible decisions for this study. The procedure undertaken to conduct the interviews is included in Appendix A.

Dissolving Lesson Plan

The first lesson plan that teachers administered to preservice teachers was the dissolving lesson, which is structured using the 5E model proposed by Bybee (1997). Elementary preservice teachers were asked to demonstrate that some mixtures, such as iron filings and sand, maintain their physical properties when dissolving. Preservice teachers were asked to answer the following five questions related to what they learned about dissolving:

1. Does stirring increase dissolving?
2. How much solid can be dissolved in 100 mL of room temperature water?
3. How does heat affect dissolving of a solid in water?
4. How does very little heat (a cold solution) affect the dissolving of a solid in water?
5. Is there a limit for how much of a solid can dissolve in 100 mL of water for different substances?

Preservice teachers' answers were collected and analyzed for the evaluation portion of the dissolving lesson plan.

Density Lesson Plan

The second lesson plan that instructors administered to preservice teachers was the density lesson. Like the dissolving lesson plan, the density lesson plan was structured using the 5E model proposed by Bybee (1997). The preservice teachers were asked to provide a pre-concept map and list of terms prior to receiving instruction and then were asked to produce a post-concept map after receiving instruction. As part of the density lesson plan, five learning experiences were used to promote the preservice teachers' understanding the concept of density. The preservice teachers were required to calculate density using two different methods, to identify an unknown substance, to create a color layered column of liquids with different densities, and to watch a hot air balloon simulation video (see Appendix B). The five learning experiences were then debriefed in the explain step of the lesson and the correct scientific definitions of density were offered along with common misconceptions. Data collected and analyzed included preservice teachers' answers to the evaluation part of the density lesson plan. The questions about density follow:

What is the formula for calculating density?

A student is given an unknown substance. The student determines that the mass of the substance is 68 g and the volume is 75.55 cm^3. Use the following chart to determine the unknown substance.

Density for Common Substances

Substance	Density g/cm^3
Acetone	0.784
Gasoline	0.700
Kerosene	0.900
Methanol	0.786

Calculate the density for each of the following substances.

Substance	Mass (g)	Volume (cm$^{3)}$	Density
Water	10.0	10.0	
Block of wood	19.9	34.8	
Rock	5.7	2.0	

Two liquids have the same volume, but one has more particles packed in the volume. Using the concept of density, provide an explanation.

Two liquids have the same volume, but one liquid has more mass. Does this mean one with greater mass is denser?
What is the relationship between mass volume and density?

Does doubling the amount of a substance change its density if the volume increases at the same rate? Why or why not?

Explain the Coke® and Diet Coke® can demonstration. *Demo by teacher.*

Explain in your own words the concept of density (go beyond just listing the density equation).

Explain the difference between density and weight.

Pilot Study

A pilot study was conducted during Fall 2011. The results of the pilot study were used to make adjustments to the main study in Spring 2012 by improving construct validity and refining the research protocol. A pilot study was chosen to enhance the validity and reliability of the research (Basit, 2010). Data collected in the pilot study were the preservice teachers' pre-concept and post-concept maps, interviews, and writing artifacts.

A low-directed C-concept map approach was used because of the C-concept map's high validity and because the C-concept map provides more information about students' thinking than other types of concept maps (Ruíz-Primo, 2000; Yin & Shavelson, 2008; Yin et al., 2005). As the research literature suggested, C-concept maps are the gold standard for concept mapping.

Next, the preservice teachers' concept maps were analyzed for thematic content using procedures for analysis described by Braun and Clarke (2006). Four experts in science education read and re-read the concept maps for familiarity, and identified recurring themes inherent within the concept maps that were highlighted and coded. The Four experts in science education then scored the concept maps using a consensus model to create a cooperative dynamic (i.e., more than one scorer was involved) and to help make the best possible decisions for the study. The scoring method of total proposition accuracy was used because of similarity in the number of propositions generated by the preservice teachers across the three sections of courses.

As part of the instructional intervention, the preservice teachers submitted writing artifacts focused on particular concepts related to the lesson topic. Select questions from the writing artifacts were analyzed and triangulated with data from the concept maps and interviews. Finally, transcript analysis of college and university courses taken by the preservice elementary teachers was conducted (see Appendix D). A total of 68 transcripts were examined. The transcript analysis included collecting a list of all science courses taken by the preservice teachers and the grades they each received for each course and then summarizing the data using the totals for the letter grades.

Data Collection

The data collected were pre/post concept maps, face-to-face interviews, and writing artifacts which were used to identify and categorize participants' common conceptions and misconceptions. The preservice teachers were asked to construct a pre concept map on their understanding of the scientific concept ahead of participating in the lesson plan activity. This was followed by the lesson plan activities that culminated in preservice teachers answering the evaluate portion of the lesson plan. A period of one week was allowed to elapse before preservice teachers were asked to draft a post concept map. Soon after, the preservice teachers were invited to participate in a face-to-face interview over their responses to the pre/post concept maps. Further evidence was collected midway through the semester through preservice teahcers' responses to midterm exam questions, and lastly by the end of the semester preservice teachers were asked to draw a picture of their understanding of the scientific concept on their final exam.

Concept maps, interviews, and writing artifacts were used to triangulate the data. Triangulation of the data offered two advantages by providing the opportunity for in-depth analysis of the data (Cohen et al., 2000) and ensuring the trustworthiness and validity of the data (Bogdan & Biklen, 2006). The writing artifacts were derived from different sources, which included preservice teachers' responses to the evaluation part of the lesson plan, to midterm questions, and to drawings. Data from all three methods for data collection were categorized using Vygotsky's (1987) theory of concept development (from complexes to pseudo-concepts to scientific concepts). In other words, once common misconceptions were identified, they were then categorized as either complexes or pseudo-concepts.

Data Analysis

In order to facilitate the quantitative analysis of this study (i.e., the concept map scores) a comparison of the means for the concept map scores at pre-instruction and post-instruction occurred via *t*-test. The maps were scored by four scorers (three faculty of education and one doctoral student) using the Total Proposition Accuracy (TPA) method similar to the method developed by Yin et al. (2005). The TPA method is simply the sum of all the correct propositions made by a student teacher on her concept map. The concept maps were then analyzed for conceptions and misconceptions that were coded and tabulated through the joint consensus of the four scorers.

The qualitative analysis involved coding the common concepts and misconceptions exhibited by preservice teachers through the method of thematic analysis Braun and Clarke

(2006). The coded concepts and misconceptions exhibited by preservice teachers were validated for trustworthiness by methodological and environmental triangulation (Guion, Diehl, & McDonald, 2002) of the data (e.g., analysis of concept maps for misconceptions, face-to-face interviews, and analysis of writing artifacts).

Thematic Data Analysis

Braun and Clarke (2006) defined thematic analysis as “a method for identifying, analyzing, and reporting patterns (themes) within data: “[Thematic analysis] is meant to minimally organize and describe … data in rich detail” (Braun & Clarke, 2006, p. 6). Thematic analysis of data allowed for the extrapolation of emerging themes. An emerging theme represented important information about the data needed for understanding at some level the patterned responses or meaning within the data set (Braun & Clarke, 2006). Braun and Clarke suggested that thematic analysis of data is more suited for an inductive investigation and the discovery latent themes when employing constructivist models of teaching, as was the case in this study.

To illustrate how the thematic analysis approach was used in this study, consider the case of dissolving. When preservice teachers’ concept maps were analyzed, the scorers marked (by circling propositions) how preservice teachers explained the concept of dissolving in their concept maps. A common theme identified in many preservice teachers’ responses was the use of the word *breakdown*. As can be seen in Figure B1, this often was followed by another concept such as molecules. The preservice teachers were explaining dissolving as a breakdown of molecules. Hence, this was identified by the scorers as an emerging theme representing a misconception that the preservice teachers used in order to explain dissolving. The next step followed by the scorers was to categorize this misconception using Vygotsky’s theory of concept development. The scorers looked at the misconception involving breakdown and categorized it as a complex concept. A complex concept is one in which the preservice teacher still has not developed a clear scientific understanding of how the dissolving process takes place. Lastly, this misconception was labeled as a robust misconception because it persisted in preservice teachers' concept maps even after receiving instructional intervention.

Trustworthiness of the Data

Researchers use methodological and environmental triangulation to enhance the validity of a study. Methodological triangulation involves using multiple qualitative and/or quantitative methods to study preservice teachers' responses to a problem. If results from different methods are similar, then the study's validity is established. Environmental triangulation involves using different locations, settings, or other key factors related to the time when data are collected (Guion, Diehl, & McDonald, 2002).

To illustrate how the validity of the results was established in this study, both methodological and environmental triangulation of the data was used. Methodological triangulation was established by using different sources of data (e.g., concepts maps, interviews, and writing artifacts), while environmental triangulation was established for this study because data were collected at different times during the semester.

For the methodological triangulation of the data, consider the misconception, dissolving is breaking down which was identified as one of the emerging themes found in the data. We find that the same misconception appears in the pre- and post-interviews of the preservice teachers, in the writing artifacts, in the midterm exam responses, and in the final exam drawings.

As to the environmental triangulation of the data, data were collected at the outset of the study via pre-concept maps and pre-interviews, during the intervention via preservice teachers' responses to the evaluation portion of the lesson activity, midway through the semester via preservice teachers' responses to midterm questions, post-intervention via post-concept maps and post-interviews, and at the end of the semester via preservice teachers' drawings on their final exams. Environmental triangulation allowed the examination of preservice teachers' misconceptions as the semester progressed and helped to establish validity for the results of this study.

Lastly, because reality is complex, qualitative researchers seek to triangulate their research by using disconfirming evidence or negative evidence in their research findings. As such, researchers must discover themes in data and categorize these themes by looking for negative evidence that is either consistent with or disconfirms these results. This approach is a constructivist approach to research because it is less systematic and relies on simultaneously examining multiple perspectives of a theme or category (Creswell & Miller, 2000).

In this study, some test-effects or instructional influences provided results that were not in accordance with the general findings of this study and represented the negative evidence needed to enhance the validity of the triangulated data. To illustrate how negative evidence was identified in this study, I looked at the midterm exam responses and found that emerging theme concepts related to concepts such as solubility were no longer being used by preservice teachers on their midterm exams. This indicated a *test effect* was taking place and provided a source of negative evidence to further enhance the validity of the data.

In agreement, Lincoln and Guba (1985) proposed four criteria and 10 techniques for judging trustworthiness of data. One of their recommendations was searching for disconfirming evidence when triangulating data (Nastasi & Schensul, 2005). Lincoln and Guba (1985) also recommended that researchers enhance the validity and trustworthiness of qualitative analysis by collecting and analyzing data through prolonged engagement, persistent observation, triangulation, peer debriefing, thick description, and audit trails (Nastasi & Schensul, 2005).

CHAPTER 4

RESULTS

The results of the study are reported in this chapter. The study began with a pilot study in the fall of 2011 that was followed by the research study that began in the spring of 2012. The pilot study was initiated to provide research study adjustments (e.g., the way preservice teachers constructed their concept maps) and to identify concepts and misconceptions on dissolving and density used by the preservice teachers. The results section is organized to provide a narrative of the quantitative results provided by the pre- and post-concept maps, followed by describing the emerging themes of misconceptions and scientific concepts in preservice teachers' responses to concept maps, face-to-face-interviews, and writing artifacts.

The following research questions were used to investigate the science content knowledge of elementary preservice teachers for the pilot study during Fall 2011 and for the follow-up study during Spring 2012.

$RQ_{1:}$ What conceptions do preservice elementary teachers have about the concept of dissolving as illustrated using concept maps, writing artifacts, interviews, examination questions, and drawings before and after instructional intervention?

$RQ_{2:}$ What conceptions do preservice elementary teachers have about the concept of density as illustrated using concept maps, writing artifacts, and interviews before and after instructional intervention?

The pilot study was conducted during Fall 2011, using concept maps, interviews, and writing artifacts to evaluate the content knowledge of elementary preservice teachers (n = 58 dissolving, n = 53 density). For the quantitative portion of the study, valuable information on the creation of concept maps was gathered. Pilot study results suggested the need to provide additional structured training for the creation of concept maps and the need for careful review of preservice teachers' concept maps prior to submission. The major themes emerging from the pilot study showed preservice teachers misconceptions around dissolving to be based on the misconception that dissolving means disappearing, disintegrating, deteriorating, eroding, going away, becoming invisible (36%), or breaking down of a substance (25%), as seen in Table 5. Similar misconceptions exhibited by preservice teachers about dissolving have been reported in the literature (Calik & Ayas, 2005; Valandis, 2000). The most common misconceptions about density included confusion about differences among density, mass, heaviness, or weight (41%) and confusion about the relationship between density and buoyancy of a substance (21%). These results confirmed similar findings in the research literature indicating that K-12 students confuse density with mass or weight (Krnel et al., 1998) and preservice teachers have difficulty relating density and buoyancy (Dawkins et al., 2008; Greenwood, 1996; Stepans et al., 1988). These results are shown in Table 6.

Table 5

*Fall 2011 Pilot Study: Frequencies and Percentages for Categorized Misconceptions in Pre-Concept and Post-Concept Maps for Dissolving (*n *= 58)*

Dissolving	*N*	%
Dissolved particles sink to the bottom.	1	2
Dissolving is a change of phase.	10	15
Dissolving is disintegrating, eroding, deteriorating, disappearing, going, or becoming invisible.	24	36
Dissolving is melting.	9	13
Dissolving is a substance getting cut into small particles.	2	3
Dissolving is related to density.	1	2
Dissolving is breaking down a substance.	17	25
Dissolving is a chemical or physical change.	3	5
Total	67	101*

Note. *Total does not sum to 100 due to rounding error.

Table 6

*Fall 2011 Pilot Study Frequencies and Percentages for Categorized Misconceptions in Pre-concept and Post-Concept Maps for Density (*n *= 53)*

Density	*n*	%
Density is confused with mass, heaviness, and weight.	35	41
Density is confused with volume and size.	8	9
Density is related to the compactness of particles.	11	13
Density related to states of matter.	13	15
Density is related to buoyancy.	18	21
Total	85	99*

Note. *Total does not sum to 100 due to rounding error.

The results from the interviews confirmed the findings in the concept maps. A total of 13 interviews were used to examine preservice teachers' understanding of dissolving. During interviews, preservice teachers were asked to explain the pre-concept and post-concept maps. The majority of the preservice teachers' responses (72%) indicated that the preservice teachers believed that a substance simply broke down (43%) or disappeared or vanished (29%) during the process of dissolving (see Table 7). Analysis of eight interviews about density showed that a majority of preservice teachers confused density with mass/weight (25%). Most other responses involved misconceptions relating density to change of state (17%) and buoyancy (17%), or to concepts such as compactness (17%) and the density formula (17%) (see Table 8).

Table 7

*Fall 2011 Pilot Study: Analysis of Interview Transcripts Dissolving (*n *= 13)*

Misconceptions/concepts	*N*	%	Direct quotes
Dissolving is melting.	1	14	"Dissolving is something where it involves, uh, temperature and will pretty much, will induce [sic] to melt."
Dissolving is disappearing and vanishing.	2	29	"[H]aving a . . . some kind of variable disappear or mixing with a solution."
Dissolving can be chemical or physical change.	1	14	"[D]issolving is change, and it can be, and I didn't put that, but it can be chemical or physical."
Dissolving is breaking down a substance.	3	43	"[D]issolving is breaking down a substance." "They just blend; their particles blend with the solvent."
Total	7	100	

Table 8

*Fall 2011 Pilot Study: Analysis of Interview Transcripts Density (*n *= 8)*

Misconceptions/Concepts	*n*	%	Direct Quotes
Density is mass or weight.	3	25	"[D]ensity is a measurement of how much . . . or at least the mass is the measurement of how many particles something has." "[D]ensity is how much space or weight matter is." "Whatever will weigh more will sink, and that has a greater density."
Density is volume.	1	8	"[D]ensity is how much space or weight matter is."
Density is a change of state.	2	17	"[W]hen, um, a solid or liquid changes form."
Density is related to the compactness of particles.	2	17	"[H]ow close or how far the molecules are from one another; so, more dense the molecules are going to be more tightly packed, and then less dense there should be more space." "How compacted an object is, uh, so if it's more compact, it's gonna have a greater density."
Density is mass divided by volume.	2	17	"[T]he equation is density is mass over volume, and we have to measure the mass and divide it by the volume to determine our density." "[I]t's mass and volume, um, the relationship between mass and volume."
Density is related to buoyancy and floating.	2	17	"I was trying to remember the formula for density; then, I remember doing an experiment in physics about buoyancy, and, um, we dropped."
Total	12	101*	

Note. Total does not sum to 100 due to rounding error.

Next, writing artifacts were used to confirm the findings derived from the concept maps and interviews with regard to the concept of dissolving. After the instructional intervention, a sample of 32 writing artifacts was examined. The writing artifacts were analyzed for major misconceptions exhibited by the preservice teachers. A series of questions accompanied the instructional intervention. Preservice teachers were first asked, “What happens to sugar and salt when they are added to water?” The majority of preservice teachers believed that sugar simply dissolves in (55%) or sinks to the bottom of water and then dissolves when stirred (28%). Results are shown in Table 9. Preservice teachers were also asked, “What is the difference between dissolving and melting?” Most preservice teachers (approximately 85%) responded that when something dissolves, it combines with water or a liquid and disappears but that when something melts, melting involves a change of state and turns into a liquid in which the particles of the original substance can still be seen. The results shown in Tables 9 and 10 showed that preservice teachers’ understanding of dissolving was limited and confused with the misconception that dissolving means disappearing. Overall, the results demonstrated that preservice teachers were thinking at the macro level (what they can physically see), and not at the micro level (what they cannot physically see), when trying to explain the process of dissolving (Valandis, 2000). Results also indicated that the preservice teachers might struggle with the concept of particles, stemming from their lack of understanding about the particulate nature of matter (Calik, et al., 2005; Devetak et al., 2009; Nakhleh, 1992).

Table 9

*Fall 2011 Pilot Study: Analysis of Writing Artifact: "What Happens to the Sugar and Salt When They Are Added to Water?" (*n *= 32)*

	N	%	Direct Quotes
The sugar and salt dissolve, and the atoms combine with the water molecules.	2	7	"The sugar and salt dissolve into the water. The atoms combine with the water molecules."
Sugar dissolved, and I couldn't see it anymore.	2	7	"Sugar dissolved once we stirred it up, couldn't [sic] see anymore."
The particles break down and disappear.	1	3	"The particles break down and disappear into the water, creating sugar-water or salt-water."
They dissolve in the water.	16	55	"They dissolve in the water."
They sink to the bottom, or they sink to the bottom and then dissolve as stirred.	8	28	"The sugar and salt sink to the bottom when added to the water. Then, as we stirred each, the sugar and salt dissolved into the water. The water became foggy."
Total	29	100	

Table 10

*Fall 2011 Pilot Study: Analysis of Writing Artifact: "What is the Difference Between Dissolving and Melting?" (*n *= 32)*

	N	%	Direct Quotes
Dissolving is combining with water, and melting is a change of state.	11	32	"Dissolve means that the something has combined with another substance to form something new. Melting is just a substance that has changed states."
Dissolving is when something is incorporated into the liquid, but melting means it turns into a liquid.	10	29	"Dissolving means the substance is incorporated into a liquid. Melting means it turns into a liquid."
Dissolving is when the particles disappear. Melting is the particles breaking down, but you can still see them.	8	24	"Dissolving a substance, the particles disappear; you no longer can see it. Melting, the particles break down, but you can still see it."
Melting involves adding heat; dissolving doesn't.	5	15	"Melting is only done with heat; dissolving can happen with a substance without heat."
Total	34	100	

Last of all, it was necessary to obtain the results of the transcript analysis for content courses taken by preservice teachers to investigate how many of the preservice teachers studied chemistry and how many studied physics. The analysis of transcripts revealed that only four of the teachers who participated in the pilot study completed coursework in chemistry. However, many of the preservice teachers (68%) took a class in conceptual physics, a class for educators, and scored a grade of A or B. The seven preservice teachers of middle school science who participated in the pilot study took more chemistry courses and other science courses than did the preservice teachers of elementary science who participated in this study.

As a result of the pilot study, the instructional intervention was changed to address preservice teachers' understanding about the particulate nature of matter, the concept of density as a relationship between mass and volume, and the concept of buoyancy and density as related to the phenomena of sinking and floating. Animations showing how salt dissolves in water and how sugar dissolves in water were added as a debriefing activity.

The pilot study supported the decision to progress to the main study conducted during Spring 2012. In the next section, the narrative of the Spring 2012 results will be presented. First, the quantitative part of the study involving the results for scoring pre- and post-concept maps will be presented. Second, the qualitative portion of the study will be presented in two parts. The first part will present the major themes identified as misconceptions and scientific concepts related to the concept of dissolving, while the second part will address the major themes identified as misconceptions or scientific concepts related to the concept of density.

Scoring Concept Maps

Overall conceptual change did take place as a result of the instructional intervention, but this change, however statistically significant, was not large. A paired sample *t*-test comparison to analyze scores of pre-concept and post-concept maps for the four course sections was performed. The initial sample consisted of 67 preservice teachers. However, a total of 61 paired concept maps were collected for the topic of dissolving. Preservice teachers with missing pre-concept or post-concept maps were eliminated from the analysis. Six maps were not included in the dissolving analysis due to missing pre-concept and/or post-concept maps. A total of 61 paired concept maps were analyzed for the topic of density. Six maps were not included in the density analysis due to missing pre-concept or post-concept maps. The results for the paired sample *t*-test for both dissolving and density are presented in Table 11.

The *t*-test for the topic of dissolving exhibited a statistical difference ($t = -5.773$, $p < .001$) between the Total Proposition Accuracy (TPA) scores for pre-concept and post-concept maps. The instructional intervention was larger for post-concept maps ($M = 1.72$, $SD = 1.77$) than for pre-concept maps ($M = .54$, $SD = 1.134$). The effect size as measured by Cohen's *d* was medium-large at .79.

Similarly, results for the TPA score comparison of the pre-concept and post-concept maps for density demonstrated that preservice teachers' scores for the topic of density were lower than they were for the topic of dissolving (Table 11). A statistically significant difference occurred between the TPA scores for the pre-concept and post-concept maps. The instructional intervention was larger for the post-concept maps ($M = 0.97$; $SD = 1.048$) than it was for pre-concept maps ($M = 0.56$, $SD = 0.807$, $t = -2.948$, $p = .005$). The effect size as measured by Cohen's *d* was small at .43.

Table 11

Paired Samples t-*Test: Comparison of Two Means of Instructional Interventions for the Concepts of Dissolving and Density*

	n	*M*	*SD*	*t*	*p*
Dissolving				-5.773	< .001
Pre-intervention	61	0.54	1.134		
Post-intervention	61	1.72	1.771		
Density				-2.948	.005
Pre-intervention	61	0.56	0.807		
Post-intervention	61	0.97	1.048		

Misconceptions about Dissolving

The major themes that emerge from the data with regard to the concept of dissolving are preservice teachers' misconceptions that dissolving involves forming a mixture, a breakdown of particles, and a chemical change. These represent robust misconceptions that persisted with preservice teachers post-instructional intervention. Some weaker misconceptions, such as confusing dissolving with melting or disappearance, were reduced significantly after the intervention. Along the way, the preservice teachers picked up emerging concepts derived from the lesson activity such as relating dissolving to rate or solubility. Very few preservice teachers used the scientifically instructed concept of a hydration shell to explain the process of dissolving.

Next, the 61 pre-concept and post-concept maps for misconceptions were categorized according to Vygotsky's (1987) theory of concept development. The categories of concept development used in this study included spontaneous concepts (i.e., associative, collection, chain, and diffuse), pseudo-concepts, and scientific concepts. Data collected from all three data sources (concept maps, interviews, and writing artifacts) are summarized in order to identify these common emerging misconceptions exhibited by preservice teachers in this study. First, Table 12 shows the frequencies and percentages of misconceptions found in pre- and post-concept maps. After receiving the 3-hour instructional intervention, some misconceptions were resolved and others were reduced significantly. The misconception that dissolving is disappearing decreased from 11% to 1%, and the misconception that dissolving is a change of state decreased from 12% to 3%. Other misconceptions proved to be more robust. The misconception that dissolving is mixing decreased from 19% to 9%, and the misconception that dissolving is a breakdown of substances or involves chemical change or reaction changed from 11% to 7%. A small percentage of preservice teachers (3%) developed scientific conceptions about dissolving, including the instructed concept about the formation of hydration shells in the process of dissolving. The percentage of preservice teachers who developed the concept that dissolving is affected by rate and such variables as heat, physical agitation, and concentration increased from 11% to 26% on the post-concept maps.

Table 12

*Frequencies and Percentages of Preservice Teachers Conceptions and Misconceptions on Pre-Concept and Post-Concept Maps for the Topic of Dissolving (*n *= 61)*

	Concept or Misconception	
Dissolving is	Pre-concept map *n* (%)	Post-concept map *n* (%)
Breakdown of Substances.	14 (11%)	10 (7%)
Mixing, Combining.	23 (19%)	13 (9%)
Chemical Change/Reaction.	14 (11%)	11(7%)
Inaccurate Vocabulary.	8 (7%)	9 (6%)
Nonsensical.	7 (6%)	8 (5%)
A Change of State.	15 (12%)	4 (3%)
Disappearance.	13 (11%)	2 (1%)
Melting.	4 (3%)	0 (0%)
Rate.	14 (11%)	40 (26%)
Solubility.	4 (3%)	25 (16%)
Non-example.	0 (0%)	14 (9%)
Accurate Academic Vocabulary.	8 (7%)	12 (8%)
A Hydration Shell.	0 (0%)	4 (3%)
Total	124 (101%)*	152 (100%)

Note. Total number of concepts identified 124 for the pre and 152 for the post. *Total does not sum to 100 due to rounding error.

After data from pre-concept and post-concept maps had been scored, the concepts were categorized according to Vygotsky's (1987) theory of concept development, labeling scientific concepts as well as classifying misconceptions as either complexes or pseudo-concepts. Vygotsky identified pseudo-concepts as misunderstood concepts or scientific terms borrowed from adults and subsequently applied to the wrong contexts (i.e., students use scientific language that superficially masquerades as scientific understanding). Complexes, on the other hand, are immediately recognizable as scientifically inaccurate constructions of knowledge. The major misconceptions were categorized as pseudo-concepts and complexes, which were identified using the preservice teachers' pre-concept and post-concept maps (Table 13).

Table 13

Categorization of Preservice Teachers Major Knowledge of Dissolving from Pre-Concept and Post-Concept Maps Based on Vygotsky's (1987) Theory of Concept Development

Dissolving	Category of Misconception
Means the mixing of two substances.	Pseudo-concept
Involves phase change from solid to liquid.	Complex
Means disappearing.	Complex
Means a substance gets cut into small particles.	Complex
Involves the breakdown of a substance.	Complex
Means melting.	Complex
Involves a chemical change or reaction.	Complex

Interviews were used to support the identification of misconceptions exhibited by the preservice teachers' concept maps and to lend more in-depth analysis of preservice teachers' responses. After a 3-hour instructional intervention, 56 elementary preservice teachers were present for the interview. There were five preservice teachers who completed pre-concept and post-concept maps but did not complete an interview. A total of 119 concepts were identified on the pre-interview concept maps, and 161 concepts were identified on the post-interview concept maps. Using SPSS® version 20.0, the preservice teachers responses were coded and analyzed for frequency and then tabulated and classified into three categories: (a) preservice teachers' responses involving misconceptions, (b) emerging concepts, and (c) scientific concepts about dissolving. The most prevalent misconceptions exhibited by preservice teachers are represented in Table 14.

Table 14

*Preservice Teachers Misconceptions about Dissolving in Pre-Concept and Post-Concept Map Interviews (*n *= 56)*

	Pre		Post		
Dissolving is/uses:	*n*	%	*n*	%	Sample Quotes from Preservice Teachers
Misconceptions					
Breaking apart.	17	14	21	13	"The sugar molecule breaks apart, and it disperses throughout the liquid."
Forming a mixture.	14	12	17	11	"Dissolving is taking a substance and putting it in a liquid and making it sort of be one. It's just making a mixture; I guess it's dissolving."
Chemical change or reaction.	16	14	8	5	"I was thinking, like, a chemical reaction is why something dissolves." "The bond is broken."
A change of state.	17	14	10	6	"I said dissolving is when something changes form; like, it can turn a solid into a liquid or something spreading."
Disappearing.	9	8	3	2	"Dissolving is, kind of just based on this map, is just things disappearing."
Inadequately explained.	7	6	7	4	"I talked about osmosis."
Inaccurately using academic vocabulary.	17	14	21	13	"A solute could be water, and the solvent could be salt."
Emerging Concepts					
Rate.	14	12	53	33	"I put that dissolving . . . happens in various temperatures; like, when you increase the temperature, it happens more quickly."
Solubility.	0	0	12	7	"And some things that affect dissolving are temperature, going from hot to cold or room temperature. And then are solubles [sic] and insolubles [sic]. And insolubles do not dissolve. And I wrote two examples, iron and gravel. And then solubles are salt and sugar, things that do dissolve in materials such as water, or any other kind of [sic]."

(table continues)

Table 14 *(continued).*

Dissolving is/uses:	Pre *n*	Pre %	Post *n*	Post %	Sample Quotes from Preservice Teachers
Scientific Concepts					
Hydration shells.	0	0	4	3	"And in the process, the molecules are rearranged into a hydration shell, where, like for example in salt, what technically is supposed to happen is that the two components, the ionic bond is broken, and, H_20, or the water, rearranges itself around it, so it makes it seem like it's invisible, but it's technically there."
Accurately uses academic vocabulary to explain dissolving.	8	7	5	3	"Sugar and salt, you see it at the bottom, you add a solvent, and you don't see it anymore, but it's still there. At one point, you would not be able to dissolve the solute anymore because the concentration would be too high, and if you boil it or raise the temperature, it will allow you to dissolve more salt or sugar. The solvent could be water or any other liquids [sic]."
Total	119	101*	161	100	

Note. Total number of concepts identified for the pre 119 and for the post 161. *Total does not sum to 100 due to rounding error.

The robust misconceptions that persisted after instructional intervention about dissolving included:

1. breaking apart (14% on pre-concept map interview and 13% on post-concept map interview)
2. forming a mixture (12% on pre-concept map interview and 11% on post-concept map interview) and
3. a chemical reaction (14% on pre-concept map interview and 5% on post-concept map interview)

With the exception of chemical reaction, which did not appear much in preservice teachers' responses, the robust misconceptions identified in the concept maps reappear in preservice teachers' responses from the interviews. The misconception of dissolving as chemical change is treated as robust because it reappears in preservice teachers' responses later in the semester as part of the midterm and final exam data collected. Other misconceptions about dissolving were less robust and were reduced after instruction. For these misconceptions dissolving involved the following:

1. a change of state (14% on pre-concept map interview and 6% on post-concept map interview)
2. a disappearance (8% on pre-concept maps and 2% on post-concept maps)

On the other hand, preservice teachers did begin to double their use of emerging concepts to define dissolving after instruction. Preservice teachers defined dissolving as rate or defined dissolving in terms of solubility (Table 14). The use of rate to define dissolving more than doubled, changing from 12% to 33%, and the use of solubility to define dissolving increased from 0% to 7%. There was little change in preservice teachers' use of scientific thinking and vocabulary to define dissolving. Samples of preservice teachers' quotes from interviews are also shown in Table 14.

Writing artifacts were used to triangulate the data. The writing artifacts comprised the third data source after concept maps and interviews. The writing artifacts consisted of preservice teachers' responses to select questions from the Evaluate portion of the lesson plan, responses to midterm questions, and analysis of drawings from the final examination.

Table 15

Spring 2012 Study: Writing Artifacts Evaluate for Dissolving Questions

Question
1. On your paper, please write a conclusion paragraph. Remember to: Restate your results. Write what you learned discuss why it is important.
2. What is the difference between dissolving and melting?
3. What happens to sugar and salt during dissolving?

In the analysis of the writing artifacts, 65 responses to open-ended questions from the evaluation section of the instructional intervention were examined in order to gain insight into preservice teachers' conceptual thinking. Preservice teachers with missing writing artifacts were removed from the total preservice teacher count. The questions are shown in Table 15.

A summary of the analysis is displayed in Tables 16 and 17. Responses to the questions revealed several misconceptions, emerging concepts, and scientific concepts associated with an understanding of the dissolving process. Table 16 provides quotes that were typical of the preservice teachers' misconceptions and their emerging concepts and scientific concepts. Table 17 provides the frequencies and percentages of misconceptions, emerging concepts, and scientific concepts associated with dissolving. The major theme emerging from preservice teachers' responses to Question 1 regarding their understanding about dissolving revealed that sixty-nine percent of the preservice teachers' responses included a discussion of rate (60%) or solubility (9%). Only three percent of the preservice teachers' responses suggested a scientific understanding of the role of a hydration shell (1%), or the use of accurate academic vocabulary (2%). This indicates that the majority of preservice teachers were borrowing from their activity to answer the question about dissolving.

Question 2 asked the preservice teachers to describe the difference between dissolving and melting. Sixty-two percent of preservice teachers' responses included misconceptions that involved breaking apart (14%), forming a mixture (23%), chemical change or reaction (20%), and disappearing (5%). Only two percent of preservice teachers used rate (2%) to describe the difference between dissolving and melting and only 8% used a discussion of a hydration shell to differentiate between dissolving and melting.

Table 16

*Preservice Teachers' Misconceptions, Emerging Concepts, and Scientific Concepts About Dissolving on Writing Artifacts (*n *= 65)*

Dissolving is/uses:	Preservice Teachers' Quotes
Misconceptions	
Breaking apart	"Melting–change in physical state. Dissolving–breaking the molecules apart."
Forming a mixture	"Melting changes a substance from a solid to a liquid, but when dissolving, a substance it integrates itself into the solution and becomes a mixture."
Chemical change or reaction	"When a substance dissolves, it is going through a chemical reaction, while melting involves a physical reaction."
Change of state	None.
Disappearing	"Dissolving is when the item (sugar or salt) disappears [sic] but keeps its [sic] chemical make-up."
Inadequately explain dissolving	"They dissolve depending on temperature."
Inaccurate use of academic vocabulary	"Dissolving–item integrates itself into solution, changing molecules."
Emerging Concepts	
Rate	"Both sugar and salt dissolve in water. The hotter the water is, the faster the solutes dissolve. Hot water allows more of the solute to be dissolved. The colder the water, the longer it took to dissolve the solute. Also, the smaller the solute, the more and the faster it will dissolve."
Solubility	"Salt and sugar dissolve in water. Iron fillings and fine gravel don't dissolve."
Scientific Concepts	
Hydration shell	"The water splits the molecules into two." "They dissolve. Water molecules create a hydration shell around the sugar molecules. Water molecules split salt and create a hydration shell around it."
Accurate use of academic vocabulary	"Melting is changing state, and dissolving is when molecules are mixing uniformly [sic] in a solution."

Table 17

*Frequencies and Percentages for Preservice Teachers' Misconceptions, Emerging Concepts, and Scientific Concepts in Writing Artifacts for the Dissolving Lesson Evaluate Component (*n *= 65)*

	Question 1		Question 2		Question 3	
Dissolving is/uses:	*n*	%	*n*	%	*n*	%
Misconceptions						
Breaking apart	1	1	9	14	8	16
Forming a mixture	3	3	15	23	5	10
Chemical change or reaction	8	9	13	20	5	10
Change of state	1	1	0	0	0	0
Disappearing	1	1	3	5	0	0
Inaccurate use of academic vocabulary	10	12	9	14	8	16
Emerging Concepts						
Rate	52	60	1	2	10	20
Solubility	8	9	0	0	1	2
Scientific Concepts						
Hydration shell	1	1	5	8	6	12
Accurate use of academic vocabulary	2	2	10	15	7	14
Total	87	99*	65	101*	50	100

Note. *Total does not sum to 100 due to rounding error.

Question 3 asked what happens to sugar and salt in the process of dissolving. Thirty-six percent of preservice teachers' responses included misconceptions about this process. Misconceptions included breaking apart (16%), forming a mixture (10%), and chemical change or reaction (10%). Twenty-two percent of preservice teachers used rate (20%) or solubility (2%) to describe what happens to sugar and salt during dissolving. Only 12% of preservice teacher responses used the hydration shell scientific concepts to describe dissolving for sugar and salt. Overall, it can be seen from the results that all three data collection tools (concept maps, interviews, and lesson plan writing artifacts) exhibit the two emerging themes of forming mixtures and breaking apart that represent robust misconceptions in preservice teachers' responses. By contrast, few preservice teachers did use the instructed concept of hydration shell in their answers.

After the instructional intervention had taken place, the midterm was administered midway through the course of the semester. The questions used on the midterm (see Table 18) and a summary of the data (Table 19) follow. Three of the four questions pertain to dissolving and one question relates to density.

Table 18

Spring 2012 Study: Dissolving and Density Midterm Questions

Question
1. Why is dissolving not a change of state?
2. When a substance such as aluminum is cut in half, what happens to density?
3. Why is dissolving not a chemical reaction?
4. Why is dissolving not melting?

Three questions regarding dissolving were pulled from the midterm examination and administered to preservice teachers midway through the semester. On Question 1, 39% of preservice teachers' responses included misconceptions about dissolving. Misconceptions included breaking apart (15%), forming a mixture (11%), chemical change or reaction (11%), and disappearing (2%).

Question 3 asked preservice teachers to discuss why dissolving is not a chemical change. Thirty-three percent of preservice teachers' responses suggested misconceptions such as breaking apart (11%), forming a mixture (11%), and chemical change or reaction (11%).

Question 4 asked preservice teachers to describe why dissolving is not melting. Thirty-two percent of preservice teachers' responses included misconceptions about dissolving including breaking apart (8%), forming a mixture (10%), and chemical change or reaction (14%).

Overall, these results show that after time had elapsed, the robust misconceptions reappeared in preservice teachers' responses and no preservice teacher had used the scientifically instructed concept of hydration shell on their midterm exam. Last of all, at the conclusion of the semester during which the main study was conducted, I analyzed 47 preservice teachers' drawings that they created in answer to two questions on the final examination involving an understanding of how sugar dissolves in water compared to how salt dissolves in water. The drawings supplemented the concept maps and were used to examine what misconceptions persisted in preservice teachers' understanding of the concepts. The drawings dealt only with the concept of dissolving; there were no drawings for the concept of density.

Preservice teachers were asked to create drawings about the process of dissolving sugar and salt as part of the final examination. The questions are shown in Table 20. Table 21 summarizes the results of the analysis for preservice teachers' drawings for dissolving. Thirty-seven percent of preservice teachers' drawings included misconceptions such as dissolving is breaking apart (22%), forming a mixture (6%), a chemical change or reaction (7%), a change of state (1%), and disappearing (1%). Five percent of preservice teachers' drawings explained dissolving using rate (4%) or solubility (1%). Fifteen percent of preservice teachers' drawings showed correct use of a hydration shell to describe the process of dissolving. The results confirmed that robust misconceptions as well as weak misconceptions reappeared on the final exam drawings and as such are maintained by preservice teachers even after a considerable period of time elapsed at the close of the semester.

Table 19

*Spring 2012 Study: Dissolving Midterm Writing Artifacts for Questions 1, 3, and 4 (*n *= 67)*

	Question 1		Question 3		Question 4	
Dissolving is/uses	*n*	%	*n*	%	*n*	%
Misconceptions						
Breaking apart	7	15	4	11	4	8
Forming a mixture	5	11	4	11	5	10
Chemical change or reaction	5	11	4	11	7	14
Change of state	0	0	1	3	1	2
Disappearing	1	2	0	0	0	0
Inaccurate use of academic vocabulary	6	13	4	11	7	14
Emerging Concepts						
Rate	0	0	0	0	0	0
Solubility	0	0	0	0	0	0
Scientific Concepts						
Hydration shell	0	0	0	0	0	0
Accurate use of academic vocabulary	22	48	20	54	28	54
Total	46	100	37	101*	52	102*

Note. *Total does not sum to 100 due to rounding error.

Table 20

Spring 2012 Study Final Examination Drawings Questions

Question
1. Describe what is going on with [Sugar dissolving] in your picture using 3-5 sentences.
2. Describe what is going on with [Salt dissolving] in your picture using 3-5 sentences.

Table 21

*Preservice Teachers' Misconceptions, Emerging Concepts, and Scientific Concepts About Dissolving on Final Examination Questions (*n *= 47)*

Dissolving is/uses	*n*	%
Misconceptions		
Preservice teachers explain dissolving as breaking apart.	18	22
Preservice teachers explain dissolving as forming a mixture.	5	6
Preservice teachers describe dissolving as a chemical change or reaction.	6	7
Preservice teachers describe dissolving as a change of state.	1	1
Preservice teachers explain dissolving as disappearance.	2	3
Preservice teachers inadequately explain dissolving.	9	11
Preservice teachers inaccurately use of academic vocabulary to explain dissolving.	15	19
Emerging Concepts		
Preservice teachers explain dissolving as rate.	3	4
Preservice teachers explain dissolving as solubility.	1	1
Scientific Concepts		
Preservice teachers explain dissolving using hydration shell.	12	15
Preservice teachers accurately use of academic vocabulary to explain dissolving.	9	11
Total	81	100

In summary, it appeared that elementary preservice teachers persisted in explaining the process of dissolving as the breaking down of a substance and the forming of a mixture which constitute the two themes found in the data with regards to robust misconceptions. When prompted to explain further in the interviews the two identified robust misconceptions, the preservice teachers struggled with explaining the concept as a physical breakdown of molecules or chemical, but they were also not sure exactly how that takes place. They tended to think of dissolving as involving the breakdown of substances, elements, and molecules but were unsure about how to continue in their explanations when asked to explain their understanding. Emerging concepts that the preservice teachers tended to report were borrowed from the activity in which dissolving was explained in terms of rate of heating or stirring a substance. Data about how preservice teachers progressed in their understanding of dissolving during the course of the semester revealed that dissolving as a breakdown of substances and formation of mixtures constituted robust misconceptions that persisted in the preservice teachers' explanations after receiving instructional intervention. This evidence appeared in their final examination drawings, for instance, but was also the extent of their explanations. All three concepts—breakdown of substances, forming a mixture, and rate of dissolving—can be thought of as concrete and as depicting preservice teachers' abilities to think at the macro level while preventing preservice teachers from transforming their abilities to think at the micro level. During the post-concept map interviews, only 3% of preservice teachers explained dissolving using a hydration shell, and only 15% depicted a hydration shell in their final examination drawings. The preservice teachers provided little or no mention of intermolecular forces on the final examinations.

Misconceptions about Density

The emerging themes identified in the analysis of concept maps revealed two robust misconceptions. These two robust misconceptions were confusing density with buoyancy to explain the phenomena of sinking and floating and confusing density with heaviness. Data collected from all three data sources (concept maps, interviews, and writing artifacts) were summarized in order to identify the common themes representing misconceptions exhibited by preservice teachers in this study (Table 22). Coming into the study, preservice teachers' knowledge showed that the majority of misconceptions about density as shown on the pre-concept maps were the following:

1. Density is buoyancy and describes floating and sinking (32.1%)
2. Density is heaviness (28.4%)

Also, preservice teachers relied on the density formula (11%) to define density in their pre-concept map responses.

Later, the frequency of propositions on post-concept maps after receiving instruction revealed some misconceptions to be weak and reduced significantly with intervention, while others proved to be robust and persisted even after receiving instruction. For instance, density as a change of state after instruction was reduced to 3% or as volume was reduced to 1%. On the other hand, the misconception of density as heaviness after instruction was a robust misconception and was only reduced from 28% to 18%. Also, the robust misconception relating density to buoyancy or to floating or sinking was reduced from 32% to 19%.

To define density, some preservice teachers tended to relate density to the emerging concept of compactness in their concept maps, with compactness constituting around 11% of the responses on the post-concept maps (Table 22). After the instructional intervention, the incidence of using the density formula on post-concept maps to define density actually increased from 11% to 32%. The scientific concept of density as a property of matter decreased to 1% on the post-concept maps. Analysis of preservice teachers' misconceptions, according to Vygotsky's (1987) theory of concept development, revealed that all misconceptions exhibited by preservice teachers appeared to be pseudo-concepts (Table 23).

Table 22

*Frequencies and Percentages of Preservice Teachers' Conceptions and Misconceptions on Pre-Concept and Post-Concept Maps for the Topic of Density (*n *= 61)*

	Concept or Misconception	
Density is/uses	Pre-concept map *n* (%)	Post-concept map *n* (%)
Buoyancy or Describes Floating and Sinking.	35 (32%)	27 (19%)
Mass, Heaviness, and Weight.	31 (28%)	25 (18%)
A Change of State.	5 (5%)	4 (3%)
Volume or Size.	5 (5%)	2 (1%)
Area.	3 (3%)	5 (4%)
Confusing Mass and Weight.	4 (4%)	4 (3%)
Thickness.	2 (2%)	0 (0%)
Nonsensical.	6 (6%)	4 (3%)
Inadequate Explanations for Proportionality.	0 (0%)	1 (1%)
Compactness of Particles.	2 (2%)	15 (11%)
A Formula.	12 (11%)	44 (32%)
Proportional Reasoning.	2 (2%)	7 (5%)
Property of Matter.	2 (2%)	1 (1%)
Total	109 (102%)*	139 (101%)*

Note. *Total number of concepts identified 109 for the pre and 139 for the post.* *Total does not sum to 100 due to rounding error.

Table 23

Categorization of Preservice Teachers' Major Knowledge of Density from Pre-Concept and Post-Concept Maps Based on Vygotsky's (1987) Theory of Concept Development

Density	Category of Misconception
Is related to states of matter.	Complex
Is confused with mass, heaviness, and weight.	Pseudo-concept
Is related to sinking and floating or buoyancy.	Pseudo-concept
Is confused with volume and size.	Pseudo-concept

The results for interviews about density were used to lend support to the identified misconceptions found in preservice teachers' concept maps as well as to offer more in-depth insight into preservice teachers' responses. Preservice teachers' interview responses are presented in Table 24. A total of a 125 concepts were identified on the pre-interview concept maps, and 147 concepts were identified on the post-interview concept maps. Using IBM SPSS® Statistics version 20.0, the preservice teachers' responses were coded and analyzed for frequency and then tabulated and classified into three categories: (a) preservice teachers' responses involving misconceptions about density, (b) emerging concepts, and (c) scientific concepts (see Table 24). The most common misconceptions about density were the following:

1. Confusing density with heaviness (19% on pre-concept map interviews and 13% on post-concept map interviews)
2. Confusing density with buoyancy (20% on pre-concept map interviews and 17% on post-concept map interviews).

These results lend support to the findings in the concept map analysis which identified both buoyancy and heaviness as robust misconceptions held on to by preservice teachers even after receiving instructional intervention.

Table 24

*Preservice Teachers' Misconceptions About Density in Pre-Concept and Post-Concept Map Interviews (*n *= 57)*

	Pre		Post		
Density is/uses:	*n*	%	*N*	%	Preservice Teachers' Quotes
Misconceptions					
Heaviness.	23	19	19	13	"I put density is how heavy something is."
Buoyancy, floating, or sinking.	25	20	25	17	"Density is, let me think here; density is what makes an object, or determines whether an object sinks or floats."
Volume or size.	5	4	4	3	"So the size, like, if it's smaller, it has less density than when it's bigger."
Change of state.	5	4	5	3	"I said density can be used to define the state of matter."
Area to describe volume.	2	2	2	1	"Volume is the area it takes up."
How thick something is.	3	2	2	1	"It can be a thick density or thin density."
Confuses mass and weight.	9	7	7	5	"[What does mass represent?] It's like matter, like how heavy something is."
Inadequately explained.	17	14	19	13	"The mass times density equals volume."
Inadequate explanations for proportionality.	0	0	1	1	"Well, I guess mass is the amount of matter that an object has, and then the volume is how much space that it takes up [sic], and that equals your density."
Emerging Concepts					
D = M / V.	27	22	38	26	"Density is mass divided by volume."
Compactness.	4	3	9	6	"Density is, like you know, how close the particles are together."
Scientific Concepts					
A property of matter.	3	2	12	8	"Density is unchanging, so it's always the same . . . because it's a physical property; it's a property of it."
Adequate explanation for proportionality.	1	1	4	3	"Because an object can be bigger; for example, a beach ball is larger than like a marble, but a marble is more likely to have, be more dense than a beach ball. It's made up of different materials."
Total	124	100	147	100	

Note. *Total number of concepts identified for the pre 125 and for the post 147.* *Total does not sum to 100 due to rounding error.

As to emerging themes, preservice teachers increasingly used the formula for density to explain density (22% on pre-concept maps and 26% on post-concept maps). Relating density to compactness doubled after receiving the intervention. Only 2% of preservice teachers utilized the correct scientific concept and scientific reasoning to define density as a property of matter on pre-concept maps; however, this percentage did increase to 8% on post-concept maps.

Last of all, writing artifacts were used to triangulate the data presented by preservice teachers' concept maps and interview responses and to further confirm the emerging themes identified in the concept maps and interview responses of the participants. The writing artifacts consisted of preservice teachers' responses to select questions from the evaluation portion of the lesson plan as well as one midterm question. A 3-hour instructional intervention was provided for the preservice teachers. The study analyzed 63 writing artifacts; preservice teachers with missing writing artifacts were removed from the total count. The questions used for the analysis can be found in Table 25.

Table 25

Spring 2012 Study: Writing Artifacts Evaluate for Density Questions

Question
6. What is the relationship between mass, volume, and density?
7. Does doubling the amount of a substance change its density if the volume increases at the same rate? Why or why not?
9. Explain in your own words the concept of density (go beyond just listing the density equation).
10. Explain the difference between density and weight.

Answers to the questions revealed several misconceptions, emerging concepts, and scientific concepts associated with the concept of density. On Question 6, 55% of the preservice teachers used the density formula to explain the relationship between mass, volume, and density. Next when asked about proportionality, the data for Question 7 demonstrated that only 31% of preservice teachers' responses adequately explained proportionality.

Question 9 demonstrated a large number of misconceptions associated with the concept of density. When asked to explain the concept of density, 17% of preservice teachers included misconceptions of heaviness in their explanations. Twenty-one percent of preservice teachers confused density with buoyancy, and 30% of preservice teachers' responses provided an inadequate response to the question. If we add these numbers, we can see that 68% of preservice teachers either could not describe the concept of density in their own words or featured a misconception in their response. This represents a large percentage of the participants and further lends proof to the point that preservice teachers were struggling to define density.

Lastly, some preservice teachers' responses demonstrated an emerging idea of density. Eight percent of the preservice teachers' responses included a discussion of the density formula, and 7% described the characteristic of compactness as related to density. Only 2% of the preservice teachers' responses described density as a property.

On Question 10, 66% of preservice teachers' responses could not explain the difference between density and weight. Some associated misconceptions included heaviness, buoyancy, confusion between density with volume, confusion between mass and weight, as well as other inadequate explanations. Twenty-three percent of preservice teachers applied the density formula or discussed compactness to describe the difference between density and weight. Only six percent of preservice teachers provided a scientific explanation of the difference between density and weight. These data are presented in Table 26 and 27. Lastly, on the midterm examination's Question 2 (Table 18) that asked what would happen to the density of an object if the object was cut in half, 91% of preservice teachers correctly answered that density would not change.

Table 26

*Preservice Teachers' Misconceptions, Emerging Concepts, and Scientific Concepts Quotations about Density for the Lesson Evaluate Component (*n *= 63)*

Density is/uses:	Preservice Teachers' Quotes
Misconceptions	
Heaviness.	"Density pertains to an object that is heavier than another."
Confusion of mass and weight.	"Mass is the weight of an object."
Buoyancy, floating, or sinking.	"Density is about whether an object will float or sink."
Volume or size.	"Density is the amount of space you take up."
Thickness.	"Density equals thickness."
Change of state.	None.
Area to describe volume.	"Mass is dispersed in a specific area of volume."
Inadequate explanations for proportionality.	"Density depends on the mass and volume of an object and how objects are compacted."
Inadequately explained.	"Don't know."
Emerging Concepts	
d = m/v.	"Mass divided by volume equals density."
Compactness.	"Density is how tightly packed the particles are."
Scientific Concepts	
A property of matter.	"Density is a property of substance."
Adequate explanation for proportionality.	"As the mass increases, density also increases. As volume increases, density decreases (inversely related)."

Table 27

*Frequencies and Percentages Table for Preservice Teachers' Misconceptions, Emerging Concepts, and Scientific Concepts about Density: Lesson Evaluate Component (*n *= 63)*

	Question 6		Question 7		Question 9		Question 10	
Density is/uses:	*n*	*%*	*n*	*%*	*n*	*%*	*n*	*%*
Misconceptions								
Heaviness.	1	1	3	4	15	17	8	9
Buoyancy.	1	1	0	0	18	21	3	3
Confused with volume.	2	3	1	1	2	2	3	3
Change of state.	0	0	0	0	0	0	0	0
Thickness.	0	0	0	0	1	1	1	1
Confuses mass and weight.	1	1	0	0	1	1	3	3
Confuses area to volume.	0	0	0	0	3	3	0	0
Inadequately explained.	18	24	20	30	26	30	41	47
Inadequate explanations for proportionality.	0	0	11	16	2	2	0	0
Emerging Concepts								
d = m/v.	41	55	6	9	7	8	13	15
Compactness.	3	4	0	0	6	7	7	8
Scientific Concepts								
A property of matter.	2	3	5	7	2	2	3	3
Adequate explanation for proportionality.	5	7	21	31	3	3	5	6
Total	74	99*	67	98*	86	97*	87	98*

Note. *Total does not sum to 100 due to rounding error.

A summary of the results for pre-concept and post-concept maps, face-to-face interviews, and writing artifacts for density are provided in Table 28. Although preservice teachers could recall and use the formula for density, most preservice teachers were unable to explain density as a property of matter. The majority of preservice teachers' responses were limited to using the density formula to define density. Common misconceptions with density were confusing density with buoyancy or floating and sinking and confusing density with heaviness, mass, or weight. Data about how preservice teachers progressed in their understanding of density during the course of the semester revealed that preservice teachers begin with misconceptions about density as buoyancy or heaviness that are robust misconceptions that persist despite instructional intervention. When prompted to develop their explanations further, many preservice teachers stopped at recalling the density formula to explain the concept of density. Only 8% of preservice teachers' responses on the post-concept map interviews explained density as a property of matter. Overall, preservice teachers struggled to explain the concepts of dissolving and density, and in a Vygotskian sense, were thinking at the complex but not at the abstract, scientific level of thinking.

One last analysis point was to look at the academic background preparation of preservice teachers in order to understand how the misconceptions exhibited by the preservice teachers could be resolved. Analysis of transcript data for preservice elementary teachers confirmed the results of the pilot study. The majority of preservice teachers did not complete a chemistry course. In a total sample of 64 elementary preservice teachers, only three individuals had taken a course in general chemistry. Similar to the results from the pilot study, the majority of the elementary preservice teachers (72%) earned a letter grade of A or B in a conceptual physics courses. Although the physics course was offered through the College of Arts and Sciences, the course was blocked for only elementary preservice teachers and was not a general course taken by non-science majors. The three preservice middle school teachers had taken at least two chemistry courses as a requirement of the degree plan.

Table 28

Results of Major Concepts/Misconceptions About Dissolving and Density from the Study's Instruments

	Concepts/Misconceptions
Dissolving	
Pre-concept maps	Preservice teachers describe dissolving as the mixing of two substances.
Pre-concept map interviews	Preservice teachers describe dissolving as the breaking down of a substances, chemical change, and change of state.
Writing artifacts	Preservice teachers use rate to describe dissolving.
Midterm questions	Preservice teachers describe dissolving as the breaking down of a substances, chemical change, and change of state.
Post-concept maps	Preservice teachers describe dissolving using rate.
Post-concept map interviews	Preservice teachers describe dissolving using rate.
Final examination drawings	Preservice teachers describe dissolving as the breaking down of a substance.
Density	
Pre-concept maps	Preservice teachers relate density to buoyancy and heaviness.
Pre-concept map interviews	Preservice teachers use the density formula to describe density as well as buoyancy and heaviness.
Writing artifacts	Preservice teachers inadequately describe density.
Midterm questions	None
Post-concept maps	Preservice teachers use the density formula to describe density as well as buoyancy and heaviness.
Post-concept map interviews	Preservice teachers use the density formula to describe density as well as buoyancy and heaviness.
Final examination drawings	None.

In the last step in the analysis of the results of the study, Vygotsky's theory of concept development was used to categorize the conceptual development in preservice teachers' understanding. For both the dissolving and density lessons, data codes from all pre-concept and post-concept maps, pre-interviews and post-interviews, and writing artifacts were analyzed. Using three stages of nonscientific thinking, emerging thinking, and scientific thinking, preservice teachers' development in learning was traced by comparing their understanding before and after an instructional intervention. Pre-concept maps and interviews were used prior to the instructional intervention. During the instructional intervention, writing artifacts from the 5E lesson (Evaluate) were collected. After the instructional intervention, post-concept maps, face-to-face interviews, midterm questions, and final examination drawings were gathered. Each data set was examined individually and then triangulated with all other data sets. Preservice teachers' stages of concept development at the end of the study were categorized based on their responses using Vygotsky's (1987) theory of concept development (see Figure 2).

Nonscientific Thinking → Emerging Thinking → Scientific Thinking

Figure 2. Stages of preservice teachers' concept development.

Preservice teachers were placed in one of the three categories to document conceptual change. The three categories were nonscientific, emerging, or scientific, and the category assigned was based on responses to the post-instruction concept maps, interviews, and drawings. For preservice teachers to be classified as emerging-scientific, they must have shown emerging concepts (e.g., rate in dissolving lesson and the density formula in the density lesson, etc.) yet zero misconceptions on their post-instruction data collection instruments (i.e., post-concept maps, post-interviews, and final examination drawings). Any appearance of a misconception in the post-instruction data collection instruments placed preservice teachers in nonscientific-emerging as an N-E. This means that although they had developed some emerging concepts, they still displayed misconceptions that continued even after receiving instruction. In effect, they moved toward emerging but had not quite arrived there. Likewise, to be categorized as emerging (E), preservice teachers only depicted emerging concepts in their post-instruction responses, or to be categorized as nonscientific (N), preservice teachers only provided non-scientific answers in their post-instruction responses. Preservice teachers with missing post-instrument responses were removed and were not counted in the final frequency and percentage counts. Results of the data analysis for preservice teachers' concept development are shown in Tables 29 and 30.

Preservice teachers' conceptual understanding for dissolving. For dissolving as seen in Table 29, 85% of preservice teachers were classified in the nonscientific-emerging category and 3% in the nonscientific category. The preservice teachers in the nonscientific category did not use rate or solubility as emerging concepts to explain the concept of dissolving and displayed mainly misconceptions about dissolving in their post-instruction responses. Those in the category of nonscientific-emerging did use rate or solubility to explain dissolving but still displayed misconceptions about dissolving in their post-instruction responses. To be categorized as emerging, preservice teachers needed to have used rate and/or solubility to explain dissolving and to have shown no misconceptions in their post-concept maps and post-concept map interviews. Only five preservice teachers (8%) were found to meet the criteria and were classified as emerging. Based on the data from interviews and post-concept maps, only three preservice teachers (5%) could be assigned to the emerging-scientific category as marked by correctly using the instructed concept of a hydration shell in addition to providing emerging concepts such as rate to explain the concept of dissolving.

Table 29

Frequencies and Percentages for Preservice Teachers' Conceptual Development in the Concept of Dissolving

	n	%*
Dissolving		
Nonscientific	2	3
Nonscientific-emerging	55	85
Emerging	5	8
Emerging-scientific	3	5
Dissolving Total	65	101*

Note. *Percentages does not sum to 100 due to rounding error.

Preservice Teachers' Conceptual Understanding for Density

With regard to density (Table 31), the majority of preservice teachers (78%) were classified as nonscientific-emerging, meaning that they used emerging concepts such as the density formula, or less frequently defined density as compactness, to explain the concept of density, yet they displayed misconceptions in their post-instruction responses. After the intervention, the preservice teachers continued to display misconceptions about the concept of density and to confuse density with heaviness or buoyancy. As a result, these preservice teachers were categorized as nonscientific-emerging. Six preservice teachers (10%) were categorized as emerging in the concept of density because they used the density formula or compactness to define density and showed no misconceptions on their post-concept maps or interviews. Six preservice teachers were categorized as nonscientific (10%), and only one preservice teacher could be placed in the emerging-scientific category, exhibiting no misconceptions in any post-instruction responses.

In all, a large number of preservice teachers may have moved into the emerging-concept category for both concepts but still struggled with misconceptions. As a consequence, these preservice teachers did not develop the scientific-concept level of thinking. Rather, the data showed that the majority of preservice teachers continued to think in the complex stage without progressing sufficiently to the abstract stage of scientific thinking.

Table 30

Frequencies and Percentages for Preservice Teachers' Conceptual Development in the Concept of Density

Density	*n*	%
Nonscientific	6	10
Nonscientific-emerging	46	78
Emerging	6	10
Emerging-scientific	1	2
Density Total	59	100

CHAPTER 5

DISCUSSION AND CONCLUSION

The findings are based on the analytical framework derived from the constructs gathered from Vygotsky's (1987) theory of concept development and the learning psychology of Ausubel (1963). These frameworks were used as analytical frames/constructs to analyze the collected data, concept mapping, interviews, writing artifacts, examination questions, and drawings to understand how elementary preservice teachers construct content knowledge about the science topics they will teach to children.

Based on the results of this study, elementary preservice teachers did not have adequate prior knowledge about the process of dissolving and density. For this reason, it is important for science methods instructors to plan instructional interventions that address teachers' prior knowledge and misconceptions to enhance teaching quality and effectiveness. Furthermore, instructional interventions must involve deliberate and explicit use of pedagogical content knowledge that is carefully aligned to learning targets and standards and that are combined with a feedback loop to target persistent misconceptions. In Chapter 5, a discussion of the results of the study is presented.

Discussion

Research Question 1

The following question is one of two research questions addressed by the research study: What conceptions do preservice elementary teachers have about the concept of dissolving as graphically illustrated using concept maps, writing artifacts, interviews, examination questions, and drawings before and after an instructional intervention?

This study showed that preservice teachers exhibited misconceptions similar to those cited in the literature (Calik et al., 2007; Prieto et al., 1989; Valandis, 2000;), yet had gained some concepts as a result of the instructional intervention. A summary table (Table 31) depicts the triangulation of the data for all data points of pre-intervention (pre-concept maps and pre-interviews), intervention (writing artifact), and post-intervention (post-concept maps, post-interviews, midterm question, and final exam drawing). The discussion section that follows will address the following: (1) Misconceptions, emerging concepts, and concepts gained on the concept of dissolving (2) the relationship between the findings and the theoretical framework and/or review of literature. (3) differences and similarities of misconceptions to the conception.

Table 31

Summary of Triangulated Data Frequencies for Preservice Teachers' Conceptual understanding of Dissolving

Misconception/ Concept	Pre-concept map	Pre-interview	Writing artifact (Q3. What happens to sugar and salt during dissolving?)	Post-concept map	Post-interview	Midterm (Q3. Why is dissolving not a chemical reaction?)	Drawing
Breakdown	14	17	8	10	21	4	18
Mixture	23	14	5	13	17	4	5
Chemical Change	14	16	5	11	8	4	6
Change of state	15	17	0	4	10	1	1
Melting	4	0	0	0	0	0	0
Disappearance	13	9	0	2	3	0	2
Rate	14	14	10	40	53	0	3
Solubility	4	0	1	25	12	0	1
Hydration shell	0	0	6	4	4	0	12

Misconceptions, Emerging Concepts, and Concepts Gained on the Concept of Dissolving

Preservice teacher misconceptions found in this research study can be categorized as robust or weak misconceptions. Robust misconceptions existed prior to the instructional intervention, during the instructional intervention, and were found in the post-intervention collected data. The robust misconceptions identified in this research study were explaining dissolving as forming a mixture, breaking down of substances, or chemical change. The misconceptions were similar to those identified in the literature breakdown (Prieto et al., 1989; Valandis, 2000) and chemical change (Calik et al., 2007; Valandis, 2000). A notable exception was the misconception on forming mixtures. This robust misconception was not found in the literature review that was conducted for this study. Weak misconceptions, on the other hand, such as change of state, disappearance or melting were either abandoned or reduced significantly as a result of the instructional intervention. Similarly weak misconceptions such as melting and disappearing exhibited by preservice teachers were reported in the literature (Calik & Ayas, 2005; Calik et al., 2007; Valandis, 2000).

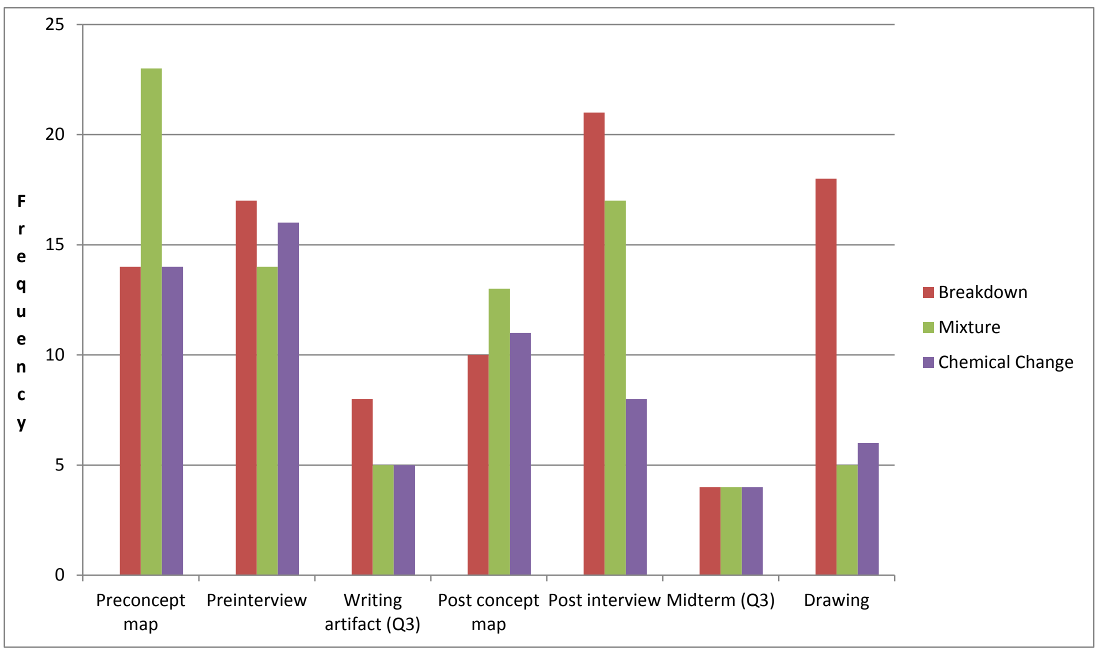


Figure 3. Robust misconceptions in preservice teachers' conceptual development of the concept of dissolving.

As can be seen in Figure 3, preservice teachers used forming mixtures, breakdown of substances, and dissolving as a chemical change throughout the triangulated data as a common way to explain dissolving. Throughout the data from pre-intervention, through intervention, and post intervention, the concepts of breakdown, forming mixtures, and chemical change were persistent and ready explanations offered to explain the dissolving process. For instance, when asked in the pre-concept maps and pre-interviews to explain the concept of dissolving, preservice teachers readily offered all three explanations. The same pattern of explanation took place during the intervention (Question 3 writing artifact: “What happens to sugar and salt during dissolving?”), the post intervention data (post-concept maps, post interviews, and the midterm Question 3, “Why is dissolving not a chemical reaction?”). Lastly, the final exam drawings included the same explanations. Unlike weak misconceptions, these robust misconceptions were neither abandoned nor reduced significantly as a result of the instructional intervention.

Some misconceptions were weak and either reduced significantly or abandoned as a result of the instructional intervention. These weak misconceptions explained dissolving as a change of state, melting, or disappearance (Figure 4).

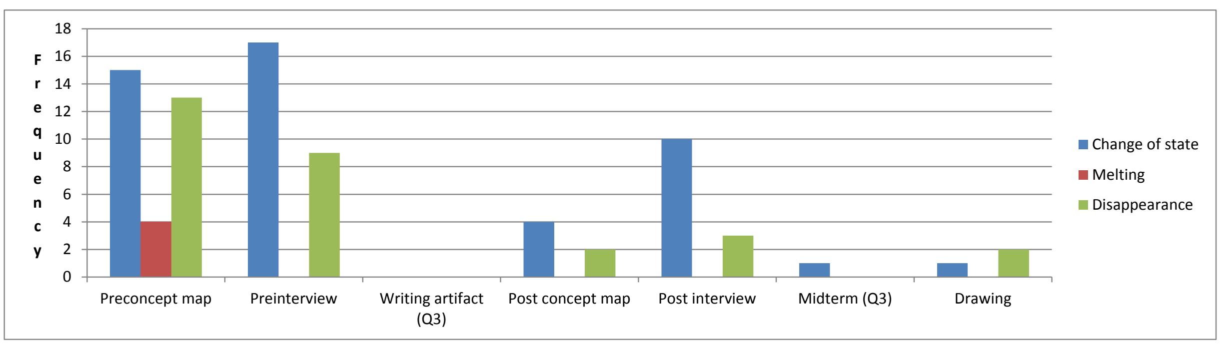


Figure 4. Weak misconceptions in preservice teachers’ conceptual development of the concept of dissolving.

Emerging concepts gained from the instructional intervention such as explaining dissolving using rate or the concept of solubility or the scientifically taught concept of hydration shell were also apparent in preservice teachers’ responses throughout the triangulation of the data and can be found in Figure 5. These emerging concepts were not common in the literature and were probably derived by preservice teachers from the lesson activities. Similarly, the instructed scientific concept of hydration shell was not found the literature search for this study.

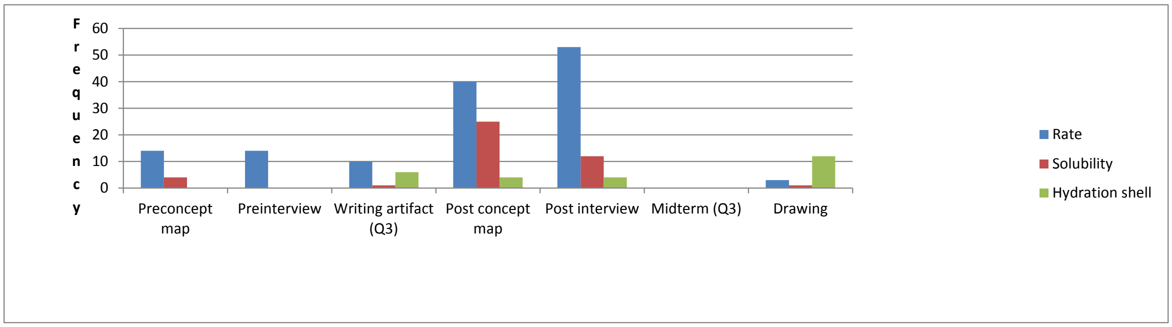


Figure 5. Emerging and scientific concepts gained in preservice teachers' conceptual development of the concept of dissolving.

The Relationship between the Findings and the Theoretical Framework and / or Review of Literature

Interestingly, although dissolving as breakdown (Prieto et al., 1989; Valandis, 2000) and chemical change (Calik et al., 2007; Valandis, 2000) can be found in the literature review, the misconception involving dissolving as forming mixtures is not as commonly found. Trying to decide what the concept of breaking down involves in preservice teachers' responses is not an easy matter. Valandis (2000) has reported that preservice teacher responses with breaking down may mean that solid grains break up into smaller invisible grains. Or that breaking up could mean that molecules break into atoms during a change of state (Prieto et al., 1989). The weak misconceptions found in this study such as melting and disappearing used by preservice teachers have been reported in the literature (Calik et al., 2007; Valandis, 2000). Interestingly, these weak misconceptions are cognitively at such a low level that they are shared by kindergartners (Kikas, 2001).

Applying the theoretical framework provided by Vygostky's (1987) construct development theory, misconceptions on forming mixtures was treated as a pseudo concept, whereas misconceptions such as change of state, disappearing, breakdown, melting, and chemical change were treated as complexes. This is in agreement with what Valandis (2000) has reported in that preservice teachers report perceptual knowledge of what they can see rather than the abstract taking place at the atomic level, which they cannot see.

Differences and Similarities of Misconceptions to the Concept

From the data collected, it was difficult to infer what preservice teachers mean by breakdown. As has been cited in the literature (Prieto et al., 1989; Valandis, 2000), breakdown can be understood to mean the physical breakdown of granules of the solute, but can also mean that molecules break down as individual atoms. What was missing from the majority of preservice teacher explanations was understanding the instructed concepts of intermolecular forces, hydrogen bonding, and van der Waals forces.

The following is an example of a preservice teacher's interview response about dissolving as breaking apart: "The sugar molecule breaks apart, and it disperses throughout the liquid. The bond is broken." This response demonstrates how diverse preservice teacher responses were about dissolving as breaking apart. When preservice teachers used breaking apart to describe dissolving, preservice teachers could mean that a chemical bond splits or that grains of a solid break apart. Preservice teachers' diverse use of the misconception of breaking apart to describe dissolving showed the limitations of using the phrase *break apart* to describe dissolving. When preservice teachers used this misconception, it was difficult to decipher whether they were thinking in a macro or micro sense. However, the preservice teachers' low percentage (3%) of use of the term *hydration shell* in the interviews indicates that they still did not understand the role of intermolecular forces in the process of formation of hydration shells and instead were relying on macro thinking to explain a micro phenomenon.

Similarly, the misconception of chemical change (Calik et al., 2007; Valandis, 2000) taking place in the process of dissolving constitutes another persistent explanation in preservice teachers' thinking. Clearly, in this case, the preservice teachers lack the proper differentiation of dissolving as a physical change most likely because of their lack of knowledge about the role of intermolecular forces.

Lastly, forming mixtures was used consistently in preservice teachers' explanation of what is taking place during the process of dissolving. This presented yet another inaccurate generalization used to explain the process of dissolving. Perhaps in this instance the preservice teachers were reporting perceptual knowledge rather than conceptual knowledge, reporting what they could actually see concretely and not the abstract concepts that could not be directly observed. This is consistent with the observation made in the literature by Valandis (2000).

An example of a preservice teacher's interview response about dissolving as mixing included the following: "Dissolving is taking a substance and putting it in a liquid and making it sort of be one. It's just making a mixture; I guess it's dissolving." Alternatively, use of the concept of mixing in preservice teachers' responses clearly indicated that preservice teachers were operating at the macro level to describe a micro-level process.

These weak misconceptions were abandoned or significantly reduced through instruction as shown in Figure 4. For example, the misconception that dissolving involves melting (Calik et al., 2007; Valandis, 2000) was abandoned by the preservice teachers as early as the pre-interview and did not appear again during the intervention nor in the post-intervention data. The other two weak misconceptions disappearance (Calik & Ayas, 2005); and change of state were significantly reduced by the time the post-intervention data were collected. Interestingly, the misconception of dissolving as related to change of state has been reported in the literature as exhibited by K-12 students (Abell & DeBoer, 2008; Prieto et al., 1989). These misconceptions represent preservice teachers perceptual rather than conceptual knowledge about dissolving. Also, change in the state of matter (i.e., sugar [a solid] changes state to a liquid, which causes dissolving) was used by some preservice teachers to explain the process of dissolving. We can infer that the concept of states of matter operates as a diffuse complex for many of the preservice teachers because this concept is the foundation for explaining many processes (including dissolving) that occur at the molecular level. The concept of states of matter represented one of the most readily available explanations for any change at the molecular level. Still, other preservice teachers used the concept of states of matter as a pseudo-concept. That is, some preservice teachers do understand the concept of states of matter for water (which can be a solid, liquid, or gas) and how the amount of space between the molecules changes as a substance changes from a solid to a liquid, a liquid to a gas, a gas to a solid, and so on. However, the preservice teachers failed to use explicitly stated ideas about how particles move with regard to the shape and volume of the container and how particles move past or slide past one another to explain dissolving. For this reason, evidence of preservice teachers' understanding of the concept for states of matter was very limited.

The use of rate or solubility to explain dissolving was most likely due to the influence of instruction on the preservice teachers' responses and was not common in the literature. This is due to the fact that many of the activities involved in the instructional intervention activity measured the rate of dissolving due to various factors such as stirring or heating or asked whether a substance was soluble or not. One of the coping strategies used by preservice teachers to mask their lack of conceptual understanding of dissolving (i.e., their lack of content knowledge) involved borrowing from the activities that occurred during the lesson intervention

(Akerson, 2005; Appleton, 2006). From all the triangulated data, preservice teachers did not have a scientific understanding of the concept of dissolving. The problem of relating the dissolving process to hydrogen bonding or intermolecular forces has been cited in the literature as a problem hindering the understanding of K-12 students (Calik, 2005; Kind, 2004). As an indication of this limited scientific understanding, most responses did not include the scientific concept of a hydration shell to describe the process of dissolving. Of the concepts gained, the concept of a hydration shell appeared most frequently towards the end with the final exam drawings and was not present in preservice teachers' responses prior to the instructional intervention (Figure 5). Moreover, the concept of a hydration shell constituted only a small portion of the majority of responses presented by preservice teachers. Instead, preservice teachers relied on rate, solubility, or other emerging concepts to define dissolving. This represents a concrete understanding of dissolving, which while necessary to the development of understanding, does not qualify as abstract because it explains the scientific phenomenon at the macro not micro (atomic level) and as such is not at the abstract level of thinking necessary for scientific understanding. The following is a sample preservice teacher's response involving rate to define dissolving:

> Both sugar and salt dissolve in water. The hotter the water is, the faster the solutes dissolve. Hot water allows more of the solute to be dissolved. The colder the water, the longer it took to dissolve the solute. Also, the smaller the solute, the more and the faster it will dissolve.

The preservice teacher clearly discussed factors that influence the dissolving process but did not define what dissolving itself is. The emerging concept of using rate to define dissolving constituted a large percent of preservice teachers' interview responses (33%), but using solubility to explain dissolving did not (7%). The following is an example a preservice teacher's response using solubility to explain dissolving:

> And some things that affect dissolving are temperature, going from hot to cold or room temperature. And then are solubles [sic] and insoluble [sic]. And insoluble do not dissolve. And I wrote two examples, iron and gravel. And then solubles [sic] are salt and sugar, things that do dissolve in materials such as water, or any other kind of [sic].

In this response, the preservice teacher is clearly using concrete observations borrowed from the lesson activity to explain emerging concepts such as rate and solubility that are related to dissolving but do not define dissolving. In essence the preservice teachers were using spontaneous concepts derived from perceptual rather than conceptual knowledge of dissolving (Valandis, 2000).

Another problem indicative of the emerging level of understanding that the preservice teachers possess is their limited use of scientific vocabulary. When prompted to expand upon their answers during interviews, preservice teachers revealed that they struggled to explain the scientific vocabulary used and what they meant by the scientific terms they used. For example, when asked what a particle is, one preservice teacher responded with the following statement: “I was thinking of the granules.” This preservice teacher confused the word *particle* with the meaning *crystals of the solid*. Similarly, preservice teachers may invoke pseudo-concepts in other instances when prompted to offer further explanations of their concepts. When the preservice teacher was asked what she meant by using the word *absorbed* in her concept map to explain dissolving, she responded with the following: “Dissolving is when a solute is absorbed by a solvent. It doesn’t disappear. It is absorbed.” This preservice teacher applied the scientific concept of absorption to the wrong context to describe dissolving, which makes this use of *absorbed* a pseudo-concept.

The correct scientific answer should have featured a reply that explained that dissolving is a *process* by which the solute dissolves into the solvent, forming a solution. This dissolution process involves the breaking of inter-molecular forces. Most often the solvent is water and thus a hydration shell forms around the solute. In the case of covalent compounds, molecules are broken apart, whereas in the case of ionic compounds, ions break apart. As can be seen with this model reply, the explanation involves the invisible processes taking place at the micro atomic level and does not rely on processes that are on the macro level only.

Lastly, a source of negative evidence in this study comes from the responses to the midterm questions. When the midterm exams were administered, a certain amount of time had elapsed in the course of the semester, so it is possible to investigate how preservice teachers' knowledge might change after a certain amount of time had elapsed from the time of the instructional intervention. Preservice teachers were asked to address their misconceptions by explaining explicitly why dissolving was not a change of state, not a chemical change, and not melting. Preservice teachers no longer used the emerging concepts they had picked up during the instructional intervention on the midterm examination (Table 19). Both rate (0%) and solubility (0%) were absent from all preservice teachers' responses. The scientific concept of a hydration shell was also unused in preservice teachers' responses to questions about dissolving on the midterm (0%, Table 19). Similarly, results from the midterm showed an increase in the number of responses with correct use of academic vocabulary (around 50% of responses compared to less than 15% of responses in which preservice teachers used academic vocabulary incorrectly in their responses). Again, this example can be seen as negative evidence indicating a test effect may have taken place.

Although asked to address explicitly their common misconceptions, many of the same misconceptions (e.g., breaking up, mixing, chemical change) were reflected in preservice teachers' answers as shown in Table 19).

No mention was made that dissolving involves both the breaking of intermolecular forces and (ionic) bonds and the formation of new weak intermolecular bonds. No preservice teacher used the concept of van der Waals forces or compared these forces to covalent and ionic bonding when teaching the concept of dissolving. Just as in the case of robust misconceptions, these results show a lack of preservice teachers' understanding at the micro level and suggest that more work is needed to move their thinking from the level of perceptual knowledge to conceptual knowledge. Consequently, it is evident that preservice teachers had limited knowledge about the process of dissolving and that their explanations had not yet reached the level of scientific conceptual understanding that was expected after the instructional intervention and were instead performing at the emerging level (Figure 2). This is most likely due to the fact that they had not sufficiently been exposed to the theory on the particulate nature of matter (Nakhleh, 1992), mostly as a result of not having taken enough chemistry courses.

Because dissolving is a concept taught in elementary school, this lack of knowledge about an introductory concept such as dissolving is shocking and suggests the need to screen more carefully and more thoroughly preservice teachers' knowledge of the elementary science topics they are required to teach before they become certified and enter classrooms as teachers of record.

Research Question 2

The following question is the second of two research questions addressed by the research study: What conceptions do preservice elementary teachers have about the concept of density as illustrated using concept maps, writing artifacts, and interviews before and after an instructional intervention?

Similar to the dissolving concept, triangulation of the data on the concept of density show that preservice teachers exhibited misconceptions similar to those cited in the literature, yet had gained some emerging concepts as well. Table 32 depicts the triangulated data derived from pre-intervention (pre concept maps and pre interviews), intervention (writing artifact Q.9), and post-intervention (post concept maps, post interviews). The discussion section that follows will address the following: (1) Misconceptions, emerging concepts, and concept gained on the concept of density (2) The relationship between the findings and the theoretical framework and/or review of literature. (3) Differences and similarities of misconceptions to the conception.

Table 32

Summary of Triangulated Data Frequencies for Preservice Teachers' Conceptual understanding of Density

Misconception/ Concept	Pre-concept map	Pre-interview	Writing artifact (Q9. Explain in your own words the concept of density [go beyond just listing the density equation]).	Post-concept map	Post-interview
Buoyancy or Describes Floating and Sinking.	35	25	18	27	25
Mass, Heaviness, and Weight.	31	23	15	25	19
A Change of State.	5	5	0	4	5
Volume or Size.	5	5	2	2	4
Thickness	2	3	1	0	2
Compactness of Particles.	2	4	6	15	9
Density Formula.	12	27	7	44	38
Property of Matter.	2	3	2	1	12

Misconceptions, Emerging Concepts, and Concepts Gained on the Concept of Density

As shown in Figure 6, across all data collected throughout the intervention, the two misconceptions of confusing density with buoyancy and confusing density with heaviness represent the most common robust misconceptions held by preservice teachers. These misconceptions are similar to those cited in the literature heaviness (Greenwood, 1996; Stepans et al., 1988) and buoyancy (Dawkins et al., 2008; Greenwood, 1996; Stepans et al., 1988). The triangulated data using concept maps, interviews, and the writing artifact data illustrate that these two robust misconceptions neither disappeared nor were significantly reduced as a result of the intervention.

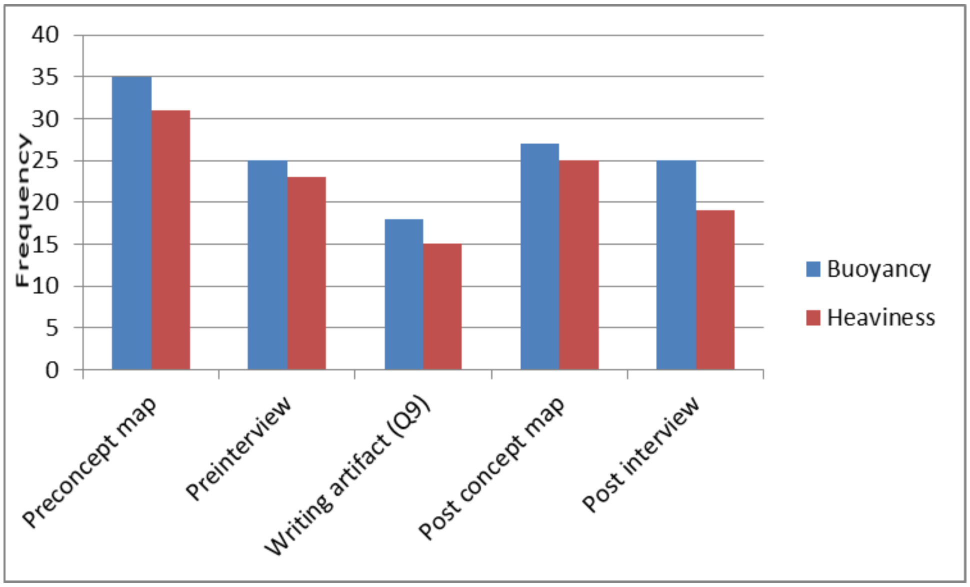


Figure 6. Robust misconceptions in preservice teachers' conceptual development of the concept of density.

Unlike the concept of dissolving, there were no weak misconceptions that were either abandoned or significantly reduced as a result of the intervention (Figure 7). Instead, these misconceptions were less common in preservice teachers' responses such as confusing density and volume and describing density as a change of state or as thickness. Thickness as used by preservice teachers is indicative of a complex level of thinking that results from spontaneous understanding derived from everyday observations, borrowed to explain a scientific concept that the preservice teacher struggles with. Similarly, change of state represents yet another ;eve; complex thinking where the concept is used erroneously to explain the scientific concept. Last of all, problems with understanding volume could interfere with understanding density as cited in the literature for K-12 students (Krnel et al., 1998; Kohn, 1993).

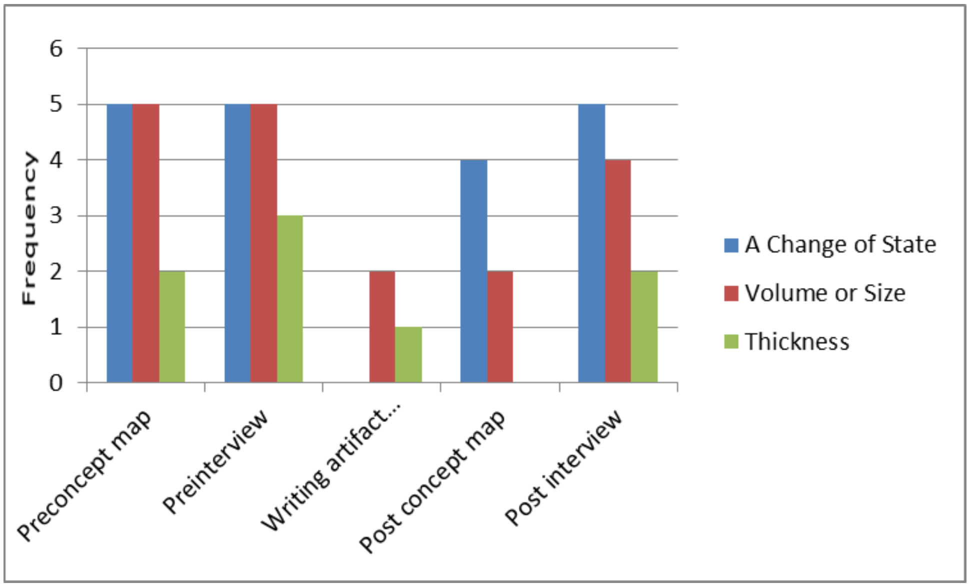


Figure 7. Less common robust misconceptions in preservice teachers' conceptual development of the concept of density.

The concepts gained as a result of the intervention are summarized in Figure 8. The results show that most preservice teachers relied on the density formula to explain the concept of density, instead of using the scientifically instructed concept of property of matter. After the instructional intervention, use of the density formula on the post-concept map increased from 11% to 32% (Table 23). Dawkins et al. (2008) have reported that preservice middle school teachers tend to rely on teaching students to focus on the density formula and that preservice middle school teachers struggle on recognizing density as a property of a substance. The emerging concept of relating density to the compactness of an object appeared in 11% of the preservice teachers' post-concept maps, and the scientific concept of defining density as a property of matter only appeared in 1% of preservice teachers' post-concept maps (Table 23). The use of the concept of compactness to explain density is similar to what Hewson (1986) has reported where high school students relate density to the packing of particles. The following is an example of a preservice teacher's response using the density formula to define density during the interviews: "Density is mass divided by volume." It can be inferred from these results that preservice teachers were using coping strategies derived from the lesson (e.g., the use of the density formula) as an emerging concept to replace the scientific definition of density. Similarly, other emerging concepts, such as relating density to compactness of objects, were present in preservice teachers' responses (3% during pre-concept interviews and 6% on post-concept interviews). The preservice teachers could recall the density formula but did not seem to understand it. Instead of defining density as a property of matter, preservice teachers who participated in this study used the formula to define density, related density to compactness, or borrowed procedural information from lesson activities to define density.

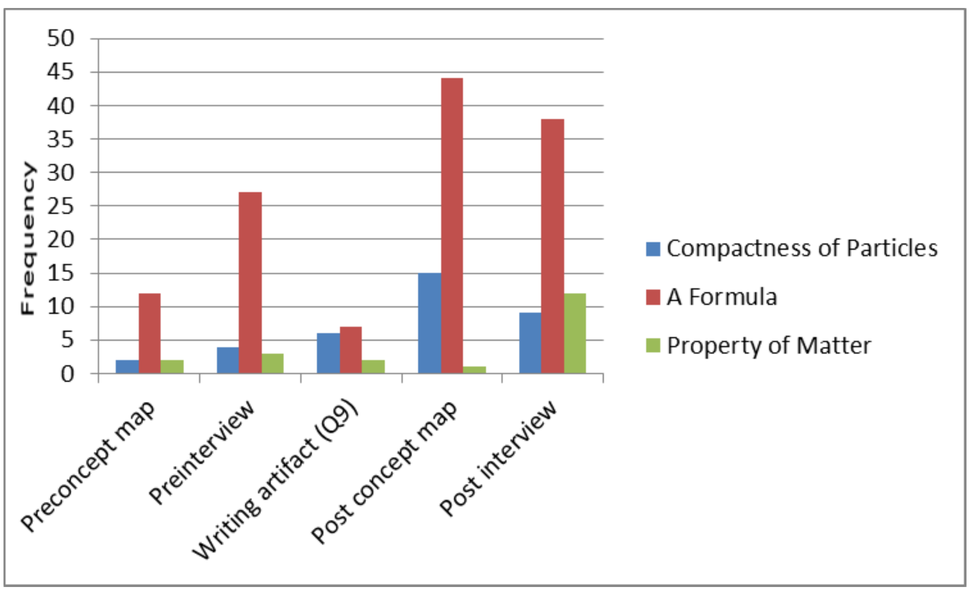


Figure 8. Emerging and scientific concepts gained in preservice teachers' conceptual development of the concept of density.

The Relationship between the Findings and the Theoretical Framework and / or Review of Literature

The two robust misconceptions of confusing density with heaviness and with buoyancy are not uncommon and have been cited in the literature as present in both children and adults.

Dawkins et al. (2008) reported that middle school preservice teachers have difficulty in understanding density as a property of matter. Similarly, the confusion between buoyancy and density by preservice teachers has been reported by several researchers (Dawkins et al., 2008; Greenwood, 1996; Stepans et al., 1988). Interestingly, the confusion between weight and density has been reported to be exhibited by students as young as elementary level (Krnel, et. al., 1998).

Applying the Vygotsky framework to these findings, it appears that complexes dominate the thinking of preservice teachers of elementary science with regard to the concept of density. Table 13 depicts the categorization of the concepts according to Vygotsky's theory of concept development. As suggested by the findings, the understandings of preservice teachers were dominated by pseudo-concepts. These are concepts that they borrowed from adult-scientific instruction but used in the wrong context. Examples included confusing density as mass, weight, heaviness, volume, or size and relating density to buoyancy in explaining floating/sinking.

On the other hand, most preservice teachers (95%) had no problem answering the questions on the evaluation portion that asked them to recall the density equation or to perform calculations using the density formula. When asked on the midterm to predict what would happen to the density of an object if the object was cut in half, 91% of preservice teachers correctly answered that density would not change. Indeed, in answer to the proportionality questions on the evaluate questions to the writing artifacts, many preservice teachers (55%) utilized the density formula on Question 6 or were able to adequately explain proportionality (31%) on Question 7. As indicated by the results, preservice teachers could use the density formula for calculating density without understanding the concept of density or being able to explain it.

Based on these findings, it can be seen that preservice teachers thought at the symbolic level (using the correct mathematical formula and symbols) but struggled to offer a conceptual explanation of the scientific concept. In a Vygotskian sense, preservice teachers remained in the complex thinking phase due to their use of several pseudo-concepts to explain their understanding of density, as can be seen from the results summarized in Table 13. In summary, the preservice teachers fell into the complex phase of thinking while struggling to transform their thinking to the higher abstract level.

Differences and Similarities of Misconceptions to the Conception

From the results it is inferred that preservice teachers struggled with the concept of density and held on to several robust misconceptions throughout the intervention: the most common were confusing density with buoyancy and confusing density with heaviness. On average, preservice teachers of elementary science were able to generate only about half of a proposition more for the topic of density accurately on their concept maps after instructional intervention.

Concerning preservice teachers' understanding of the concept of density, the majority of preservice teachers confused the concept of density with the concept of buoyancy by using density to describe how an object sinks or floats. A sample response from a preservice teacher's writing artifact illustrates this point: "Density is something that make it [sic] heavy [sic] and stay [sic] at the bottom of line then [sic] something that is less dense which floats." Furthermore, preservice teachers struggled with relating density to mass, heaviness, and weight and often confused the different concepts. When asked to describe density, one preservice teacher responded, "Density pertains to an object that is heavier than another." The following is a sample of a preservice teacher's response using density to explain floating and sinking: "Density is, let me think here, density is what makes an object or determines whether an object sinks or floats." Next is a sample of a preservice teacher's response using heaviness to describe density: "I put density in how heavy something is." Both responses reflect that preservice teachers confused density with buoyancy and heaviness.

Preservice teachers' responses about density indicated their lack of adequate understanding of the Archimedes' principle and a lack of ability to relate density to mass. Buoyancy (not density) determines whether something floats or sinks; weight is more closely related to buoyancy, and mass is related to density (but does not define it solely). The preservice teachers who participated in this study confused buoyancy and density but also erroneously related a single variable, heaviness, weight, and mass to density.

It is incorrect to say that an object sinks because it is heavy and to use this as a premise to say that an object is dense. An object sinks because it overcomes the buoyant force that keeps it afloat. Whether an object sinks or floats depends on several factors listed in the Archimedes' principle; density of the medium is only one of those factors. To say that density is what determines if an object sinks or floats is an oversimplification against which instructors should warn students as part of content instruction. Mass is only one of two variables that define density. It is incorrect to say that one object is denser than another object because the first object has a larger mass. Both mass and volume must increase in proportion to one another to make something more or less dense. Density is a relationship which cannot be directly perceived.

Some of the preservice teachers explained their understanding of density by using words indicating thick or thin. When asked what they thought of density, one preservice teacher responded, "I thought of how thick or thin a substance is." Other preservice teachers were challenged to relate a macro concept, such as density, to micro concepts, such as molecules. In one interview, a preservice teacher defined density as “how heavy the molecules were.”

Some preservice teachers related density to particles but could not explain the two concepts’ relationship. This conundrum indicated that preservice teachers borrowed and transferred scientific terms from one topic (possibly dissolving) onto another topic (density) without realizing the relevance of the scientific terms to the topic at hand. Again, this confusion shows that preservice teachers confuse the macro (regarding a concept such as density) to the micro (particles) without understanding the boundaries that separate the two levels of chemistry. Preservice teachers also used the word *concentration* to explain density. Concentration can perhaps be related to compactness in the sense of packing of particles. Using concentration to define density is an example of using a micro concept to define a macro concept. However, the goal of instruction in the lesson on density was to enable preservice teachers to define density as an intensive property of matter, which was the scientific concept to be learned and not to think about density at the micro subatomic level. Again, this example illustrates the learning difficulty the preservice teachers displayed by delineating the micro level from the macro level in their conceptual understanding of density as a macro-level concept.

Conclusion

In conclusion, the robust misconceptions persistent in preservice teachers’ understanding of dissolving resulted from their lack of knowledge about abstract concepts such as the intermolecular forces involved in the process of dissolving and suggest that preservice teachers had not yet reached the scientific level of understanding as described by Vygotsky. In essence, the preservice teachers were still operating at the perceptual rather than conceptual level of scientific understanding. Consequently, the majority of the participants in this study were operating on what Vygotsky would term the non-scientific level of thinking and still required more instruction to move them to the scientific stage of thinking.

As to the preservice teachers' misconceptions about density, it can be concluded from the results of the study that the misconceptions of buoyancy and heaviness probably stem from a lack of understanding about what distinguishes density and buoyant force and in turn possibly come from preservice teachers' lack of adequate exposure to this concept in conjunction with learning Archimedes' principle. Density is the relationship between mass and volume, but buoyancy of a solid object floating in a fluid is related to the volume of the object, the density of the fluid, and specific gravity. Based on the findings, preservice teachers confused two related topics (buoyancy and density) to explain macro phenomena such as sinking and floating.

In addition to dissolving, density is another introductory science concept that is taught in elementary school and about which preservice teachers' lack of content knowledge will impair their ability to correctly teach the concept. Based on results from this study, it is important that teachers understand the content they are expected to teach at the micro and macro levels if they are to ensure their students can become scientifically literate. Moreover, these findings raise important questions with regard to using instructional tools, such as density blocks, which are commonly used to teach the concept of density. It may be important that these instructional tools are carefully sequenced to be sure students develop a coherent understanding about density and how density relates to buoyancy. Because sinking and floating are taught as concrete concepts during grades 3 through 5 (elementary school), teachers of elementary science should deliberately and carefully ensure that the concept of density will eventually and properly develop into the students' prior knowledge before the concept of buoyancy is explained. A very basic understanding that should come from any initial instruction about sinking and floating involves learning about the material characteristics of objects that sink and float and learning that heavier objects tend to sink. As students continue the investigation of floating and sinking in higher-grade levels, students should learn about how specific gravity, displacement of volume, and density affect buoyancy.

Last of all, a comparison of means regarding density as buoyancy and density as heaviness from pre-instruction to post-instruction proved not to be statistically significant, indicating that these misconceptions did not change as a result of instruction and were indeed robust.

Summary

In summary, this study represented an attempt to address a gap in the literature because of the presence of only a few studies about the misconceptions of preservice teachers, especially at the elementary level. Although preservice teachers showed a statistically significant gain in conceptual understanding of the concepts of dissolving and density as evidenced by their pre- and post-concept map scores, they still exhibited robust misconceptions that persisted even after receiving instruction. These robust misconceptions were in explaining dissolving as breaking apart, as forming a mixture, and as involving chemical change, whereas for density they were in confusing density with buoyancy and mass/heaviness/weight. The misconceptions of dissolving show the preservice teachers expressing macro rather than micro understanding of the concept. This most likely comes from their lack of understanding of the particulate nature of matter because of their lack of enrollment in a college chemistry course during their course of study. With regards to density, the misconception in confusing density with buoyancy probably comes from the preservice teachers' lack of adequate understanding of Archimedes' principle. In a Vygotskian sense, the preservice teachers are in the complex level of thinking and have not advanced enough to the scientific level. They struggle to transform their concrete thinking into the abstract thinking characteristic of scientific understanding. In accordance with Vygotsky's theory of conceptual development and as shown by the results of this study, most of the preservice teachers can be placed in the nonscientific–emerging stage of conceptual development.

Implications

The implications of this study can be related to science teacher education, content preparation of preservice teachers, and professional development. Current teacher preparation programs strive to provide the best quality science teachers. Mostly this preparation involves pedagogical as well as content knowledge (Appleton, 2006). Both dimensions are important because they affect the science literacy of students, especially those at the elementary level. Having the correct conceptual understanding of science content at the elementary level devoid of misconceptions can ensure that students build on this knowledge on sound foundations. Such correct understanding also helps avoid situations in which teachers who have misconceptions of important introductory science concepts (such as dissolving or density) can in turn transfer these misconceptions to their students (Calik & Ayas, 2005). These very same misconceptions can be a hindrance to conceptual change (Chi, 2005). They also can form incorrect starting points for later concepts to be learned (Joung, 2009).

Science teacher preparation can be related to providing adequate course content for elementary preservice teachers and ongoing in-service professional development for teachers of record. The first implication of this research study is that preservice teachers of elementary science should be required to take a chemistry class during their teacher preparation coursework. Chemistry course completion would ensure that preservice teachers have been instructed adequately on the particulate nature of matter and the role of intermolecular forces, including the use of hydration shells, in the process of dissolving. Furthermore, preservice teachers need to use models and technology simulations to get past their macro-level thinking and to instruct their own students about the micro-level particulate nature of matter.

Another challenge for teacher preparation programs is to ensure that preservice teachers have the ability to link and to distinguish different topics about which they learn in their science content classes. For example, even though states of matter and dissolving are taught separately, course instructors should make it clear to preservice teachers how the states of matter and dissolving are related and unrelated to one another. This clarity insures that preservice teachers can link and delink the two concepts in a scientifically accurate way.

Likewise, preservice teachers must receive adequate instruction in physics courses about the differences between density and buoyant force. Instructors of physics content must insure that preservice teachers understand the differences between the two concepts and which concept to use to explain the phenomena of sinking and floating. Preservice teachers must be able to understand that the concept of density is a physical property of matter and not an object itself. Similarly, preservice teachers need to be instructed in their chemistry courses that dissolving is a process and not a concrete object.

There are implications for the science methods courses taught at the university hosting this study. Instructors need to eliminate all floating activities such as those involving bowling balls, coke cans, and layering from learning activities about density and instead focus on teaching density as a property of matter. Preservice teachers do not understand how sinking and floating relates to the density of solids in fluids and thus are led to a variety of misconceptions.

Also, teacher preparation programs must develop content courses for in-service elementary science teachers that emphasize the instruction on the particulate nature of matter and Archimedes' principle as part of their professional development efforts. This intervention becomes especially important for in-service teachers who have never taken any college-level chemistry or physics courses and who are currently teaching.

Yet another implication of the results of this study concerns the design, construction, and adequate scoring of concept maps and their potential use in large school districts. The scoring method of total propositional accuracy used in this study was developed as a result of the pilot study that helped to demonstrate to preservice teachers how to generate a concept map that is able to be scored. Results from the pilot study informed the main study about some of the issues that could arise as a result of failing to use arrows or linking phrases on concept maps. If concept maps are used by preservice teachers as an instructional tool or for student assessment, science methods course designers must adequately instruct preservice teachers about the construction and scoring of concept maps. Last of all, it would be interesting to see if the scoring method of total propositional accuracy could be used for large-scale concept map field scoring, such as on the school district level as a supplemental means for student evaluation alongside more traditional forms of testing that include multiple choice and essay type tests.

Finally, the method of comparison for the pre-concept and post-concept maps revealed the preservice teachers' misconceptions and helped with understanding how preservice teachers reorganize their conceptual knowledge (Borda et al., 2009). This method could be valuable to researchers interested in using concept maps to measure and assess conceptual changes experienced by preservice teachers.

Suggestions for Future Research

Replicating this study may induce more conceptual change in the density lesson, as was witnessed in these research findings. Future instructional intervention may also include units for density as part of the lesson objectives to be learned. Moreover, future researchers may want to examine how many of the identified misconceptions exhibited by preservice teachers are transferred to their students once they become teachers of record.

Finally, it would be interesting to take this research a step further to examine how instructing preservice teachers about the particulate nature of matter affects their demonstrations of conceptual change in post-concept maps. Similarly, it would be worthwhile to investigate how instruction in Archimedes' principle and in distinguishing density and buoyancy could affect preservice teachers' conceptual understanding of density.

APPENDIX A

SEMISTRUCTURED INTERVIEW PROTOCOL

Spring 2012 Interview Questions for Dissolving/Density

Begin with small talk to gain comfort with the interview process

Question:	What can you tell me about dissolving/density using your pre-concept map?
Question:	What can you tell me about dissolving/density using your post-concept map?
Probe:	Would you explain that further? Could you give an example? Can you elaborate on that idea? What does ________ mean? What happens when ________
Closure:	Is there anything else?

APPENDIX B

SAMPLES OF PRESERVICE TEACHERS' CONCEPT MAPS

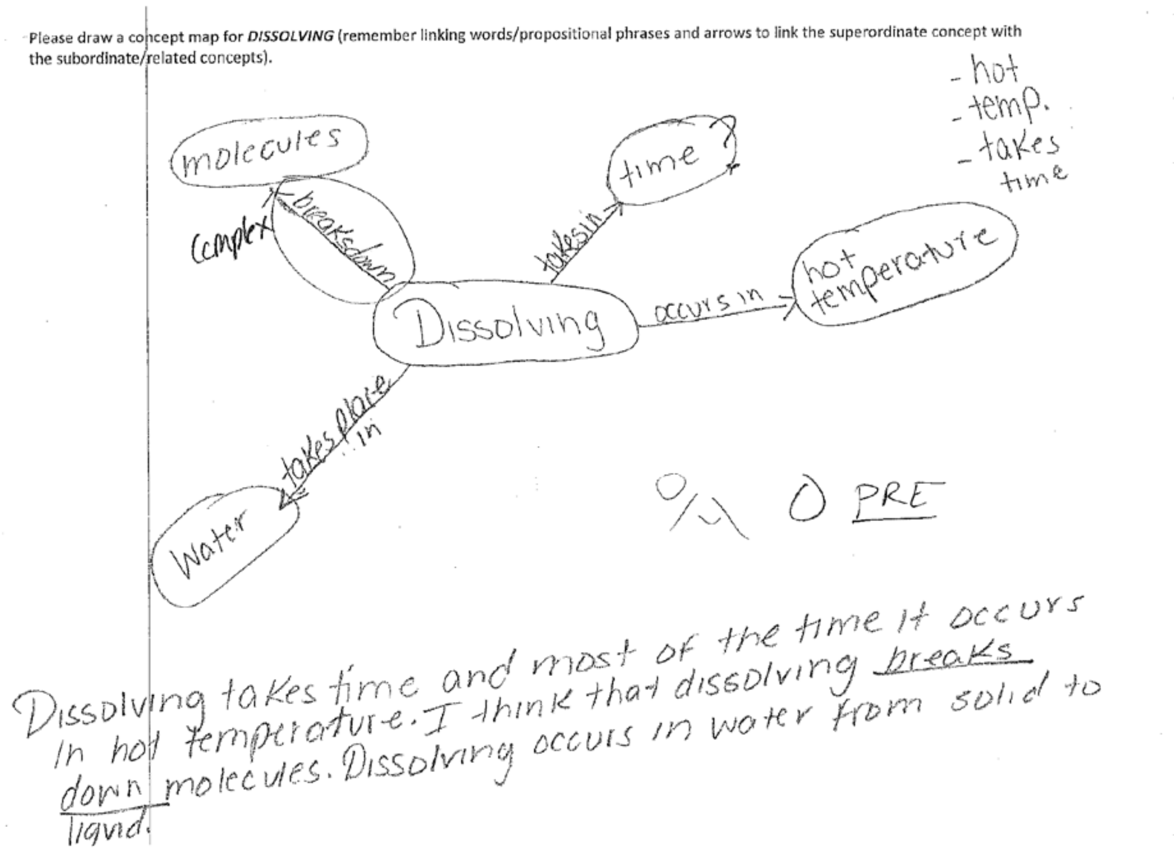


Figure B1. Preservice teacher pre-concept map for dissolving.

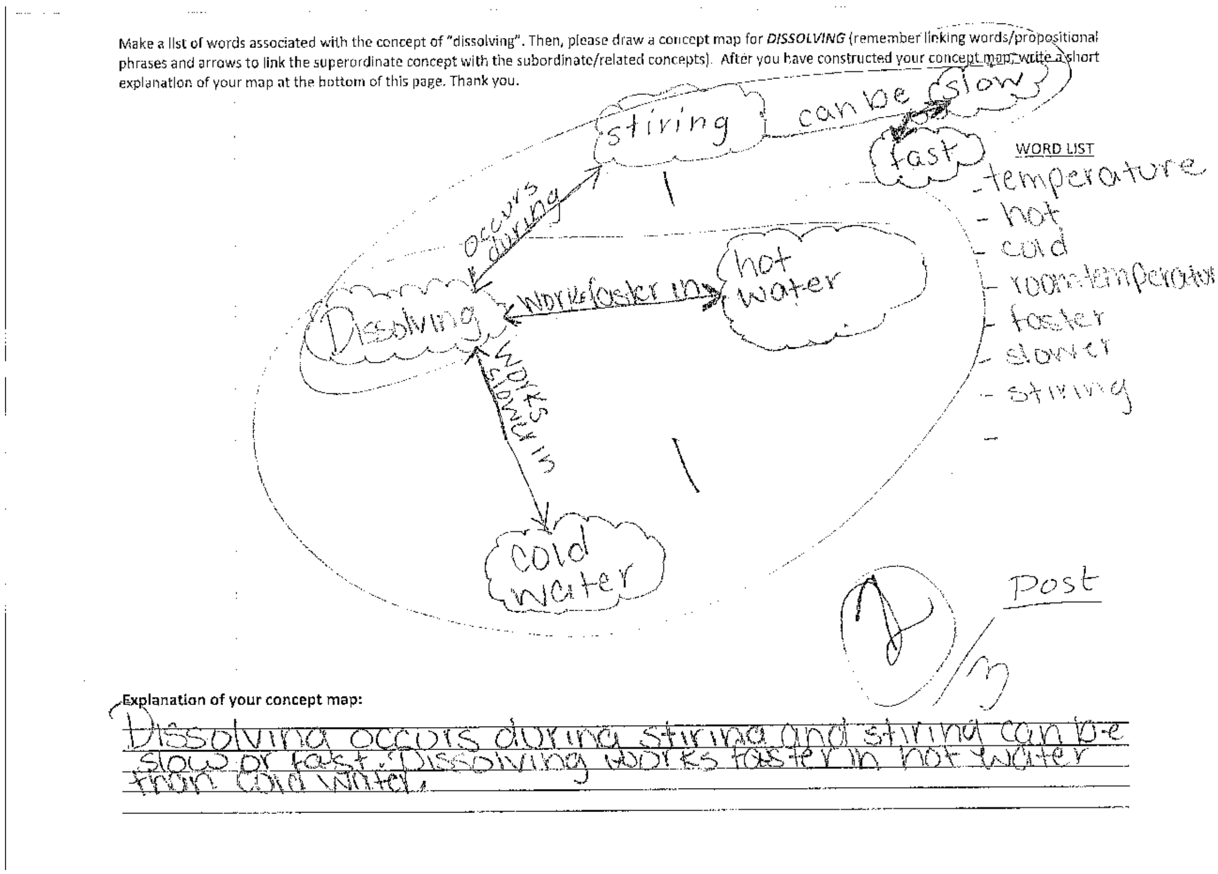
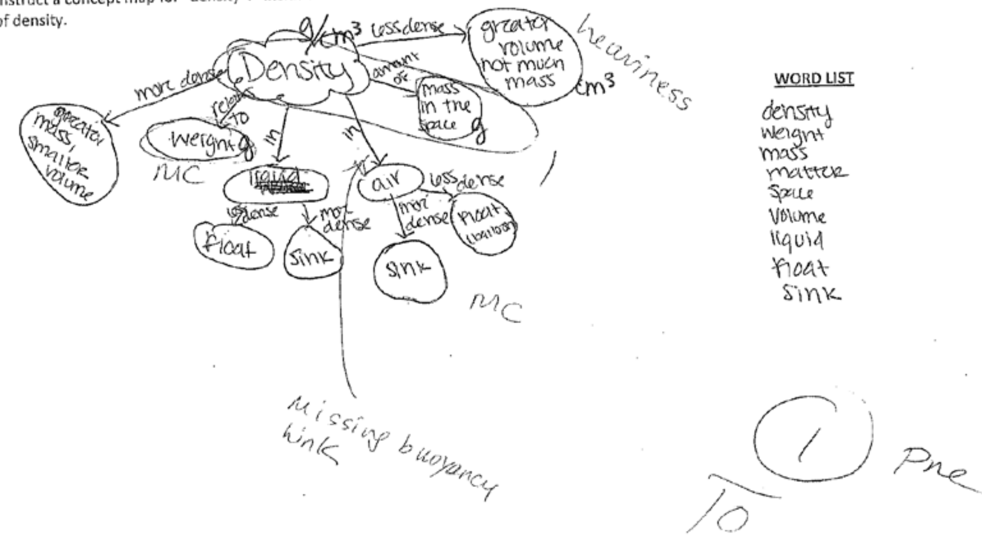


Figure B2. Preservice teacher post-concept map for dissolving.

Please construct a concept map for "density". Include arrows with linking words / propositional phrases and a short narrative explaining your concept of density.



Explanation of concept map:

Density relates to the amount of mass in a given space. If an item is heavy and more condensed it has a greater density. If another item had the same mass but greater volume it would have a smaller density. If an object sinks it has a greater density than the substance surrounding it. If an object floats it is less dense than the matter surrounding it. Boats (if successful) are less dense (bouyant) than the water they are in. MC

Figure B3. Preservice teacher pre-concept map for density.

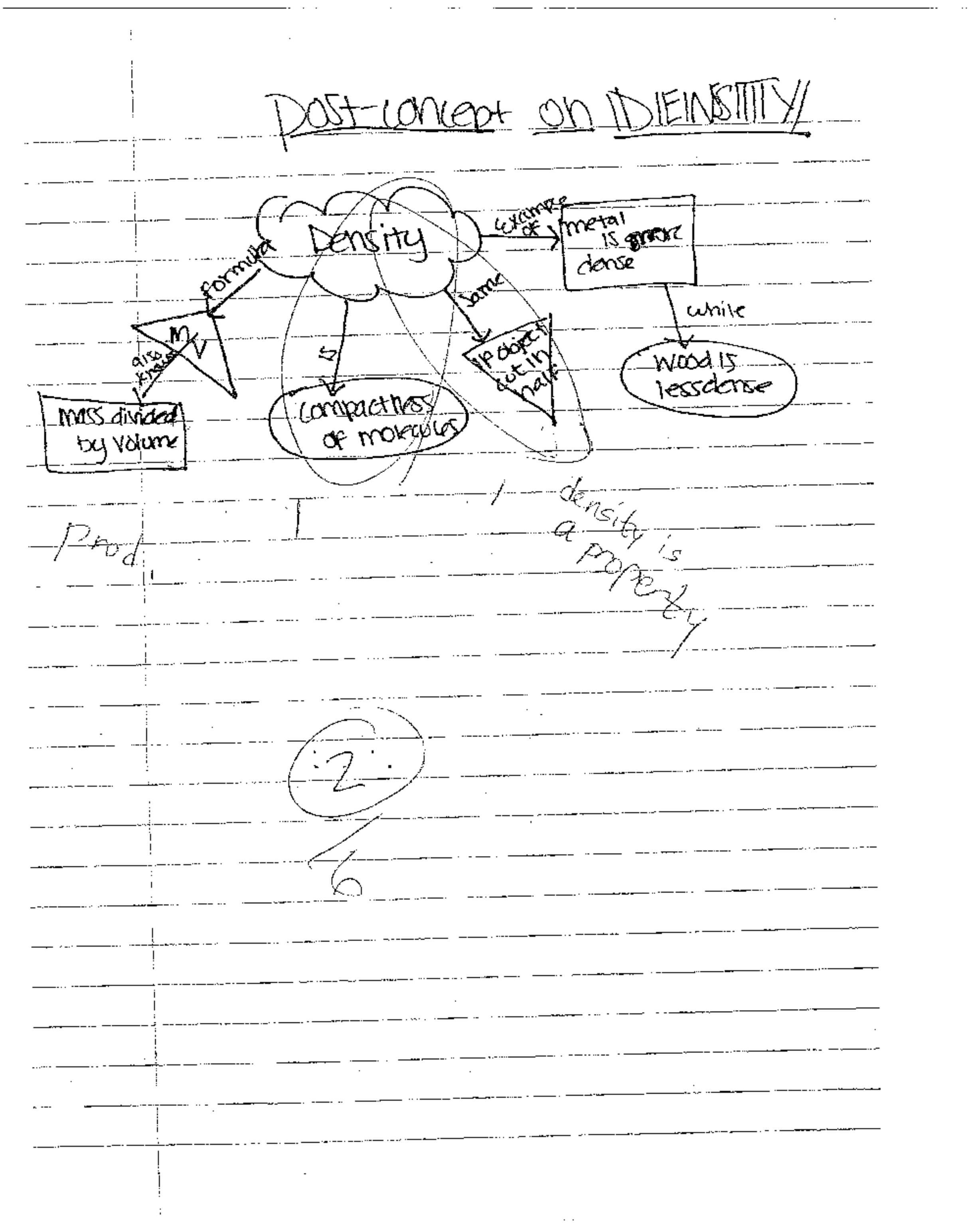


Figure B4. Preservice teacher post-concept map for density.

APPENDIX C

PILOT STUDY DATA TABLES FOR SCIENCE COURSE WORK TAKEN BY PARTICIPANTS

Table C1

Fall 2011 Pilot Study: Courses Taken by Elementary Preservice Teachers

	Student *n*	Grade *n*
Anatomy & Physiology I	1	1B
Anatomy & Physiology II	1	1C
Biology (Transfer Course)	17	5A, 5B, 7C
Biology for Educators	38	7A, 20B, 11C
Chemistry (Transfer Course)	1	1B
Conceptual Physics	57	19A, 20B, 16C, 2D
Contemporary Biology	1	1B
Context of Chemistry	1	1A
Descriptive Astronomy	4	1B, 3D
Earth Science	62	15A, 26B, 19C, 2D
Environmental Science	52	13A, 26B, 12C, 1D
Essentials Chemistry	1	1C
General Chemistry	1	1D
Geology (Transfer Course)	2	1B, 1C
Introduction to Physics	5	3C, 1A, 1B
Physical Geology	5	1C, 2B, 2C
Principle Biology I	5	3C, 1A, 1D
Principle Biology II	4	1B, 2A, 1D
Solar Systems	2	2C
Stars and the Universe	1	1C
Stellar System Observation	2	1C, 1A
World Regional Geography	1	1D

(table continues)

Table continued.

	Student *n*	Grade *n*
Biology (Transfer Course)	1	1C
Context of Chemistry	1	1A
Earth Science	7	3A, 4B
Environmental Science	7	5A, 2C
General Chemistry Science I	6	1B, 3C, 2D
General Chemistry Science II	5	2A, 1B, 2D
General Physics I	6	1A, 3B, 2C
General Physics II	5	1A, 1B, 3C
Geology (Transfer Course)	1	1A
Honors Principles of Biology II	1	1B
Human Anatomy & Physiology I	1	1B
Human Anatomy & Physiology II	2	1B, 1D
Mechanics	1	1C
Organic Chemistry	3	2B, 1NP
Physical Geology	1	1A
Principles of Biology I	74	5B, 2C
Principles of Biology II	4	2A, 1B, 1D
Solar System	6	4A, 1B, 1C
Starts & the Universe	1	1B

APPENDIX D

PILOT STUDY DATA TABLES FOR CONCEPT MAP SCORES FOR DISSOLVING PER ELEMENTARY PRESERVICE TEACHER

Table D1

Pilot Study Total Proposition Accuracy (TPA) Scores for Teacher 1–Elementary For Dissolving

TPA Score for Density	
Pre	Post
MLP	MLP
MLP	MLP
MLP	MLP
0	1
MLP	2
MLP	MLP
MLP	MLP
MLP	MLP
MLP	MLP
MLP	MLP
MLP	2
MLP	MLP
MLP	MLP

TPA Score for Dissolving	
Pre	Post
2	0
0	MLP
0	7
MLP	MLP
0	5
3	2
5	MLP
MLP	MLP
1	MLP
MLP	MLP
MLP	MLP

Note. *MLP designates a concept map that cannot be scored because it has a missing linking phrase.

Table D2

Pilot Study Total Proposition Accuracy (TPA) Scores for Teacher 1–Middle School

TPA Score for Density		TPA Score for Dissolving	
Pre	Post	Pre	Post
MLP	9	MLP	3
0	3	4	13
4	2	0	MLP
MLP	MLP	6	8
MLP	MLP	2	MLP
8	MLP	MLP	MLP

Note. *MLP designates a concept map that cannot be scored because it has a missing linking phrase.

Table D3

Pilot Study Total Proposition Accuracy (TPA) Scores for Teacher 2–Elementary

TPA Score for Density	
Pre	Post
0	3
1	6
0	4
0	0
0	1
0	5
0	0
1	6
1	13
1	5
0	0
0	5
4	5
0	3
0	11
0	7
0	0
0	7

TPA Score for Dissolving	
Pre	Post
0	0
0	0
0	0
6	9
0	8
0	9
0	0
2	3
0	8
1	17
0	0
0	0
7	MLP
0	8
3	9
0	0
0	2
0	0
0	11
0	9
MLP	MLP
0	11

Note. *MLP designates a concept map that cannot be scored because it has a missing linking phrase.

Table D4

Pilot study Total Proposition Accuracy (TPA) Scores for Teacher 3–Elementary

TPA Score for Density	
Pre	Post
MLP	3
1	6
0	1
MLP	2
0	2
MLP	0
-	-
-	-
-	-
0	5
MLP	MLP
0	1
0	1
0	1
0	4
0	1
0	4
0	1
0	0

TPA Score for Dissolving	
Pre	Post
MLP	MLP
MLP	MLP
MLP	0
0	1
0	MLP
MLP	3
3	10
MLP	5
MLP	MLP
MLP	MLP
MLP	MLP
0	0
MLP	MLP
MLP	3
MLP	MLP
MLP	MLP
0	0
0	0
MLP	1
MLP	MLP

Note. *MLP designates a concept map that cannot be scored because it has a missing linking phrase.

APPENDIX E

SPRING 2012 SCIENCE COURSE WORK TAKEN BY PARTICIPANTS

Table E1

Spring 2012 Research Study: Courses Taken by Elementary Preservice Teachers

	Student *n*	Grade *n*
Anatomy & Physiology I	1	1B
Biology for Educators	33	5A, 18B, 9C, 1D
Biology for Elementary Educators	1	1C
Biology (Transfer Course)	20	4A, 6B, 10C
Chemistry (Transfer Course)	1	1B
Conceptual Physics	57	19A, 22B, 13C, 3D
Descriptive Astronomy	1	1A
Earth Science	55	19A, 22B, 14C
Environmental Science	57	26A, 22B, 8C, 1D
General Chemistry	2	1C, 1B
General Physics I	1	1B
Geo-Culture: Environment & Society	1	1C
Geology (Transfer Course)	2	1B, 1C
Introduction to Physics	1	1B
Physical Geology	1	1A
Physics: Special Problem	1	1C
Plant Biology	1	1C
Principle of Biology I	4	1A, 2C, 1D
Principle of Biology II	3	2A, 1C
Solar System Observation	1	1A
Solar Systems	1	1A
Stars & the Universe	2	1A, 1D
Stellar System Observation	1	1A

APPENDIX F

SPRING 2012 RESULTS FOR CONCEPT MAP SCORES

Table F1

*Spring 2012 Study: Total Proposition Accuracy (TPA) Scores for Dissolving (*n *= 61)*

Pre-concept Map Score	Post-concept Map Score
0	0
0	0
2	1
0	1
0	2
2	3
0	3
1	3
0	2
0	1
0	0
0	0
0	0
0	0
0	2
1	6
0	2
4	2
0	2
0	2
0	2
0	1
5	4
0	0
4	7
1	1
0	1
1	1
0	0
0	3
0	1
0	0
0	3
0	0
0	2
0	1
0	0
0	0
0	0
3	2
1	7
1	1
1	1
0	1
0	2
0	0
3	5
0	7
0	3
0	1
0	3
0	1
0	0
1	2
0	1
0	1
0	0
0	2
0	2
0	1
2	3

Table F2

*Spring 2012 Study: Total Proposition Accuracy (TPA) Scores for Density (*n *= 61)*

Pre-concept Map Score	Post-concept Map Score
0	0
0	1
1	3
1	1
0	1
2	1
1	0
0	1
0	1
0	1
0	0
1	1
1	2
2	2
1	2
0	1
3	1
2	0
2	0
1	1
1	2
1	2
0	0
0	1
0	0
3	5
0	2
0	0
0	0
0	1
0	0
0	0
0	0
0	3
0	0
0	1
0	0
1	0
1	2
0	1
0	2
0	0
0	1
0	1
0	2

(table continues)

Table continued.

Pre-concept Map Score	Post-concept Map Score
2	2
1	0
0	1
1	0
1	0
0	0
0	0
0	0
1	2
0	0
0	2
0	3
1	2
2	1
0	0
0	0

Table F3

Legend for Table G4

Dissolving Misconception	Symbol
Prehydration	A
Prechange of State	B
Predisappear	C
Prebreak	D
Premixing	E
Prechem	F
Premelting	G
Posthydration	H
Postchange of state	I
Postdisappear	J
Postbreak	K
Postmixing	O
Postchem	P
Postmelting	Q

Table F4

*Spring 2012 Study: SPSS Categorization of Concepts/Misconceptions for Dissolving (*n *= 61)*

Student	A	B	C	D	E	F	G	H	I	J	K	O	P	Q
1	0	0	1	1	0	1	0	0	1	0	1	0	0	0
2	0	1	0	0	0	0	1	0	0	0	0	1	0	0
3	0	1	1	1	1	0	0	0	0	1	1	0	0	0
4	0	1	0	0	0	1	0	0	0	0	0	1	0	0
5	0	0	1	0	1	0	0	0	0	0	0	0	0	0
6	0	0	0	0	1	0	0	0	0	0	0	1	0	0
7	0	0	1	1	0	0	0	0	0	1	1	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	1	0	0	0	0	0	0	1	0	0	0
10	0	0	0	0	1	0	0	0	0	0	0	1	0	0
11	0	0	0	1	1	0	0	0	0	0	0	0	0	0
12	0	0	0	1	0	0	0	0	0	0	1	1	0	0
13	0	0	0	0	1	0	0	0	0	0	0	1	0	0
14	0	0	0	1	1	0	0	0	0	0	0	1	0	0
15	0	1	1	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	1	1	0	0	0	0	0	0	0	0
17	0	0	0	0	1	0	1	0	0	0	0	0	0	0
18	0	1	0	0	1	0	0	0	0	0	0	0	0	0
19	0	0	0	0	1	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	1	1	0
21	0	0	1	0	1	0	0	0	1	0	0	0	0	0
22	0	0	0	0	1	0	0	0	0	0	0	1	1	0
23	0	0	0	0	0	0	0	1	0	0	1	0	0	0
24	0	0	1	0	1	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0	0	1	0	0
26	0	0	1	0	1	0	0	0	0	0	0	1	0	1
27	0	0	0	0	1	0	0	0	0	0	0	1	0	0
28	0	0	0	0	1	0	0	0	0	0	0	1	0	0
29	0	0	1	0	0	0	0	0	0	0	0	0	0	0
30	0	1	1	0	0	0	0	0	0	0	0	0	0	0
31	0	0	0	1	0	0	0	0	0	0	0	0	0	0
32	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0	0	0	0	1	0	0	0
34	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35	0	1	1	0	0	0	1	0	0	0	0	0	0	0
36	0	1	0	1	0	0	0	0	1	0	0	0	0	0
37	0	1	0	1	0	0	0	0	0	0	0	0	0	0
38	0	0	0	0	0	0	0	0	0	0	0	0	0	0
39	0	0	0	0	0	0	0	0	0	0	0	0	0	0
40	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41	0	0	0	0	1	0	0	0	0	0	1	0	0	0
42	0	0	0	0	0	1	0	0	1	0	0	0	0	0
43	0	1	0	1	0	0	0	0	0	0	1	0	0	0
44	0	0	0	0	1	0	0	0	0	0	0	0	0	0
45	0	0	0	0	0	0	0	0	0	0	0	0	0	0
46	0	1	0	0	0	0	0	0	1	0	0	0	0	0
47	0	0	0	0	0	0	0	0	0	0	1	0	0	0
48	0	1	0	0	0	0	0	1	0	0	0	0	0	0
49	0	0	0	0	1	0	0	0	0	0	0	0	0	0
50	0	0	0	1	1	1	0	0	0	0	1	0	1	0
51	0	0	1	1	0	0	0	0	0	1	0	0	0	0
52	0	1	0	0	0	1	0	0	0	0	0	0	0	0
53	0	0	0	0	0	0	0	0	0	0	0	0	0	0
54	0	0	0	0	0	1	0	1	0	0	0	0	0	0
55	0	0	1	0	1	0	0	0	0	0	0	0	0	0
56	0	0	0	1	0	1	0	0	0	1	0	0	1	0
57	0	0	1	0	1	0	1	0	0	0	0	0	0	0
58	0	0	0	0	0	1	0	0	0	0	0	0	1	0
59	0	1	0	0	0	0	0	0	1	0	0	0	0	0
60	0	1	0	0	1	0	0	0	0	0	1	0	0	0
61	0	0	1	0	1	0	0	0	0	0	0	1	0	0

Table F5

Legend for Table G6

Density Misconception	Symbol
PrehHeaviness	A
PrebBuoyancy	B
Preformula	C
Preproperty	D
Precompact	E
Presize	F
Premass/Weight	G
Prechange of State	H
Postheaviness	I
Postbuoyancy	J
Postformula	K
Postproperty	L
Postcompact	M
PostsSize	N
Postmass/Weight	O
Postchange of State	P

Table F6

*Spring 2012 Study: SPSS Categorization of Concepts/Misconceptions for Density (*n *= 58)*

Student	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	1	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0
2	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0
3	0	0	0	0	0	0	1	0	1	0	1	0	0	0	1	0
4	1	1	0	1	0	0	0	0	1	0	1	0	0	0	0	0
5	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
6	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0
7	0	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0
8	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0
9	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0
10	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0
11	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0
12	1	1	1	0	0	0	0	1	1	1	1	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0
14	0	0	1	0	1	0	0	0	0	0	1	0	1	0	0	0
15	0	1	0	1	0	0	0	0	0	1	0	0	0	0	0	0
16	1	0	0	0	0	0	1	1	0	1	0	0	1	0	0	0
17	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0
18	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0
19	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	1	1	0	0	0	0	1	0	0	1	0	0	0	0	0
21	1	0	1	0	1	0	0	0	0	1	1	0	0	1	0	0
22	0	1	1	1	0	0	0	0	0	1	1	0	0	0	0	0
23	1	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0
24	0	1	0	0	0	0	0	0	0	1	1	0	0	0	0	0
25	0	1	0	0	1	0	0	1	0	0	0	0	0	0	0	0
26	1	1	1	0	0	0	0	0	0	0	1	0	0	0	0	0
27	1	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0
28	1	0	0	0	0	1	0	0	1	1	0	0	0	0	0	0
29	0	1	0	0	0	0	0	0	1	1	0	0	0	1	0	0
30	1	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0
31	0	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0
32	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0
33	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0
34	1	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0
35	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36	0	1	0	0	0	1	0	0	0	0	1	0	0	0	0	0
37	0	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0
38	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0
39	0	1	0	0	0	0	0	0	0	1	1	0	0	0	0	0
40	1	1	0	0	0	0	0	0	1	0	1	0	0	0	0	0
41	1	1	0	0	0	0	0	0	0	1	1	0	1	0	0	0
42	1	0	0	0	0	1	0	0	1	1	0	0	0	0	0	0
43	1	1	0	0	0	0	0	0	1	0	1	0	0	0	0	0
44	1	1	0	0	0	0	0	0	1	0	1	0	0	0	0	0
45	1	1	0	0	0	0	0	0	0	1	1	0	0	0	0	0
46	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0
47	1	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0
48	1	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0
49	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	1
50	1	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0
51	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0
52	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
53	0	1	1	0	0	0	0	0	0	0	1	0	0	0	0	0
54	0	0	1	0	0	0	0	0	0	0	1	0	1	0	0	1
55	1	1	0	0	0	0	0	0	0	0	1	0	1	0	0	0
56	0	1	0	0	0	0	0	0	0	0	1	0	1	0	0	0
57	1	1	0	0	0	0	0	0	1	0	1	0	0	0	0	0
58	1	1	0	0	0	0	0	0	0	0	1	0	1	0	0	0

APPENDIX G

SAMPLES OF PRESERVICE TEACHERS' DRAWINGS FROM FINAL EXAMS

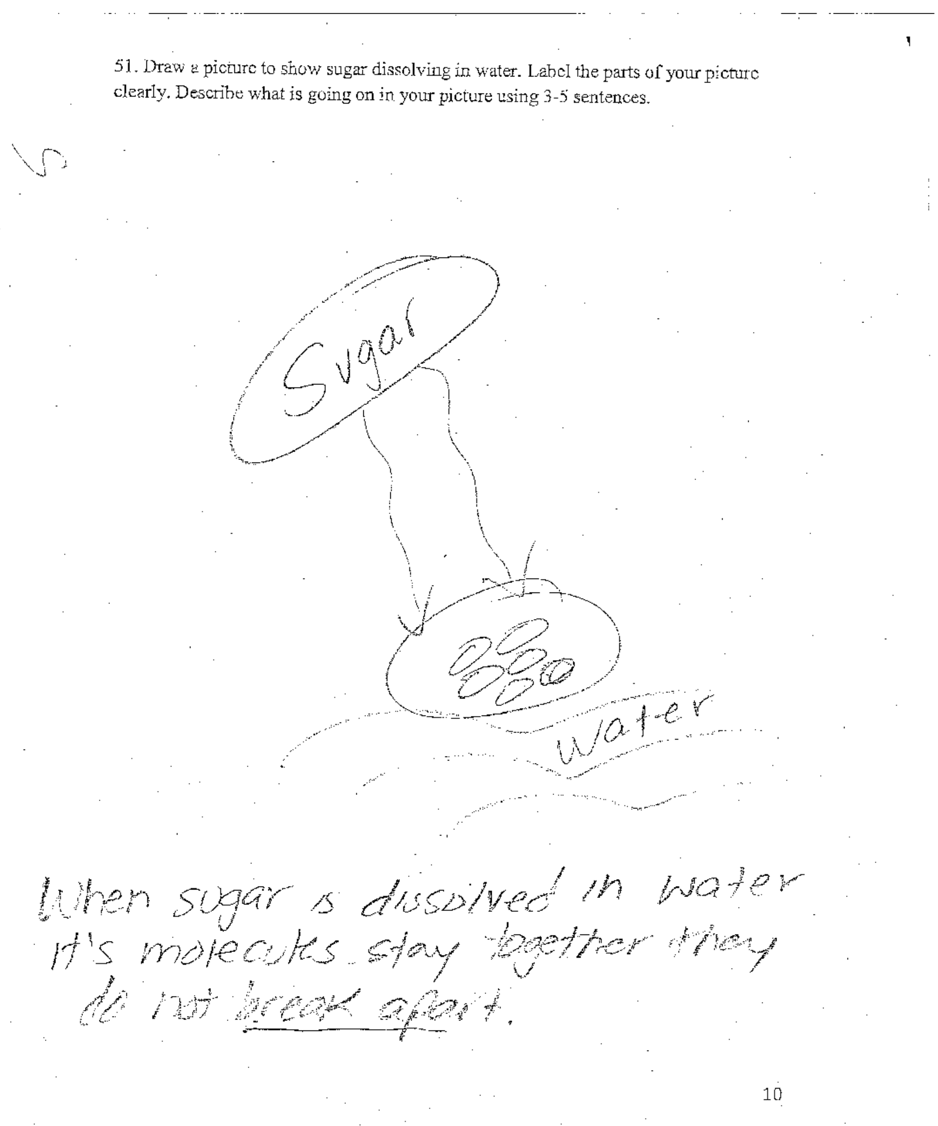


Figure G1. Preservice teacher sample drawing for dissolving sugar.

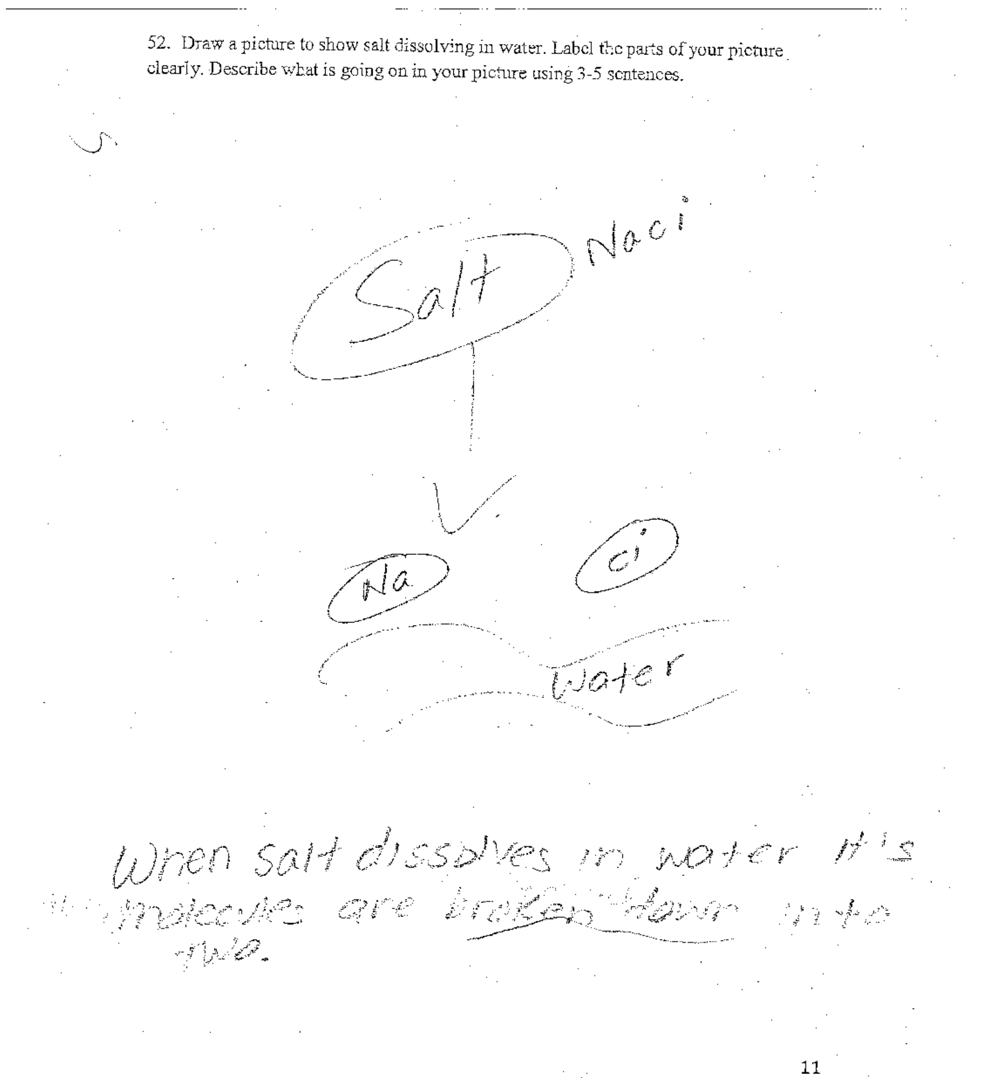


Figure G2. Preservice teacher sample drawing for dissolving salt.

APPENDIX H

CONCEPTUAL DEVELOPMENT TABLE USING CODES FROM TRIANGULATED DATA

Table H1

Spring 2012 Dissolving Summary Table for Triangulated Data

#	Nonsense	Physical Breakdown	Mix	Chemical Breakdown	Change of State	Disappear	Melt	Rate	Academic Vocabulary	Solubility	Hydration Shell	Non Example	SLC
1				W PRCM POCM	POI M			W POI POCM	PRI D M POCM				N-E
2	POI M		PRCM POCM W	PRI POCM				W POCM	M	PRI W PRCM POCM	W	W	N-E
3	W M	POI	PRI PRCM	POI		D		W POI POCM	M	PRI PRCM			N-E
4	W M	PRI POI M D		D PRCM	PRCM POCM PRI POI			W POCM	W M	POCM			N-E
5	M W		M W POCM		PRCM		M	W		POCM			N-E
6	M PRI W	D	W D	M				PRI W POI D PRCM POCM	M PRCM	D PRCM POCM			N-E
7	W D		POI M	PRI POI W M PRCM POCM				W POI POCM		POCM		POI	N-E
8		POI M	PRI M POCM PRCM	POI				W POI	PRI POI W M POCM	W POCM	W		N-E

(table continues)

Table continued.

#	Nonsense	Physical Breakdown	Mix	Chemical Breakdown	Change of State	Disappear	Melt	Rate	Academic Vocabulary	Solubility	Hydration Shell	Non Example	SLC
9		W	PRI W POI	W M				POI PRI W POCM	W D PRCM M	W POI			N-E
10	M	PRCM	POI PRI M POCM	PRCM	PRI PRCM			W POI PRCM POCM	PRI POI D		D		N-E
11	W D	POI	PRCM	W M POI					PRI W M PRCM		D		N-E
12	W M	D PRCM			PRCM	PRI POI PRCM W M		PRI POI W	PRI	POCM			N-E
13	W M	PRI POI PRCM	POI PRCM POCM	M				W POCM	W	W POCM		POCM	N-E
14	W M POCM	PRI M						W	POCM				N-E
15	W POCM	PRI POI W POCM		PRI				PRI POI W PRCM POCM	D M W POI POCM	W POI PRCM	W		N-E
16	W M		POI D PRI W PRCM POCM	W POI POCM				POCM	M			POCM W POI	N-E

(table continues)

Table continued.

#	Nonsense	Physical Breakdown	Mix	Chemical Breakdown	Change of State	Disappear	Melt	Rate	Academic Vocabulary	Solubility	Hydration Shell	Non Example	SLC
17	M	M POCM	W	W D				POCM				W	N
18	W	M		M				W PRCM POCM	W M	W POCM			E
19	M	W PRCM	PRI POI M					W POCM	M	W		W	N-E
20	PRCM POCM	W D	PRCM POCM	M		D		PRI W POI	M	W POCM	W		N-E
21	W M	POCM	PRCM	W POCM	PRCM			PRI PRCM	POI M PRCM		D	W	N-E
22	PRI W	W POI M PRCM POCM	W		PRI POI PRCM			W POI POCM	D M		D		N-E
23	M PRCM	W	POI					W POCM	W D M	W			N-E
24	W D	W M		PRI M PRCM	PRI POI			PRI POI W PRCM POCM	PRCM POCM	W	W		N-E
25		POI	POCM	PRI W PRCM	PRI			W POI PRCM POCM	W M	W POI	D POCM	POI POCM	N-E
26	M							W POI POCM	M PRCM POCM		W POI	W	E

(table continues)

Table continued.

#	Nonsense	Physical Breakdown	Mix	Chemical Breakdown	Change of State	Disappear	Melt	Rate	Academic Vocabulary	Solubility	Hydration Shell	Non Example	SLC
27	M			M				PRI W POI PRCM POCM	PRI POI W D M PRCM POCM		W POI POCM		E-S
28	M	PRI PRCM	W PRCM					W POI POCM	W M	W POI POCM	POI		E-S
29	W	PRI POI M PRCM	W					W POI	M	W			N-E
30	W M	D	PRI POI D PRCM	PRI POI PRCM				W POI	M	W POCM		W POCM	N-E
31	W D M PRCM	POI		M		PRI		POI	M	W POI			N-E
32	W M	PRI POI M PRCM POCM		POI		W PRCM POCM		PRI POCM	POCM		D		N-E
33	W M POCM	PRCM	POI M PRCM	PRI				W POI	POI				N-E
34	PRI POI D M POCM		PRCM POCM	W		W		W D POCM	M		W		N-E

(table continues)

Table continued.

#	Nonsense	Physical Breakdown	Mix	Chemical Breakdown	Change of State	Disappear	Melt	Rate	Academic Vocabulary	Solubility	Hydration Shell	Non Example	SLC
35	W M PRCM	PRI POI	D	PRI				POI D	D	W POCM			N-E
36	W M	PRI POI POCM PRCM	PRI W POI M POCM	PRI PRCM	PRI			W POI POCM	M	W POI			N-E
37	M	W POI		W				W POI POCM PRCM	PRI POI M PRCM	W POCM	POI D POCM	POCM POI	N-E
38	W M	D			PRI	PRI PRCM	PRCM	W POI POCM PRCM	M	W POCM			N-E
39	M	M			PRCM	PRCM		W POCM	W M		W	W	E
40	PRI W				PRI POI M PRCM POCM			W	D M	W	D		E-S
41	W M	W D	PRI POI PRCM POCM			PRCM		PRI POI W PRCM POCM	M		D	POCM POI	N-E
42	W D M	W D	PRI PRCM	W				W POI POCM	W				N-E
43	W	PRI POI M PRCM POCM	W			PRI PRCM POCM		W POI POCM		W POI POCM			N-E

(table continues)

Table continued.

#	Nonsense	Physical Breakdown	Mix	Chemical Breakdown	Change of State	Disappear	Melt	Rate	Academic Vocabulary	Solubility	Hydration Shell	Non Example	SLC
44	W M	PRI POI POCM		PRI PRCM	POCM POI	PRCM		W POI POCM	W	POI POCM		POCM	N-E
45	W		W PRCM			PRCM		W POCM	M	POCM			E
46	W D M POCM	D PRCM	PRI POI W M PRCM					POI		POCM			N-E
47	W M		POI M POCM	PRI PRCM	PRCM PRI	W		W POI POCM		POCM		POCM POI	N-E
48	W M	PRI POI D PRCM POCM W	W		W PRCM			W POI PRCM	M	PRI POCM	D		N-E
49	PRI W M POCM		PRCM	POI D		PRCM		POI	W				N-E
50	W M	PRI D	W POI M PRCM		PRI PRCM	PRI PRCM		W POI POCM	POCM	W POCM			N-E
51	W D M PRCM POCM	D				POI		PRI W POI	M	W POI POCM			N-E
52	M	PRI POI D	W	PRCM				W POI PRCM POCM	M	W			N-E
53		POI D	PRCM	W POCM	PRI		PRCM	W POI PRCM	M			W POI POCM	N-E

(table continues)

Table continued.

#	Nonsense	Physical Breakdown	Mix	Chemical breakdown	Change of State	Disappear	Melt	Rate	Academic Vocabulary	Solubility	Hydration Shell	Non Example	SLC
54	W POI M PRCM	POCM		PRI W D M POCM	POI			W POI POCM	M		W		N-E
55	PRI POI M	PRI POI	POI D	PRI W PRCM	PRI	PRI POI		W POI POCM		POCM			N-E
56	W M	D	PRI W POI POCM	PRI M POCM	PRI POI PRCM	PRI	POCM	PRI W	M	POI			N-E
57		PRCM		M POCM					M PRCM				N
58	D PRCM	PRI POI POCM	W	PRI D				W POCM POI	M	W			N-E
59	PRI POI W M	W	PRCM POCM	PRCM				POI	PRI W M	W			N-E
60	W	D M PRCM	PRCM	W PRCM POCM		PRCM		W	W M			POCM	N-E
61			W	POCM	PRI			PRI POI W PRCM POCM	W M POCM	W	D POCM	POCM	N-E
62	M		PRCM	PRI W D M POCM			PRCM	POI POCM	POI POCM	POI	D	POCM	N-E
63	W M	W PRCM						PRI W D PRCM POCM	M	PRI POI POCM			E

(table continues)

Table continued.

#	Nonsense	Physical Breakdown	Mix	Chemical breakdown	Change of State	Disappear	Melt	Rate	Academic Vocabulary	Solubility	Hydration Shell	Non Example	SLC
64	W POI M	PRI PRCM	PRI POI W PRCM		PRI PRCM	PRI PRCM		W POI	M			POI POCM	N-E
65	W POI M		PRI PRCM	W M	PRI POI POCM D	PRCM PRI		W	M			POCM W POI	N-E

Note. W = writing artifact; M = midterm examination; D = drawing; PRI = pre-interview; POI = post-interview; PRCM = pre-concept map; POCM = post-concept map.

Table H2

Spring 2012 Density Summary Table for Triangulated Data

#	Non-sense	Buoyancy	Heavy	Mass/ Weight Confusion	Volume	Area	Change of State	Thickness	Formula	Proportional Reasoning	Property of Matter	Compact-ness	Nonproportional Reasoning	SLC
1	POI	PRI W POCM	PRI POI W PRCM	PRI POCM		W POC M			W POI POCM	W				N-E
2	W POI	PRI W POI PRCM POCM	W POI PRCM POCM	POCM	W				W POI POCM					N-E
3		W	PRI W PRCM			POI			W POI POCM	W				E
4	W	PRI W PRCM	PRI POI PRCM POCM						W POI POCM	POCM POI	POI			N-E
5	W	W PRCM POCM	PRCM POCM			W			W POCM	W				N-E
6	W	PRI PRCM POCM	PRI POI PRCM POCM				POI	W	W POI POCM	POCM POI				N-E
7	PRI W	W	W		PRI				PRI POI W PRCM POCM		PRI W POI	POI POCM		E
8			PRI W POI	POI					PRI. POI PRCM POCM W	W	W	PRI		N-E
9	W	PRI PRCM	PRI POCM		W				PRI POI W					N-E

(table continues)

Table continued.

#	Non-sense	Buoyancy	Heavy	Mass/ Weight Confusion	Volume	Area	Change of State	Thickness	Formula	Proportional Reasoning	Property of Matter	Compact-ness	Nonproportional Reasoning	SLC
10	W	PRI PRCM	W PRCM						PRI POI POCM	W		POI POCM		E
11	W								POCM					E
12	PRI W POCM	W POI PRCM			PRI			PRI POI	W					N-E
13	PRI POI POCM M	POI	PRCM						PRI POI W	W	POI	W	W	N-E
14	PRI POI W			PRCM					PRI W POI PRCM POCM	W	W			N-E
15	W	POI PRCM PRI	PRCM	PRI	W				W POI POCM	W				N-E
16	W POI	W POCM	W PRCM	PRI W PRCM		PRI POI PRCM POCM			PRI W POI PRCM POCM	W				N-E
17			PRI PRCM POCM		POI			POI	POI POCM					N-E
18	W POI PRCM	PRI PRCM POCM		POI					POCM	POCM W				N-E
19	W	PRI POI PRCM POCM						PRI POI	PRI POI					N-E
20		POI POCM					PRI		W PRCM POCM		PRI			N-E

(table continues)

Table continued.

#	Non-sense	Buoyancy	Heavy	Mass/ Weight Confusion	Volume	Area	Change of State	Thickness	Formula	Proportional Reasoning	Property of Matter	Compact-ness	Nonproportional Reasoning	SLC
21	W POI	PRI PRCM	PRI PRCM POCM			W			W POI POCM		W		W	N-E
22	W	PRCM	W PRCM POCM						W POCM	W		W	W	N-E
23	W POI	PRI POI PRCM POCM	W						PRI W POI POCM					N-E
24	W								W PRI POI PRCM POCM		POI PRCM		W	E-S
25	PRI W	POI POCM	POI PRCM POCM	POI	POI PRCM				PRI W	W				N
26	W POCM	PRI W PRCM	POI		POI								W	N
27	PRI W	POI POCM	PRI POI PRCM POCM	POI					POI POCM		W POI			N-E
28	W POI	POCM	W PRI POI PRCM POCM	PRI										N
29	W	PRI PRCM		PRCM POI					W PRI POI PRCM POCM	W		W		N-E
30	W		PRI				PRI POI PRCM POCM		PRI W	W		W POI POCM		N-E

(table continues)

Table continued.

#	Non-sense	Buoyancy	Heavy	Mass/ Weight Confusion	Volume	Area	Change of State	Thickness	Formula	Proportional Reasoning	Property of Matter	Compact-ness	Nonproportional Reasoning	SLC
31		W PRCM POCM	W	W		PRI PRCM			W POI POCM			POI POCM		N-E
32	W PRCM		PRI W PRCM POCM POI						W					N
33		PRI W POI PRCM POCM					POI		PRI PRCM POCM	POCM PRI W		PRI W POI PRCM POCM		N-E
34	PRI W	PRI W PRCM	PRI W POI PRCM POCM	PRI					PRI W POI POCM	W				N-E
35	PRI W	PRI W POI PRCM POCM			W				PRI W POI PRCM POCM				POCM	N-E
36	W	PRI POI PRCM	PRI W PRCM			W			PRI W POI POCM	PRCM POCM		PRI POI PRCM POCM	W	N-E
37	W PRCM	POCM							PRI POI POCM				POI	N-E
38	W	PRI POI PRCM POCM	PRI W POCM	POI	PRCM				POCM	W		PRI POI		N-E
39	POI	W POI PRCM	PRI PRCM POCM		W				POI POCM	W			W	N-E
40	W POI		W PRCM						PRI POI POCM	POCM	POI		W	N-E

(table continues)

Table continued.

#	Non-sense	Buoyancy	Heavy	Mass/ Weight Confusion	Volume	Area	Change of State	Thickness	Formula	Proportional Reasoning	Property of Matter	Compact-ness	Nonproportional Reasoning	SLC
41	PRI W POI	W	PRI W PRCM						PRI W POI POCM		POI			N-E
42	PRI W		PRI W PRCM POCM					PRI PRCM	W POI POCM		POI	POI POCM		N-E
43	W		PRCM						W POCM	W		W POCM		E
44	W POI		W PRCM POCM		PRI PRCM POCM									N
45	W PRI	POI POCM	POI PRCM POCM	PRI POCM					W PRI POI				W	N-E
46	W	POI POCM	PRI POI PRCM POCM		W				W POCM					N-E
47	W PRI	PRI POI PRCM POCM	POCM	PRCM	POCM	PRCM			W PRI POI					N-E
48	POI	POI POCM	PRI M PRCM				PRI PRCM	W PRI	W POI	W		W POCM		N-E
49	W POI POCM		W						W PRI PRCM					N
50	W PRI	PRI PRCM	W POI		PRI PRCM		POI POCM		W PRI POI POCM		POI		W	N-E
51	W PRI POI PRCM						PRI PRCM		PRI POI POCM		POCM	W POCM		N-E
52	W PRCM	PRCM			PRI				W POI POCM	PRCM POCM		POCM		E

(table continues)

Table continued.

#	Non-sense	Buoyancy	Heavy	Mass/ Weight Confusion	Volume	Area	Change of State	Thickness	Formula	Proportional Reasoning	Property of Matter	Compact-ness	Nonproportional Reasoning	SLC
53	W	PRI POI PRCM POCM	PRI POI POCM	POI					W			POI		N-E
54	PRI	POI POCM	POI PRCM				PRI PRCM		PRI PRCM POCM	W	W	POCM		N-E
55	PRI	PRI POI PRCM POCM	PRCM						POI POCM					N-E
56		PRI POI PRCM POCM	W						W POI POCM	W	PRI PRCM			N-E
57	W POI	PRI POI PRCM	POI POCM		POI				W	W		POCM	W	N-E
58	W	W PRCM	PRI W POI POCM	PRI W POI POCM					W POCM		W		W	N-E
59	W PRI POI	POI PRCM	POCM				PRCM POCM		PRI W PRCM POCM			POCM		N-E

Note. W = writing artifact; M = midterm examination; D = drawing; PRI = pre-interview; POI = post-interview; PRCM = pre-concept map; POCM = post-concept map.

Table H3

Spring 2012 Dissolving Writing Artifacts Emerging Themes Coding Table

Concept/Misconception	Description
Mixes (nonspecific)	Mix, absorb, fuse, integrates, goes into water
Physical Breakdown	Breaks down, pull apart, spread out, or separate
Chemical Breakdown	Involves breaking of bonds (chemical change)
Inaccurate Vocabulary	Uses academic vocabulary inaccurately
Nonsense	Does not answer the question, makes an observation, parrots, provides a nonsensical answer
Change of State	Describes dissolving as a change of state
Disappear	Describes dissolving as disappearance, dis-integrating, invisible
Melt	Describes dissolving as melting
Rate	Rate is affected by heat, physical agitation, amount and concentration.
Solubility	Confuses dissolving and solubility (uses soluble and insoluble to describe what dissolving is)
Academic Vocabulary	Uses academic vocabulary accurately
Non-example	Provides a non-example to answer the question on dissolving
Hydration Shell	Uses hydration shell accurately to describe the process of dissolving

Table H4

Spring 2012 Density Writing Artifacts Emerging Themes Coding Table

Concept/Misconception	Description
Buoyancy	Buoyancy floating sinking
Nonsense	Lacks intelligent meaning.
Heavy	Describes density in terms of mass or heft.
Mass/Weight Confusion	Confuses mass with weight
Volume	Describes density in terms of volume
Area	Uses area to describe volume
Thickness	Uses thickness to describes how dense a substance is
Change of State	Changes physical state.
Formula	Recognizes formula correctly D=M/V
Proportional Reasoning	Density is the amount of mass per volume, is a relationship between mass and volume or depends on mass and volume.
Property of Matter	Recognizes density as an intensive property of a substance.
Compactness	Characterizes particles as close, tight, or dense within a volume.
Nonproportional Reasoning	Confuses some aspect of proportional reasoning.

Table H5

Student Learning Code Symbols

SLC (Student Learning code)	Symbol
Nonscientific	N
Emerging	E
Scientific	S

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