

Teachers Need to Be Smarter Than A 5th Grader: What Elementary Pre-service Teachers Know About Density

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Abstract

This article details a study that investigated 55 elementary pre-service teachers' content knowledge about density. Using a mixed-methods approach, pre/post face-to-face interviews and pre/post concepts maps (Cmaps) were used as data to document changes in teacher knowledge which occurred over a 15-week science methods course. Thematic analysis was used to capture patterns within the interview data and a paired-sample *t*-test was conducted to compare pre/post Cmap scores. Results before instruction indicate a weak framework of prior knowledge about density which was a mosaic of alternative conceptions and a few learned concepts. Many participants focused on a single aspect of density and were unable to engage in relational causality which involves the consideration of two variables simultaneously. After instruction, robust alternative conceptions continued to be observed (e.g., density is buoyancy and density is the same as heaviness, mass, or weight) and learned concepts were concrete and rote. The most common learned concept was the density algorithm (~40%) followed by the learned concept that density is an intensive property of matter (22%) and demonstrated understandings of proportional reasoning (7%). Results of the paired sample *t*-test demonstrate a statistically significant difference between the total proposition accuracy scores for pre/post Cmaps ($t = -3.178$, $p < .002$) with the instructional intervention larger for post-Cmap scores ($M = 1.02$; $SD = 1.063$) than for pre-Cmap scores ($M = 0.55$; $SD = 0.812$). The effect size was medium.

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Introduction

Teacher content is a key variable associated with student achievement (Darling-Hammond, 1999; Hill, Rowan, & Ball 2005; National Commission on Teaching & America's Future, 1996) and new understanding is needed about elementary pre-service teacher content knowledge of science topics which are tied to state standards and the Next Generation Science Standards (National Research Council, 2013). While there have been numerous research studies

that address student understanding of important science concepts such as density, there are only a handful of studies that address common scientific understandings held by elementary pre-service teachers (Dawkins, Dickerson, McKinney, & Butler, 2008; Greenwood, 1996; Hamed, 2008; Hewson, 1978; Stepan, Dyche, & Beiswenger, 1988) (See Appendix A).

This research effort aimed to address this gap in the literature using pre/post concept maps and interviews associated with an instructional intervention designed to investigate elementary pre-service teacher conceptual understanding of density. Specifically, the purpose of this study was to assess understanding about density as measured using the hierarchical organization of the concept map as an indicator of content knowledge and depth (Novak, 2010) and to classify concept type as abstract scientific concepts and spontaneous concepts (concrete concepts) using Vygotsky's theory of concept development (1986).

Literature Review

Density

The Scientific Concept of Density. According to Considine (2005) density is an intensive property of a substance which is expressed as a ratio of its mass to its volume. That is, density cannot be directly perceived or measured as it is a relationship. Density is algorithmically expressed as $D = M/V$. The units for density are also expressed in this relationship, for example, g/cm^3 . The density of most materials varies with temperature and pressure, and for this reason precise measurements of density take these variables into account.

At the particle level, differences in density are a function of atomic mass in relation to the closeness or compactness of bonding within a given volume (Considine, 2005). The greater the atomic mass of a given material per unit of volume, the more dense the material.

Equally important and underlying the concept of density is the idea that matter has weight and takes up space. Even when matter is not visible, it continues to exist maintaining its identity. For instance, when a sample of material is divided in half, then divided in half again and again to the point of not being visible, it will continue to have mass and take up space. In terms of the M/V ratio, the big mathematical idea in this example is that the ratio of one part of the substance to another part of the substance is invariant due to the values of both quantities changing by the same factor (Lobato, Ellis, & Zbiek, 2010). That is, the substance will continue to retain the characteristic property of density when pressure and temperature are held constant (Lehrer, Schauble, Strom, & Pligg, 2001).

Alternative Conceptions about Density. Common alternative conceptions held by K-12 students related to density originate with a confusion of density with the concept of heaviness, mass, or weight (Dawkins et al., 2008; Hewson, 1978; Penner & Klahr, 1996; Smith, Carey, & Wisner, 1985; Smith, Snir, & Grosslight 1992; Tasdere & Ercan, 2011). The meaning of the academic vocabulary as well as the idea that heavier objects sink while lighter objects float or that mass, weight, or heaviness are equivalent set the stage for difficulty in understanding the two dimensional nature of density. K-12 students and teachers alike hold extensive views of density reducing the two variables of mass and volume to one variable depending on the context involved. For example, density is attributed to mass on its own (heaviness of objects) or volume

on its own (size) rather than determined by both mass and volume (Carey, 1985; Hewson, 1978; Kind, 2004; Pick & Pick, 1967; Schmidt, 1997; Shavelson, 2006; Smith et al., 1985; Smith, et al, 1997; Smith & Unger 1997; Viennot, 1993).

A common, but incomplete understanding of density is use of the density formula. Dawkins and her colleagues (2008) found that many middle school pre-service teachers did not share a fully differentiated concept of density. Rather, these pre-service teachers were able to recite the algorithm for density, and/or perform calculations with the density formula, but failed to understand density as a property of material kind (Dawkins et al., 2008).

Another source of confusion about density includes the standard density experiments that involve floating and sinking (Rohrig, 2001). Although the Archimedes principle clearly makes the connection between buoyancy and density, showing how the two concepts are related, students of all ages struggle with making this connection. Students often report that density is what determines whether an object sinks or floats whereas the correct scientific notion is to state that it is buoyancy that determines whether an object will sink or float (Dawkins et al., 2008; Kohn, 1993; Penner & Klahr, 1996; Tasdere & Ercan, 2011). The formula for Buoyant Force can be expressed as: $V \times \rho \times g$ where V is the volume of fluid displaced, ρ is the density of the fluid and g is gravity. In essence the buoyant force is equal to the weight of the fluid displaced. As such, weight of the object is related to buoyancy, not the density of the object. K-12 students' and teachers' alternative conceptions, as such, derive from confusing the relationship of weight of an object to its density.

Frameworks

The theoretical frameworks used in this study include the theory of concept development (Vygotsky, 1986) and concept mapping (Novak & Gowin, 1984) which is based on meaningful learning theory (Ausubel, 1968). These theories are used to bridge the gap between lower and higher mental function using various psychological tools that include the use of language and, "various systems for counting; mnemonic techniques; algebraic symbol systems; works of art; writing; schemes, diagrams, maps, and technical drawings; all sorts of conventional signs, and so on" (Vygotsky, 1981, p 137).

Vygotsky's Theory of Concept Development. Vygotsky (1986) described the way individuals understand everyday phenomena through social interactions. According to Vygotsky, children understand natural phenomena through practical activities encountered through everyday life. These concepts are called spontaneous concepts which: (1) originate from concrete everyday activities; (2) are acquired in a non-systematic fashion; and (3) develop from the bottom up. However, the derivation of knowledge of the world through real-life interactions falls substantially short of scientific understanding. For this reason, the typical individual will not be able to understand or explain scientific phenomena.

In contrast to spontaneous concepts, Vygotsky characterized scientific concepts as abstract, and systematically presented and developed. Scientific concepts begin with a verbal explanation that is connected to the child's concrete experiences (spontaneous concepts). Scientific concepts (1) originate from explicit instruction; (2) exist as a unified system of interrelated ideas; and (3) develop from top-down. This type of systematic, hierarchical

organization is marked by voluntary control, the ability to think abstractly and to generalize a concept across multiple contexts.

In addition to the above mentioned differences between spontaneous and scientific concepts, there is, at the same time, a reciprocal dependence which is expressed between spontaneous and scientific concepts (Vygotsky, 1986). Hence, there is simultaneous bottom-up and top-down development. When instruction is used to elevate student understanding to scientific understanding, the student must be aided by an individual with knowledge about how to build on the concrete spontaneous concepts because it is these concepts which are used as bridges to scientific thinking. This movement toward the acquisition of scientific concepts necessitates the social interaction of a more learned individual operating within what Vygotsky terms as the Zone of Proximal Development (ZPD) or where the students' current knowledge learned through cultural practice is situated (Vygotsky, 1986). It is the downward movement of the scientific concept, which supplies the structure for the upward development of the everyday spontaneous concept. If concept acquisition is successful, then word meaning and abstract categories will dominate and restructure the learning experience. It is the more learned individual who will attach word meaning and vocabulary during the learning experience to replace the use of generic and often ambiguous natural language. This is not just rote memory learning, where a definition is attached to a word, but rather the individual integrates the word with what it means in terms of the regularity or pattern represented by the word or symbol. How well the teacher uses the students' language and connects it to language labels and concept learning will determine how effective instruction is within the ZPD. Scientific concepts are thus unified systems, grounded in general principles which can be applied to new situations (Smagornsky, Cook, & Johnson, 2003).

Vygotsky (1986) refers to the bridging of spontaneous concepts as *pseudo-concepts*. The pseudo-concept often masquerades as a scientific concept when students accurately use vocabulary in a singular concept, but then fail to generalize across multiple concepts. Similar, the pseudo-concept may also present itself as an incomplete or alternative concept when an attempt is made to apply a pseudo-concept to an inappropriate context. For example, a student may compare the density of aluminum (2.7) to water (~1) and judge this metal to always sink. In this case, the student fails to realize the complexity of the buoyant force.

In summary, Vygotsky proposed that spontaneous and scientific concepts exist in a dialectical relationship to one another. Spontaneous concepts are derived through a bottom-to-top approach from every day experiences. The spontaneous concepts carried by the child "are strong in what concerns the situational, empirical, and practical" (Vygotsky, 1986, p. 194). On the other hand, scientific concepts are derived in a top-down approach through the instructor and as such necessitate both the presence of the instructor and the social interaction in-between student and teacher. Ultimately, in order to facilitate conceptual change in student conceptual understanding, an inter-play between spontaneous thinking and scientific thinking is necessary and it is through dialectical exchange between spontaneous thinking and scientific thinking that scientific concepts emerge (Au, 1992).

Theory Underlying Concept Mapping. Concept maps may be used as both learning and assessment tools. The use of concept maps as an assessment tool has been supported by a

number of researchers (Francisco, Nakhleh, Nurrenbern, & Miller, 2002, Novak, 2010; Ruiz-Primo, 2000; Ruiz-Primo & Shavelson, 1996, Yin, Vanides, Ruiz-Primo, Ayala, & Shavelson, 2004, 2005). Concept maps offer the researcher a diagnostic tool for assessing prior knowledge of an individual as well as a post-assessment tool to measure the individual's conceptual change. Furthermore, the concept map can reveal a framework for how knowledge for a particular concept is constructed and whether the framework used is valid or includes unrelated concept linkages such as the inclusion of an alternative conception. Thus, concept maps function as mental models that reflect internal thinking about how knowledge is organized and if this organization is meaningful or not (Greca & Moreira, 2000).

Novak's research on concept mapping, as used in this study, coheres with Ausubel's Theory of Learning (1968). Ausubel (1968) suggests that new concepts can be incorporated into more comprehensive concepts within a hierarchical structure. Meaningful learning begins when the individual relates new ideas to previous knowledge. This concept learning may appear as concept formation or concept assimilation. That is, the new ideas can be subsumed within more inclusive concepts or used to anchor new ideas (Ausubel, Novak, & Hanesian, 1978; Novak, 2010). As children begin school, they have already formed *primary concepts* (Ausubel, 1968) through direct observation and recognition of regularities or patterns in the world around them. *Secondary concepts* are acquired during school using concept assimilation, a process that continues throughout life. According to Ausubel (1968) there are three pre-requisites to meaningful learning: access to prior knowledge; the material must be conceptually clear and have meaning for the learner; and the learner must *choose* to engage in meaningful learning. Optimally, concept development is best when the most general concepts are introduced first and followed by concepts that are increasingly specific (progressively differentiated). Over time, the quantity and quality of the students' cognitive structure organization will determine the degree to which learning is observed.

This study used concept maps constructed from memory (C-concept maps) to offer content validity in that the interrelationships among the concepts represent a property of knowledge (Barenholz & Tamir 1992; Lomask, Baron, Greig, & Harrison, 1992). Concept maps have also been reported (Stoddart et al, 2000) as highly correlated to conventional test scores when compared to tests that require application of knowledge as opposed to recall of knowledge and this high correlation to conventional tests has been confirmed by Hoz, Bowman, and Chacham (1997). The concurrent validity for concept mapping has been established using a variety of traditional assessment instruments used to assess student achievement (Stoddart et al, 2000; Hoz et al., 1997). For these reasons, concept mapping was selected as an appropriate tool for this investigation.

Methodology

The purpose of this study was to assess understanding about density as measured using the hierarchical organization of the concept map as an indicator of content knowledge and depth (Novak, 2010) and to classify concept type as abstract scientific concepts and spontaneous concepts (concrete concepts) using Vygotsky's theory of concept development (1986). The primary research question was, "What are the concepts that make up pre-service

teachers' conceptual understanding of density?" The two sub-questions that guided the study included:

1. What are the concepts that that make up pre-service teachers' conceptual understanding of density prior to an instructional intervention?
2. What are the concepts that that make up pre-service teachers' conceptual understanding of density after an instructional intervention?

The nature of the research questions informed a mixed-methods approach to data collection and analysis. As the focus of the study was to identify concepts about density before and after an instructional intervention, quantitative and qualitative approaches were used to collect and analyze data. A quantitative approach was used to tabulate numbers of propositions from concept maps and perform tests of significance.

The research design was informed by a pilot study completed during the previous year. The pilot study demonstrated the need for knowledge about the conventions for concept mapping such as the construction of concept maps with a specific focus on proposition accuracy (Derbentseva, Safayeni, & Cañas 2007) and the concept of density as an intensive property of matter. Pilot study results revealed several problems associated with student construction of concept maps. Many of the concept maps were missing linking phrases or directional arrows to indicate the hierarchical relationship of the concepts. Subsequently, a 30 minute concept map training session was provided prior to the research study. In addition to instruction about how to create concept maps, the participants completed group and individual concept maps to assist them in mastering how to make a C-map.

Context & Participants

The initial sample population consisted of 63 pre-service teachers enrolled in four sections of an elementary science methods course at a large university in the southwest region of the United States. This teacher preparation program prepares over 450 licensed elementary teachers each year. Two sections were taught by the authors and the other two sections by another science teacher educator. A total of 55 participants completed all assessments including the pre/posttest concept maps and pre/posttest interviews. Eight participants were excluded from the study as they were missing either a pre/post concept map and/or pre/post interview.

The teacher preparation program is accredited by the National Council for the Accreditation of Teacher Education and is rated as an exemplary program. All participants met a minimum GPA requirement of 2.75 (4.0 = A) and met minimum standardized test requirements. All participant degree plans included twelve semester credit hours of science coursework including a course in conceptual physics or general physics taught within the academic discipline. The ethnicity of the participants included White (67%); Hispanic (22%); Asian (9%) and African American (2%). While most participants were females, three participants were male.

Instructional Context

The instructional intervention was based on the 5E lesson format (Abell & Volkman, 2006). Formative assessment was used throughout the intervention in an effort to monitor participant understanding. The scientific concepts associated with the learning experience

included: (1) application of the density formula via density calculations; (2) classification of substances using density calculations; (3) descriptions of the relationship between mass and volume; (4) an explanation describing density as an intensive property of a substance; and (5) use of inquiry to explain why less dense fluids rise above fluids with greater density.

The Engage phase of instruction involved an activity analogous to the dots per box activity (Smith & Unger, 1997). One bag was filled with donut holes and a second bag with a greater number of donut holes. The students were allowed to handle the closed bags and determine the volume. A triple beam balance was used to determine the mass for each bag. Based on this observation, the students initially stated their thinking about the relationship between mass and volume.

During the Explore phase of instruction, participants measured, massed, and recorded data for a set of density blocks. In this activity, the participants continued to explore the idea that objects with the same volume do not necessarily have the same mass. This was the first attempt to help the participant understand how the concepts of mass and volume are no longer viewed separately. That is, density is an expression of a relationship between mass and volume and cannot be directly observed. The participants then used the density formula to calculate the density of the blocks. Using a table, the participants classified the blocks according to substance.

The Explain phase asked questions that related to density as an intensive property of a substance. For example, "If one of the density blocks is cut in half, then what is the density of the two smaller blocks?" Conversely, "If one of the density blocks is doubled, then what is the density of the larger block?"

A supporting learning experience included placing the density blocks in a graduated cylinder filled with 50 ml of water. The participants were then asked to compare the amount of water displaced by the block to the volume of the block which was calculated using a metric ruler. The purpose of this learning experience was to familiarize the participant with how to calculate the volume of an irregularly shaped object. Once again, the density of the blocks was calculated. The Explain phase related the previous activity and compared the results of the regular shaped density cube to the displaced water volume.

Next, a density layering lab was employed to examine the density of fluids. Sixty milliliters of five substances were added to a large test tube. Substances such as wintergreen alcohol and water were used to create discrepant events (alcohol is less dense than water). Participants were asked to make inferences based on their observations of the density liquid layering lab. In this activity, the participant's attention was once again focused on the densities of liquids to help conceptualize the idea that the underlying causal structure is relational.

The last learning experience used a hot-air balloon simulation which allowed the participant to compare the air temperature inside and outside the hot air balloon. Discussion of this variation on the topic included conceptual knowledge such as, "Why does a hot air balloon float?", "Why does a hot air balloon remain level in the air?" and "How does a hot air balloon come back to the landing pad?"

In addition to the “big ideas” from this instructional intervention, a number of common alternative misconceptions were discussed. During the debriefing of the learning experiences, common alternative conceptions and methods for developing conceptual understanding were introduced. For example, someone might suggest that larger objects are denser than smaller objects. Demonstrating how a larger pumice stone floats while a smaller rock such as a pebble sinks could be used to address this particular alternative conception.

Following the debriefing activities, the Elaborate phase explored real work connections to density. For example, oil floating in the ocean after the BP oil spill is an example of how density relates to everyday life. Other examples include bone density, Italian salad dressing and a density table display for common substances. Increasingly complex ideas about density could include discussions about the role of atomic mass in density. For example, the density of Platinum is 21.4 g/cm^3 and Gold is 19.3 g/cm^3 , while the Atomic Mass number for Platinum is 195, and it is 197 for Gold).

Concluding the instruction intervention, the Evaluate phase included density calculations; explaining relational causation (e.g., two liquids have the same volume, but one has more mass, is it the one with more mass denser?); describing the relationship between mass, volume, and density; and providing a scientific explanation for density following a teacher demo showing that a can of diet Coke® floating in a water-filled aquarium while a can of regular Coke® sinks.

Data Collection

The study began with a collection of pre-Cmaps and pre-interviews for the topic of density, followed by an instructional intervention and collection of post-Cmaps and interviews. In total, four sets of data were collected throughout the duration of the study.

Concept maps. The collection of participants’ pre- and post- concept maps followed the conventions for concept mapping (Moon et al., 2011; Novak & Cañas, 2008) and should not be confused with graphic representations referred to as concept maps, but not based on a theory of learning. For purposes of this study, concepts maps are defined as representations of knowledge that display explicit Novakian “concept-link-concept” propositional structures with each proposition serving as a stand-alone unit of meaning. That is, the proposition consists of two concepts/ideas joined together by a linking word/phrase that makes a meaningful statement. In particular, the linking words/phrases should utilize precise language to produce better concept maps. (Kharatmal & Nagarjuna, 2006) and display a hierarchical arrangement with the subordinate concept at the top and subordinate concepts below, arranged in terms of their inclusiveness (Novak & Cañas, 2008). Additionally, in this study, arrowheads were used to note the direction of the proposition relationship (Moon, Hoffman, Eskridge, & Coffeuy, 2011).

A focus question, “What is density?” was administered to the participants prior to the instructional intervention. Participants were made aware that “density” was the root concept and participants were required to provide a list of subordinate concepts, appropriate linking words, and directional arrows to construct their concept maps (Krajcik & Czerniak, 2007). Researchers have generally regarded concept maps constructed in this manner (C-concept maps) as the golden standard for concept maps (Ruiz-Primo et al., 2001; Yin et al., 2004).

Interviews. Open-ended interviews were conducted with 55 participants at two points of the study, immediately after the collection of pre-Cmaps and after the collection of post-Cmaps respectively. During the interview, each participant was asked to describe and discuss the relationship between the root concept of density and the subordinate concepts. All interviews were recorded and transcribed. The interviews served to gain deeper insights into participants' own interpretations of their pre- and post-Cmaps (Patton, 2002) and to provide validity checks by allowing participants to describe, explain, and interpret their understandings of spontaneous and scientific concepts to the authors, and help to alleviate the dependence on the authors' sole interpretation of participants' concept maps (Ruiz-Primo et al., 2001; Novak & Cañas 2008).

Data analysis

The research design employed the use of total proposition accuracy scores for concept maps as described by Ruiz-Primo, Schultz, Li, and Shavelson, (2001) as well as a paired sample *t*-test. Qualitative methods were used to interpret and categorize pre/post concept map propositions for accuracy, theme, and category (e.g., spontaneous or scientific concept) while pre/post interview transcripts were used to categorize concepts as either spontaneous or scientific concepts using Vygotsky's theory of concept development (1986) and to identify themes emerging from the interview data (Boyatzis, 1998; Braun & Clark, 2006). The qualitative methods were important in that the information gleaned from identification of themes and interviews provided additional insight into the participants' own meanings and intentions with regard to their content knowledge.

Concept maps. Each pre/post Cmap was first individually examined and marked by four education experts for progressive differentiation of propositions. Each progressively differentiated proposition on the Cmaps was marked as either a scientific or spontaneous concept. The final analysis employed a consensus model for identification and classification of Cmap propositions as scientific or spontaneous concepts. The same consensus model was used to thematically analyze participants' concepts derived from pre/post interview transcripts. Using a triangulation approach, data were used to identify and categorize participant scientific concepts and spontaneous concepts about the process of density before and after an instruction intervention.

***t*-Tests.** A paired sample *t*-test using SPSS version 20.0 was used to conduct a test of statistical significant using the total proposition accuracy scores from the pre/post Cmaps. The total proposition accuracy scoring technique (Ruiz-Primo et al., 2001) begins with the superordinate concept (density) and examines each proposition for accuracy and also for accurate progressive differentiation for each sub-concept of the branching hierarchy. Each scientifically accurate proposition was scored as one point.

Results

Analysis of data collected throughout the study revealed participants held two robust spontaneous pseudo-concepts (alternative conceptions) for density: (1) buoyancy and (2) heaviness/mass/weight (Table 1). Several other pseudo-concepts for density were noted, but these appeared in small frequencies: (1) volume; (2) mass/weight confusion; (3) change of state; (4) area; and (5) thickness. These concepts were categorized as spontaneous concepts,

specifically pseudo-concepts because the participants understood and applied these concepts accurately in some contexts, but inaccurately generalized these concepts to density, therefore exposing a gap in their conceptual understandings.

Table 1
Results for Pre/Post Cmaps and Pre/Post Interviews

	Pre-Intervention		Post-Intervention		Occurrence Across Time
	Pre-Cmap	Pre- Interview	Post Cmap	Post- Interview	
Spontaneous Pseudo-concepts (based on factual resemblance, not abstract understanding)					
Occurrence Per Assessment	99	111	107	118	435
Buoyancy	34	25	26	25	110
Heavy/Mass/Weight	27	23	21	19	90
Volume/Size	7	13	13	4	37
Mass/Weight Confusion	2	9	1	7	19
Change of State	6	5	1	5	17
Area	3	2	2	2	9
Thickness	1	3	0	2	6
Formula	12	27	37	38	114
Property of Matter	4	3	2	12	21
Proportional Reasoning	3	1	4	4	12

Scientific - True Concept (Hierarchical systematic organization, abstract, and generalizable)

Note: Formula, property of matter, and proportional reasoning represent pseudo-concepts which were accurate scientific concepts, but lacked the characteristics of scientific - true concepts.

Examination of data also revealed that participants held certain accurate ideas about density including the memorization and application of the density formula, proportional reasoning, and density as a property of material kind (Figure 1). These concepts were also classified as spontaneous pseudo-concepts because they were not described by participants using an abstract and generalizable hierarchical system (scientific true-concepts). That is, participants held a limited view of density that was characterized as a non-unified system of ideas, which nested a few accurate ideas alongside a number of alternative conception(s). Pseudo-concepts were observed to function as alternative conceptions in data collected from pre/post concept maps and pre/post face-to-face interviews. Six alternative conceptions about density were

derived from the data including the idea that density is: equivalent to buoyancy; the same as heaviness, mass, or weight; equivalent to volume or size, like area, the same as a change of state, or indistinguishable from thickness.

Figure 1. Elementary Preservice Teacher Scientific Pseudoconcepts About Density

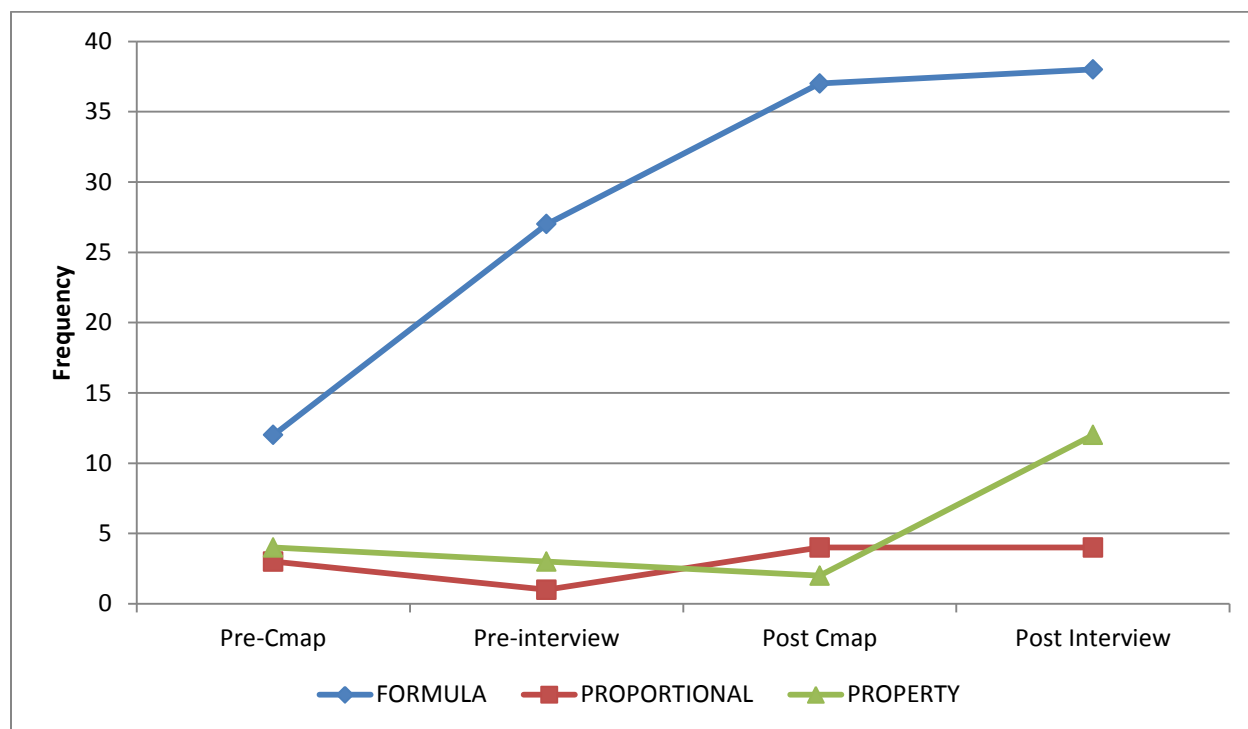


Figure 1. Frequency of pseudo-concepts expressed as learned concepts. Data from four assessments were collected from which were derived three learned concepts for density: the density formula, examples of proportional reasoning, and descriptions of density as a property of a material.

Robust Alternative Conceptions about Density

Equating density with buoyancy and heaviness/mass/weight appeared as robust spontaneous pseudo-concepts throughout the study. Thirty-four percent of participants' pre-Cmaps included the pseudo-concept of buoyancy is equated with density and 27% showed heaviness, mass, or weight equated with density. At the end of the study, post-interviews suggested these pseudo-concepts were persistent with regard to buoyancy (21%) and heaviness, mass, or weight (16%). It is notable that equating density with volume peaked during pre-interviews and on post-Cmaps, and then declined significantly during the post-interview. Table 2 and Figure 2 show the frequencies of occurrences for various pseudo-concepts about density which were illustrated on pre/post concept maps and which were described during pre/post interviews.

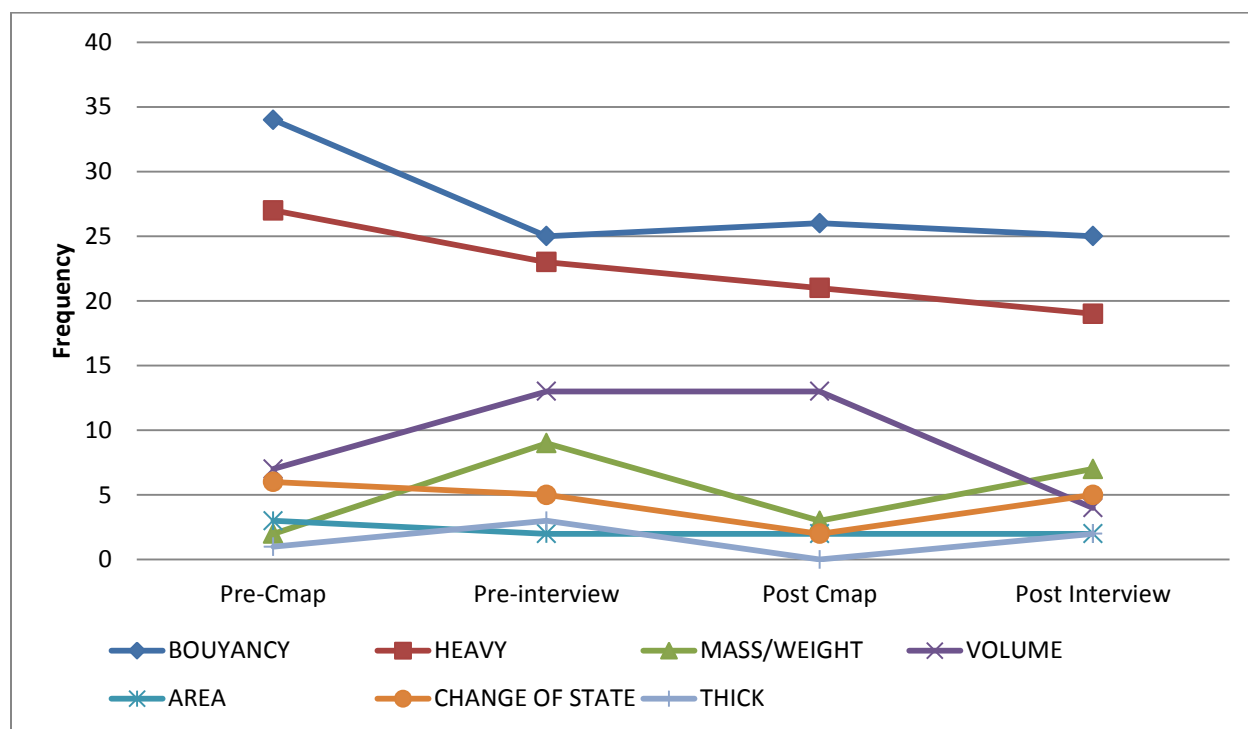
Figure 2. Elementary Preservice Teacher Alternative Conceptions about Density

Figure 2. Pseudo-concepts were observed to function as alternative conceptions in data collected from pre/post concept maps and pre/post face-to-face interviews. Six alternative conceptions about density were derived from the data including the idea that density is: equivalent to buoyancy; the same as heaviness, mass, or weight; equivalent to volume or size, like area, the same as a change of state, or indistinguishable from thickness.

Occurrences of buoyancy equated with density was the most robust pseudo-concept observed in the data (Cmaps and interviews) and was consistent throughout the study ranging from a low of 25 occurrences described during the pre-interviews to a high of 34 occurrences displayed on pre-Cmaps. Participants suggested that light objects float and have less density, while heavy ones do not float and have more density. Also, the participants tended to focus on weight and not on the relationship between mass to volume.

Nested within participants' ideas equating density with buoyancy were also subordinate concepts which focused on a single aspect of density (i.e., heaviness, mass, weight or volume). Density described as heaviness, mass, or weight was included on pre/post concept maps (27 and 21 occurrences respectively) and during face-to-face interviews (23 and 19 occurrences respectively). Density is the same as volume was featured on seven pre-Cmaps. This stand-alone idea increased on pre-interviews and post-Cmaps (13 occurrences) then was almost eliminated during post-interview discussions (4 occurrences).

It should not go unnoticed that mass/weight confusion, change of state, area, and thickness represented other pseudo-concepts which were extended to participant's understanding of the concept of density. The frequency of such occurrences was low, and ranged from zero to 9% on pre/post concept maps and pre/post interviews.

Learned Concepts about Density

The density formula, density as a property of matter, and the mathematical idea of proportional reasoning represent pseudo-concepts associated with the instructional intervention. We refer to these concepts as *learned pseudo-concepts* because the participants did not organize these concepts within a system which communicated the participant understood the concept of density as an abstract, generalizable, and hierarchical system. Frequencies of occurrences for learned pseudo-concepts about density and which were illustrated on pre/post concept maps and described during pre/post interviews (Table 2 and Figure 2).

The density formula as a learned pseudo-concept. The density formula represents the most common pseudo-concept acquired over the course of the study. Participants were able to recite, write, and/or describe the formula (including appropriate units). Approximately 25% of the participants referenced the density formula in pre-Cmaps or provided this information during pre-interviews when prompted for the density formula (Table 2, Figure 1). This number increased to 33% after the instructional intervention.

Density is an intensive property as a learned pseudo-concept. Very few participants provided any data that suggested an understanding that density is an intensive property of matter (Table 2 and Figure 1). Only 5% of total occurrences over the study accounted for this key idea. As previously mentioned, participants commonly confused density with other extensive properties of matter such as weight, mass, and volume.

Proportional reasoning as a learned pseudo-concept about density. Pre/post Cmaps show little evidence of proportional reasoning as a learned pseudo-concept. When participants in the post interview were asked what happens to the density of materials when the quantity of the material is halved, only 3% of total occurrences over the course of the study suggested that density is an intensive property of a material (12/435). As shown in Table 2 and Figure 1, evidence of proportional reasoning remained almost unchanged over the course of the study.

Concepts about Density Held by Individual Pre-service Teachers

Figure 3 summarizes the number and types of concepts (alternative- and learned) exhibited by the participants during the study. The following were evident from the data: (1) All 55 participants learned between zero and two concepts and held between zero and between zero and four alternative conceptions; (2) 10 participants learned zero concepts; (3) Thirty-four participants learned one concept; (4) Eleven participants learned two concepts; (5) four participants held no alternative conceptions; (6) Twenty-one participants exhibited one alternative conception; (7) Nineteen participants held two alternative conceptions; (8) Nine participants held three alternative conceptions; and, (9) Two participants held four alternative conceptions.

Figure 3. Frequency of Learned Pseudo-concepts and Pseudo-concepts Functioning as Alternative Conceptions

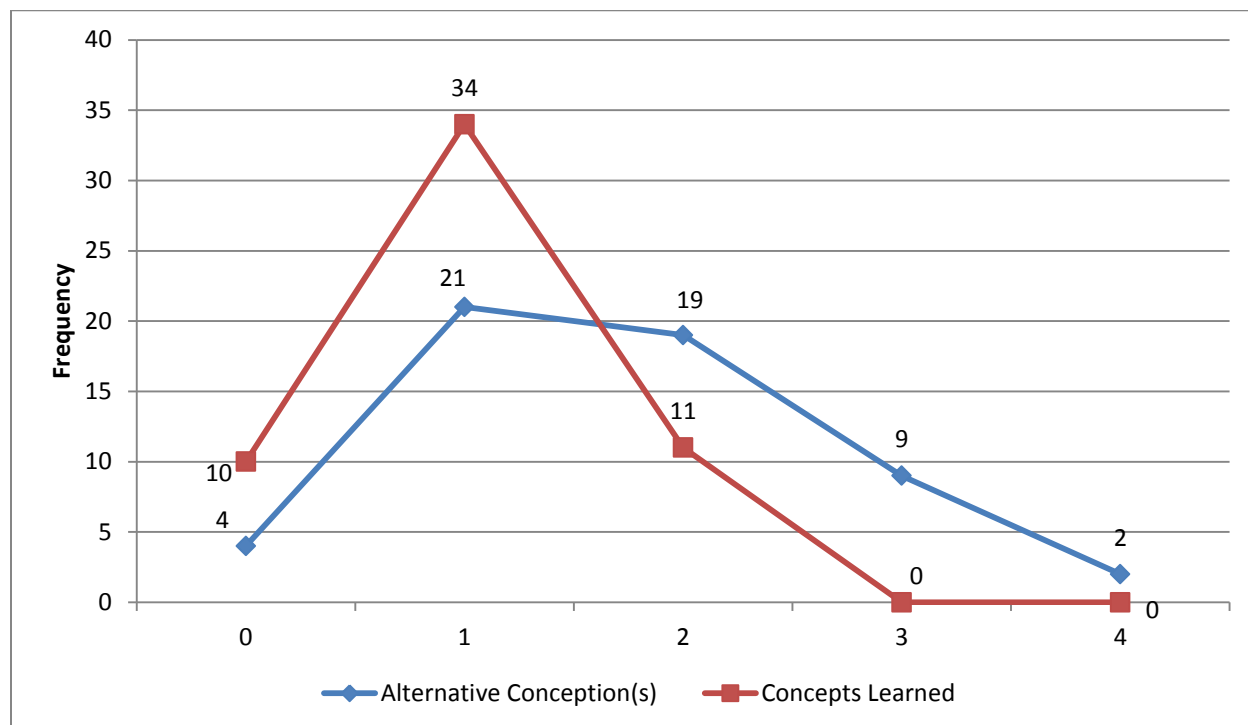


Figure 3. Frequency of participants holding pseudo-concepts as alternative conceptions and pseudo-concept held as learned concepts (n = 55).

Figure 4 shows the frequency of participants who held various paired combinations of learned concepts functioning as learned pseudo-concepts and alternative conceptions. As shown in Figure 4, only four participants had no alternative conceptions while 48 participants held alternative conceptions that were equal to or greater than the pseudo-concepts which represented accurate albeit piecemeal understandings.

Figure 4. Frequency of Participants Holding Various Paired Combinations of Pseudo-concepts Functioning as Learned Concepts and Alternative Conceptions.

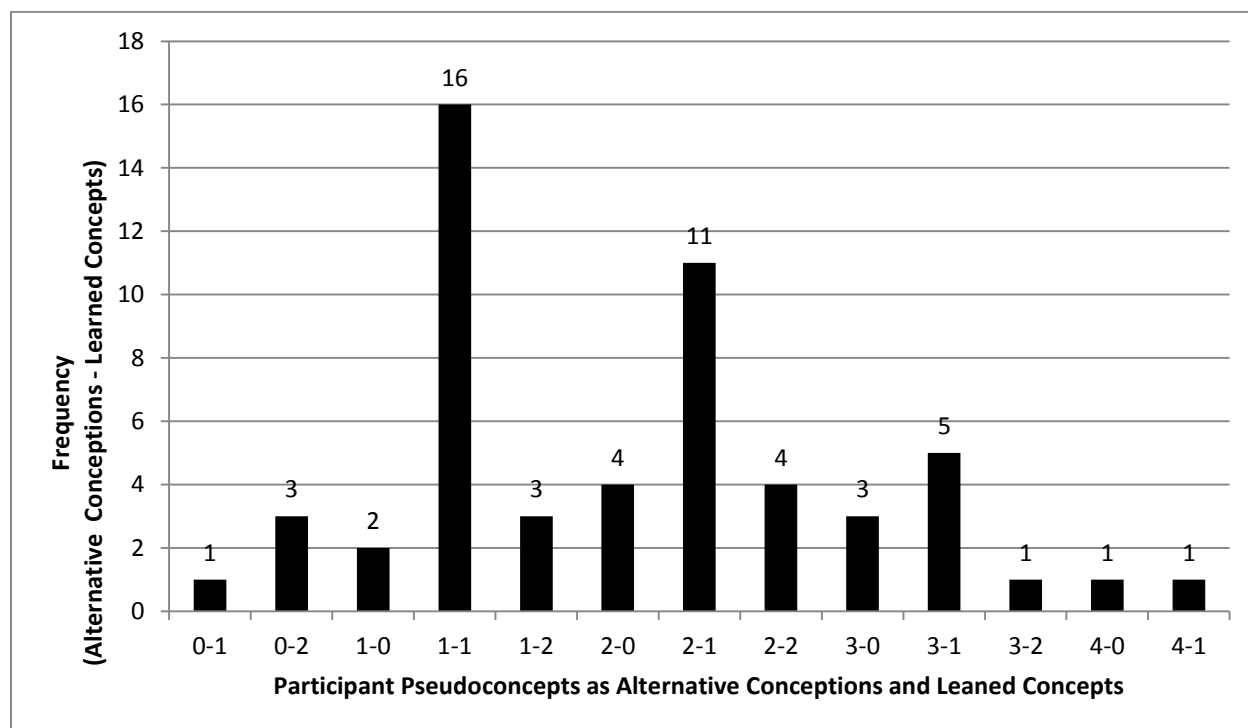


Figure 4. Frequency of participants who held various paired combinations of pseudo-concepts functioning as alternative conceptions and as learned concepts. The first numeral for each pair represents the number of alternative conceptions held by the participants, and the second numeral for each pair represents the number of learned concepts. For example, 0-1 represents a participant for whom no misconceptions and one learned concept was observed ($n = 55$).

***t*-Tests**

Using the SPSS 20 statistical package a paired-sample *t*-test was conducted. The results for the paired *t*-test for the density lesson are presented in Table 3. Results indicate a statistically significant difference between the pre/post concept map TPA scores. The instructional intervention was larger for the post concept map ($M = 1.02$, $SD = 1.063$) compared to pre-concept map scores ($M = 0.55$, $SD = 0.812$); $t = -3.178$, $p = 0.002$. Cohen's *d* was .43, and the effect size was medium.

Table 3

Paired Sample t-Test: Comparison of Two Means of Instructional Interventions for the Concept of Density

	n	Mean	SD	<i>t</i>	<i>p</i>
Density				-3.178	.002
Pre-Intervention	55	0.55	0.812		
Post-Intervention	55	1.02	1.063		

Discussion

Research Question 1: What are the concepts that that make up pre-service teachers' conceptual understanding of density prior to an instructional intervention?

The analysis of pre-instructional intervention data unmasked participants' weak framework of prior knowledge for density which was a mosaic of alternative conceptions and a few learned concepts. Overall, this framework was dominated by robust alternative conceptions (i.e., density is buoyancy and/or heaviness, mass, weight) and 69% of the participants displayed only one learned concept (the density formula) which was rote memorized and concrete. Many participants focused on a single variable conceptualization assuming one variable accounts for a phenomena (e.g., density is weight). That is, the participants were unable to engage in relational causality which involves consideration of two variables at once (i.e., $D = M/V$).

All participants' had taken and passed a college course in either conceptual physics or introductory physics within the academic discipline. Although over 70% of participants earned a grade of A or B in a physics course, their knowledge framework was not unified and would not be characterized as an abstract, generalizable, and hierarchical system. That is, these content trainings which were to prepare the pre-service teachers with the knowledge needed to teach children were inadequate and failed to present content which was situated within the prior knowledge of the participant and which was presented with conceptual clarity.

For those few participants who did bring scientific knowledge to the science methods course, this study also illuminated that their knowledge included only concepts that were observable and macro-level. For example, participants could recite the density formula, but fail to describe density as an intensive property of materials as well as convey the important role that proportionality plays in understanding density.

Research Question 2: What are the concepts that that make up pre-service teachers' conceptual understanding of density after an instructional intervention?

Findings from the post-Cmap and post-interview data indicate the participants continued to hold two pseudo-concepts which functioned as robust alternative conceptions. Over the course of the study, occurrences characterizing density as buoyancy and density as heaviness/mass/weight dropped 27% and 30% respectively and remained high at the conclusion of the study (25 and 19 participants). With the exception of volume, the remaining alternative concepts, which were not robust alternative concepts, declined or remained unchanged after the instructional intervention. Fundamentally, most of the participants continued their inability to engage in relational causality which involves consideration of two variables at once.

Similarly, participants continued to hold-on to the learned pseudo-concept of the density formula, and this particular concept almost doubled in frequency from the pre-intervention to post-intervention assessments. Sixty-nine percent of participants described their understanding of density as a property on their post-Cmap and/or during the post-interview. Although density as a property occurred with low frequency during the pre-intervention, the number of participants describing density as a property of materials did significantly increase post-intervention. However, 22% of participants describing density as a property represent an alarmingly low

overall percentage when one considers the importance of this idea and the fact that it was an objective stated for the instructional intervention. Similarly, very few participants were able to make the connection involving proportional reasoning (7%) and this too was an objective stated for the instructional intervention. Plainly, the majority of participants acquired only concrete knowledge expressed as memorization of the density algorithm, and used the density formula to describe their concept of density. Similar to pre-intervention findings, the participants carried away a mosaic of pseudo-concepts functioning as alternative conceptions and concrete learned concepts which nevertheless were improved, compared to the pre-intervention data. This finding implies an unacceptably weak conceptual understanding of density which would be detrimental to children's learning of important science concepts.

In summary, this study shows that many participants considered single aspects related to density, such as compactness of particles (Smith & Unger, 1997) instead of centering on concentrations of particles within a given volume (e.g., *dots-per-box* model). That is, participants did not acknowledge that both the mass of a material, in terms of the total number of particles present, as well as the distance between those particles affects the density of a material. The participants did not realize that it is possible for a material to have particles with more mass that were spaced farther apart (i.e., more dense) compared to a material with particles of less mass and spaced closer together (i.e., less dense).

Similarly, the data collected showed many participants focused on either mass, weight, heaviness or volume separately as extensive properties of materials that can be directly perceived (Fassouloupoulos, G., Kariotoglou, P. & Koumaras, P., 2003) and failed to simultaneously focus on both variables (Dawkins, 2008). In other words, the participants were unable to engage in relational causality which involves the simultaneous consideration of two variables and instead tended to lapse back to considering the variables separately.

Finally, a number of participants in this study equated density with buoyancy predicting that heavier objects will sink while lighter objects will float (Smith et al., 1985; Penner & Klahr, 1996). Consistent with other findings, the participants related density to sinking and floating without being able to explain the factors that influence sinking and floating and without relating density to buoyancy (Dawkins, 2008; Kohn, 1993; Stephans et al., 1988; Tasdere & Ercan, 2011). This was the most prevalent alternative conception found in this study.

Conclusions and Implications

Given the importance of teacher knowledge, which also forms the foundation for pedagogical content knowledge (Dawkins, 2008) it is important that individuals involved in teacher preparation closely examine their own pre-service teachers who may have similar content needs as reported in this study. In this study, pre-service teachers struggled to bridge the gap between everyday concrete experiences and the abstract ideas that accompanied scientific concepts.

Within the broader context, the concept of density underlies more complex topics which will be introduced at higher grades. Concepts such as buoyancy consider density of the fluid as well as other variables related to the buoyant force. Similarly, other science topics, including

such topics as the formation of hurricanes and the movement of the oceanic crust away from a ridge require a foundational understanding of density. Students need a firm grasp of density to understand convection which explores the gain/loss of heat and pressure due to spatial variations of materials such as oceans, air, and the mantle. Without such an understanding of density as a property of materials, children will experience much difficulty making the leap to understand how density changes due to heat and pressure and how this affects the world we live in.

These findings also suggest that both academic faculty and science teacher educators should take into account the tenacity and strong role of student prior knowledge as they design learning experiences. Familiarity with prior knowledge of the students will help position instruction within the zone of proximal development (Vygotsky, 1986) and diagnostically can provide the opportunity for the student to engage in tutoring or other activities to strengthen prior knowledge. Also, some topics require extra time in order for the student to gain access to increasing complex knowledge. For this reason, topics which are so fundamental to the understanding of more complex phenomena should be given sufficient time to develop and ought to be re-examined for retention in long-term memory.

Finally, researchers became additionally aware of how social interaction might serve as an important assessment tool. For example, though participants did not include the density formula on their pre-Cmap, they were able to express this knowledge during the pre-interview. Thus, in the interest of measuring improved understanding of elementary preservice teachers' science content knowledge, future researchers might plan to incorporate a variety of assessment tools to increase students' opportunity to make their knowledge explicit.

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Appendix A

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

Description of Density	Researcher(s), Year
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
Description of Density	Researcher(s), Year
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 mass of particles.	Hewson, 1986
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 more dense objects will sink.	Dawkins et al., 2008
