

The Use of Concept Maps as a Tool for Understanding Conceptual Change in Preservice Elementary Teachers on the Concept of Density

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Abstract: In this article, the researcher will report on methods for scoring concept maps to assess conceptual change in preservice elementary teachers' understanding of the concept of density. The researcher used the method of Total Proposition Accuracy (TPA) scoring to assess conceptual understanding of density prior to and post instruction. The researcher categorized students' misconceptions about density as either spontaneous or scientific concepts using Vygotsky's (1987) theory of concept development. The researcher used a paired sample t-test analysis and determined that after instructional intervention, students demonstrated statistically significant improvement from pre- to post-concept maps ($t = -2.89, p = .005$). Some spontaneous concepts that appeared on pre-concept maps were either reduced or eliminated on post-concept maps; other spontaneous concepts proved to be more robust and persisted after intervention. Although small, statistically significant gains were noted in the t-test analysis; these findings suggest that elementary preservice teachers' content knowledge about density is weak; the average TPA score after receiving instruction was one proposition ($n = 56$), and many teachers continued to hold the same misconceptions post-instruction as did other K-12 students who participated in other studies. After receiving instructional intervention, the majority of students who participated in this study used the emerging concept of the density formula (67%) to define density, and others (30%) used procedural information that was featured in the lesson activities. The two robust misconceptions about density related to confusing density and buoyancy to explain the phenomena of floating and sinking (42%) and confusing density with heaviness, mass, and weight (23%). Only 4% of students used the scientific definition of property of matter to define density correctly. These results suggest that teachers have well-developed idiosyncratic conceptions about density that will take considerable time and effort to reduce or eliminate. Based on the results of this research, the researcher recommends—that teacher training programs help preservice teachers improve their elementary content knowledge about density by focusing on the Archimedes principle during content course instruction.

Keywords: Concept Maps

1 Introduction

Many researchers have studied K-12 students' misconceptions about density, but few researchers have studied elementary preservice teachers' misconceptions about density. Most of the studies about density misconceptions rely on students' responses on tests and during interviews. This study is unique because it not only fills a gap in the research literature about preservice teachers' misconceptions but also relies on concept maps to understand conceptual change that affects teachers' understanding about the concept of density. The researcher categorized teachers' misconceptions exhibited as either scientific or spontaneous by using Vygotsky's (1987) theory of concept development. Therefore, the two theoretical frameworks that guided this study were constructs from concept mapping and Vygotsky's (1987) theory of concept development.

The significance of this study is to use concept maps and Vygotsky's (1987) theory of concept development to offer further insight into misconceptions exhibited by preservice elementary teachers at a large university in the U.S. and to suggest how universities can improve their teacher preparation programs. The principle questions addressed in this study include the following:

*RQ*₁: What types of misconceptions do preservice elementary teachers exhibit?

*RQ*₂: What are the categories of misconceptions according to Vygotsky's (1987) theory of concept development?

*RQ*₃: What suggestions to improve teacher preparation programs can be made based on the results of this study?

Concept Maps

In 1972, Novak and Musonda (1991) suggested that researchers use concept maps to assess conceptual understanding of students. Novak and Musonda (1991) focused on hierarchical maps featuring central concepts that act as superordinates and several other concepts that act as subordinates to the central concepts. The various concepts form nodes and connect through linking phrases. Two nodes connected by an arrow and labeled with a linking phrase make for a proposition. Novak and Canas (2008) cited advantages of using concept maps to understand the complex ways in which students think, ways that can include higher-order thinking. With concept maps, the hierarchical way in which students must represent their conceptual understanding of a central concept mimics the way in which an expert would organize information. Novak and Canas (2008) argued that scaffolding concepts into a template of organized information enables students to store information first in their working memories and eventually in their long-term memories, which helps students recall information and facilitates meaningful learning. Brain research studies have confirmed this finding about scaffolding concepts. For example, Brooks and Shell (2006) distinguished experts from novices by the way in which experts “chunk” information in an organized way into their long-term memories. Concept mapping is a method of chunking information, a method which enables students to store information in their long-term memories and to recall this information in the working memory in the same way in which experts do. Furthermore, hierarchical concept mapping may also improve students’ knowledge acquisition because of how human brains organize information. Other research findings have suggested that human brains work to organize information in a hierarchical fashion, so learning strategies that mimic this hierarchical organization enhance students’ abilities to retain information (Bransford, Brown, & Cocking, 1999).

Novak’s and Canas’s (2008) work in concept mapping is rooted in the learning psychology advanced by Ausubel (1963), who distinguished between rote and meaningful learning. According to Novak and Canas (2008), meaningful learning necessitates three conditions:

1. Learning material must be conceptually clear and presented with language and examples related to learners’ prior knowledge (concept maps meet the requirements of this condition because they can be used to identify general conceptions and their sequencing prior to learning).
2. Learners’ must possess relevant prior knowledge.
3. Learners’ must choose to learn meaningfully.

Concept maps meet these three requirements for meaningful learning and work both as diagnostic tools to assess students’ knowledge prior to instruction and as assessment tools to measure students’ conceptual change post instruction. Researchers can also use concept maps to reveal patterns in the ways in which students’ construct their knowledge of a particular concept and to determine whether misconceptions exist. Using concepts maps with interviews can further support data about students’ misconceptions and can guide future instruction in a particular concept. Students’ misconceptions often manifest as pseudo-concepts that masquerade as scientific concepts. Students who use pseudo-concepts borrow scientific language from and misconstrue generalizations made by adults and teachers. Using concept maps and interviews together can reveal students’ pseudo-concepts as misconceptions when students apply pseudo-concepts in the wrong contexts.

Designing and scoring concept maps.

In the last two decades, concept maps as tools to measure students’ concept development have attracted the attention of other research groups that began to develop methods to design and score concept maps to assess students’ conceptual understanding (Ruíz-Primo, 2000; Ruíz -Primo & Shavelson, 1996; Yin, Vanides, Ruíz-Primo, Ayala, & Shavelson, 2005). There are two steps to using concept maps: constructing and scoring concept maps. Also, there are two types of concept maps: S-concept maps and C-concept maps. Yin, Vanides, Ruíz-Primo, Ayala, and Shavelson (2005) preferred C-concept maps to S-concept maps because they argued that C-concept maps offer better validity. Yin et al. stated that C-concept maps are low-directed, which means that students derive their own list of keywords for a concept

and make their own linking phrases for concept maps. Despite the benefits of C-concept maps, Yin et al. argued that S-concept maps are better for administration in large-scale settings (such as student assessments at a large school district). S-concept maps offer higher reliability than do C-concept maps and are practical for administration on a large-scale because S-concept maps are easy to administer and can be scored automatically using computer programs. The standard method for scoring concept maps follows Novak's and Gowin's (1984) method for scoring, which utilizes all four aspects of TPA scoring, including number of propositions scored, number of cross-links, accuracy of propositions, and comparison of similarities between expert and novice concept maps.

Concept maps as instructional tools.

Historically, concept maps have been used as instructional tools and have shown good results in enabling students' learning in classrooms (Markow & Lonning, 1998). Mason (1992) examined the use of concept maps in her two-year study of preservice teachers in science education and found that student teachers had declarative knowledge but lacked conceptual understanding of subject content. Mason used concept maps to help teachers understand relationships among cohesive concepts that teachers had learned in isolation. Other researchers have studied the impact that concept maps have on students' conceptual understanding in classrooms (Roletto, Regis, & Albertazzi, 1996; Roth & Roychoudhury, 1993; Wilson, 1994). Their studies revealed that concept maps can be a powerful tool in understanding students' conceptual development in classrooms.

Concept maps versus conventional assessment tools.

Some researchers have studied concept maps to determine how well concept maps correlate with conventional methods of conceptual assessment. Stoddart's, Abrams's, Gasper's, and Canaday's (2000) research showed that concept maps correlated to conventional test scores when comparing tests that require students to apply, rather than to recall, knowledge. Hoz, Bowman, and Chacham (1997) and Liu and Hinchey (1993) confirmed correlation between concept maps and conventional tools for assessing students' conceptual development. In addition, Esiobu and Soyibo (1995) found in their study of academic achievement for eighth-grade students in ecology and genetics that the experimental group who used concept and Vee maps scored better than did the control group who did not use concept and Vee maps. In a similar study of students taking a college course in calculus, Park (1993) also found strong correlation between students' scores on concept maps and post-instruction tests. Williams (1998) concluded that concept maps can help researchers categorize students' knowledge and do reveal more about students' knowledge than do pen-and-pencil tests. Along with the previously mentioned researchers, Francisco, Nakhleh, Nurrenbern, and Miller (2002), Novak and Gowin (1984), Ruíz-Primo (2000), and Ruíz-Primo and Shavelson (1996) have all supported using concept maps as evaluation tools to assess students' learning.

Validity and reliability of concept maps.

Ruíz-Primo and Shavelson (1996) discussed three types of validity issues with regards to concept maps: content validity, concurrent validity, and construct validity. In general, researchers have reported that C-concept maps offer higher validity than do S-concept maps and that S-concept maps offer higher reliability than do C-concept maps (Yin & Shavelson, 2008). S-concept maps are like multiple-choice exams, and C-concept maps are like essay-type exams. Researchers have generally regarded C-concept maps as the standard of concept mapping (Ruíz-Primo, Schultz, Li, & Shavelson, 2001). The researcher of this study chose low-directed C-concept maps because of their higher validity (Ruíz-Primo, 2000). The researcher addressed the inter-rater reliability and content validity of the concept maps that were used as instruments in this study by seeking forced consensus among four education experts about the maps.

Misconceptions About Density

Most of the literature about misconceptions of the concept of density has focused on the misconceptions of K-12 students (Kohn, 1993; Krnel, Watson, & Glazar, 1998; Penner & Klahr, 1996; Smith, Carey, & Wisner, 1985; Smith, Maclin, Grosslight, & Davis 1997; Smith, Snir, & Grosslight, 1992; Tasdere & Ercan, 2011). In general, researchers have identified the following student misconceptions about density:

confusing density and weight, difficulty relating density to buoyancy when explaining the phenomena of floating and sinking, or believing that weight alone determines whether objects sink or float (Knel et al., 1998; Penner & Klahr, 1996; Smith et al., 1985; Smith et al., 1997; Smith et al., 1992; Tasdere & Ercan, 2011). Students who related density to buoyancy to explain floating and sinking overgeneralized their knowledge about density by relating sinking and floating to size, shape, or material alone (Libarkin, Crockett, & Sadler, 2003). Moreover, Heyworth (1999) found in a study of volumetric analysis that students relate density to concentration and that students who struggle with scientific concepts generally lack conceptual and/or procedural understanding about the concepts. Hewson (1986) reported that some students relate density to how closely particles are packed in an object.

Limited data about elementary preservice teachers' misconceptions of density display commonalities with data about K–12 students' misconceptions: like K–12 students, preservice teachers of elementary science also have difficulty relating density to buoyancy (Greenwood, 1996; Stepan, Dyché, & Beiswenger, 1988). In addition, Dawkins, Dickerson, McKinnet, and Butler (2008) found that preservice teachers of middle school science may have discrete understanding of science content but may not have connected that understanding in a coherent way. That is, preservice teachers may be able to recite the algorithm for density or to perform calculations with the density formula but fail to understand that density is a property of matter (Dawkins, Dickerson, McKinnet, & Butler 2008). Preservice teachers may struggle to relate density to buoyancy or fail to recognize density is a property of matter. Generally speaking, younger students have an intuitive understanding of density, and older students in middle and high school focus on memorizing the definition of density and using the algorithm $D = M / V$ (Dawkins et al., 2008).

Chi (2005) argued that not all misconceptions are the same because some misconceptions can be classified as weak and can be reduced or removed with instruction but others are robust, are more difficult to change, and may persist even after instruction. Chi (2005) explained instructors must accomplish two things to change robust misconceptions: convince students that conceptual change is necessary and help students build new schemata for new concepts. If old schemata exist, then students must replace old schemata with new schemata; if no old schemata exist, then students must construct new schemata.

One of the more robust misconceptions that both students and student teachers display is confusing density and buoyancy. The Archimedes principle connects buoyancy and density by describing how the two concepts are related. Students and student teachers struggle to make this connection, often reporting that density determines whether objects sink or float even though the correct scientific notion is that buoyancy determines whether objects sink or float. Kohn (1993) reported that children can often relate the concept of density to buoyancy as early as age 4. However, both student teachers and their students commonly confuse density with buoyancy.

Another common misconception related to density is confusing density with the concepts of heaviness, mass, or weight (Penner & Klahr, 1996; Smith et al., 1985). Students often have the misconceptions that heavier objects sink and that lighter objects float. Smith, Carey, and Wiser (1985) found that distinguishing between the concepts of density and weight requires certain levels of conceptual development. Consequently, distinguishing between the concepts of density and weight is generally a problem when students are in second grade but typically goes away when students reach fourth grade.

The accepted scientific conception of density is that density is an intensive property of matter, a property derived from the relationship between mass and volume. Density has the units g/cm^3 and is calculated using the formula $D = M / V$. Buoyant force, not density, determines whether an object floats or sinks. The Archimedes principle and the density formula describe the relationship that governs buoyancy and density. This relationship between buoyancy and density is expressed as follows: buoyant force is equal to the weight of the fluid displaced by an object. The formula for this relationship is V (volume of fluid displaced) \times D (density of the fluid) \times G (gravity). In essence, the buoyant force of a fluid is equal to the weight of the fluid displaced by an object. Therefore weight of the displaced fluid, not density, is what is equivalent to the buoyant force. Student misconceptions about the relationship among density, weight, and buoyancy derive from confusing the relationship between the weight of an object and the density of that

object. Sometimes, students erroneously report that heavier objects sink and are therefore denser than are lighter objects. Other times, students mistakenly attribute the phenomena of sinking or floating to an object's density instead of to its buoyancy.

Vygotskian Theoretical Framework for Understanding Misconceptions

The researcher used Vygotsky's (1987) theory of concept development to categorize the misconceptions that govern student teachers' understanding the concept of density. According to Vygotsky (1986), children pass through three phases of concept development (see Table 1): In Phase I, children form conceptual understanding by using syncretic images or heaps. In Phase II, children think in complexes, and in Phase III, children develop scientific conceptual understanding. Children begin understanding concepts by observing natural phenomena in their everyday interactions. Because children derive knowledge through practical interactions in their daily activities, they often develop misconceptions about scientific phenomena they encounter because children rely on what Vygotsky (1986) called spontaneous thinking. At this phase of concept development, students think in complexes, and instructors help students progress to complex thinking in Phase II and eventually to scientific thinking in Phase III.

Table 1 : Vygotsky's (1986) Three Types of Concept Development

	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.
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 operation).

		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 using 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	Child's grouping seems externally similar to 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, conscious awareness (e.g., generalizing density over multiple contexts).

Vygotsky (1986) defined spontaneous concepts as un-unified concepts based on concrete, factual groupings and scientific concepts as hierarchically organized concepts unified in a knowledge system. The goal of instruction thus becomes to elevate students' understanding to Phase III of conceptual development, the phase in which students achieve scientific understanding. Aided by instructors, students build on their spontaneous conceptions until they reach scientific thinking. Conceptual development of scientific understanding necessitates social interaction between adults (e.g., instructors) operating within students' Zones of Proximal Development (ZPD). ZPD is a conceptual zone that contains the starting point or level of students' current content knowledge is and that indicates the conceptual level which students have the potential to reach with the aid of instructors.

Emerging concepts are in between spontaneous and scientific concepts; students can develop emerging concepts from information received from instructors or from lesson activities. Ackerson (2005) reported that student teachers may use coping strategies to teach scientific content. An example of an emerging concept used as a coping strategy might be using the density formula or compactness to define density. Emerging concepts derived from coping strategies are distinguished from scientific thinking in that emerging concepts are derived from concrete rather than abstract thinking.

Vygotsky (1986) identified pseudo-concepts as one of the most common types of misconceptions. Pseudo-concepts often masquerades as true scientific concepts but can be exposed as pseudo-concepts. For example, students who use pseudo-concepts may borrow adult scientific concepts that sound scientific but are exposed as pseudo-concepts by experts when students apply the pseudo-concepts in the wrong contexts.

Vygotsky (1986) believed that spontaneous and scientific concepts exist in a dialectical relationship with one another. Spontaneous concepts are derived through a bottom-to-top approach to learning from

everyday experiences. Children's spontaneous concepts "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-to-bottom approach beginning with instructors; as such necessitate, students' development of scientific concepts depends both on the knowledge of instructors and on the social interactions between instructors and students. To facilitate conceptual change in students' conceptual understanding, instructors must create interplay between spontaneous and scientific concepts in classrooms. Although spontaneous and scientific thinking develop from two independent courses, true concepts only emerge through the dialectical exchange between the two (Au, 1992).

Method

Research Design

The methodology used in this study was a mixed-methods approach to research. The quantitative research design involved a pre-experimental research design: the one-group, pretest-posttest design. This study was informed by a pilot study conducted the semester prior to this research. For both the qualitative and quantitative elements of this research design, the researcher used a thematic approach to analyze data collected on pre- and post-concept maps to identify students' concepts and misconceptions that predominated this study (Boyatzis, 1998; Braun & Clark, 2006). The researcher also used a forced-consensus model for the qualitative and quantitative elements of this study to determine the number of accurate propositions and to identify and classify propositions as scientific or spontaneous concepts using student teachers' pre- and post-concept maps. . A forced consensus model is a model in which researchers score concept maps collectively and discuss and resolve issues to come to a consensus. Each pre- and post-concept map was examined individually and scored with the TPA method of scoring as either scientific or spontaneous. The researcher derived the TPA method of scoring the concept maps using recommendations made by Novak and Gowin (1984) and Ruíz-Primo (2000). TPA is a simple method for tallying the total number of correct propositions in students' concept maps.

Sample

The sample for this study included a total of 63 preservice teachers who were enrolled in a science methods course in a university teacher preparation program before the semester of student teaching. The students were mostly elementary preservice teachers, but three were middle school preservice teachers. Three out of 63 preservice teachers who participated in this study were male. The following are the ethnic groups of the preservice teachers who participated in this study: Caucasian (67%); Hispanic (22%); Asian (9%); and African American (2%). Only three of the participants had taken a course in general chemistry. The majority of the elementary preservice teachers who participated in this study (72%) scored an A or B in their conceptual physics courses for elementary student teachers.

Data Collection

The researcher collected data for this study by using pre- and post-concept maps and an instructional intervention. The concept maps were low-level directed concept maps on which students were asked to provide their own lists of concepts and linking phrases (Ruíz-Primo, 2000). The instructional intervention was in the form of a 5E Model of constructivism in which the participants are first engaged with an activity involving dropping two bowling balls of the same size into a tub of water and observing one ball sink and the other ball float. The instructor followed the lesson activity about density with a discussion of the concepts to be learned. During this discussion phase of the instruction intervention, participants were asked to explain their findings, and, if necessary, the instructor provided additional information related to the lesson. Participants then used their experiences during the lesson activity to elaborate on the concept in relation to real-world applications (e.g., using a computer simulation of a hot air balloon to explain why the balloon floats or sinks).

The scientific concepts associated with the learning activity in the instructional intervention included following:

- Students will be able to calculate density using the density formula.
- Students will use the concept of density to classify substances.

- Students will describe the relationship between mass and volume with regard to density.
- Students will explain why density is a physical property of matter.
- Students will explain why less dense fluids rise above objects with greater density.

Data Analysis

Four education experts scored the concept maps (three science education faculty and one doctoral student) using a forced-consensus model. Each map was examined, and concerns were raised and resolved one by one. The TPA method of scoring involved a total count of correct propositions as determined by consensus of the four experts. The four experts employed the same procedure to classify concept map propositions as either scientific or spontaneous. TPA scores from pre- and post-concept maps were entered into SPSS 20 statistical software program to conduct a two-tailed paired sample t-test. The effect size of the data was measured using Cohen's *d*.

Results

Pilot Study

Pilot study results revealed several problems associated with students' construction of concept maps. Many of the concept maps were not capable of being scored because they were missing linking phrases or had no clear nodes, making the concept maps useless. This issue was subsequently addressed in the following semester during which student teachers received 30 minutes of instruction about how to construct a C-concept map. In addition to instruction, the teachers completed group and individual concept maps to assist them in mastering how to make a C-concept map. A C-concept map is student directed without the benefit of a word bank or given linking phrases.

As a result of the pilot study, changes were made to the instructional intervention to clarify any misconceptions found previously with student teachers in the pilot study. The researcher used a forced-consensus method for scoring concept maps based on TPA scoring. Each preservice teacher completed a C-concept map prior to instruction (pre-concept map). One week after receiving the 3-hour instructional intervention, preservice teachers completed a second C-concept map after instruction (post concept map). TPA results for a paired sample t-test were calculated using SPSS 20.

Moreover, for all data reported henceforth only preservice teachers with paired concept maps were included in the analysis. Where a preservice teacher was missing a pre-concept map or post-concept map, their data was removed from the analysis. Furthermore, select population sizes were chosen out of convenience for each results table presented, however for all data analyzed the number of concept maps always had a population size that was greater than 40. Results for the paired t-test for the density lesson are presented in Table 2. These results indicate a statistically significant difference exists between preservice teachers' scores on pre- and post-concept map scores. The scores were greater for post-concept maps ($M = 1.00$; $SD = 0.81$) than they were for pre-concept maps ($M = 0.57$, $SD = 0.81$); $t = -2.89$, $p = .005$).

Table 2 : Paired Samples *t* Test: Comparison of Two Means of Instructional Interventions for the Concept of Density

	N	Mean	SD	<i>t</i>	<i>p</i>
Density				-2.89	.005
Pre-Intervention	56	.57	.81		
Post-Intervention	56	1.00	.14		

Research Study

Results for the identification of preservice teachers' misconceptions about density are shown in Table 3. Categorizing preservice teachers' misconceptions revealed that the following are the major misconceptions about density that persisted after the teachers received the instructional intervention:

- Density is buoyancy or describes floating and sinking (42%).
- Density is described using procedural methods (30%).
- Density is mass, heaviness, or weight (23%).

The frequency of propositions of post-concept maps indicating that density is a change of state, is a chemical reaction, or is volume were reduced to zero after receiving instruction; however, the concept of density as heaviness was only reduced in part from 33% to 23% after receiving instruction. The more robust concept relating density to buoyancy or to floating or sinking showed only a small reduction from 49% to 42%. Students also introduced procedural information (30%) in their post-concept maps, information they derived from the experiments they conducted during the lesson activity. This procedural information included methods used to determine the volume of an object (e.g., using a ruler to measure $W \times H \times L$, using the water displacement method to determine volume, or using a balance to measure mass). For emerging concepts related to the concept of density, 5% of students defined density using compactness (see Table 3). Though 67% of students used the density formula to define density, only 4% of students used the correct scientific term of property of matter to define the concept of density (see Table 4).

Table 3: *Frequencies and Percentages of Students' Conceptions and Misconceptions on Pre- and Post-Concept Maps for the Topic of Density (n = 43)*

	Frequency	%
Density is mass, heaviness, or weight.		
Pre-Concept Map	23	33.0
Post-Concept Map	15	23.0
Density is mass or size.		
Pre-Concept Map	2	3.0
Post-Concept Map	0	.0
Density is the compactness of particles.		
Pre-Concept Map	3	4.0
Post-Concept Map	3	5.0
Density is related to states of matter.		
Pre-Concept Map	4	6.0
Post-Concept Map	0	.0
Density is buoyancy and describes floating or sinking.		
Pre-Concept Map	34	49.0
Post-Concept Map	28	42.0
Density is described using procedural methods.		
Pre-Concept Map	2	3.0
Post-Concept Map	20	30.0

Density is a chemical reaction.

Pre-Concept Map	1	1.0
Post-Concept Map	0	.0

Table 4:

Frequencies and Percentages of Students' Conceptions and Misconceptions on Pre-Concept Maps (n = 63) and Post-Concept Maps (n = 58)* for the Topic of Density*

	Frequency	%
Density is defined using the formula for density.		
Pre-Concept Map	13	21.0
Post-Concept Map	39	67.0
Density is defined as a property of matter.		
Pre-Concept Map	4	5.0
Post-Concept Map	3	4.0

Note. *Students with missing concept maps were removed.

Discussion

Effectiveness of Using Concept Maps to Measure Conceptual Change

The TPA method of scoring concept maps proved to be an effective tool for measuring conceptual change in students' understanding. Results from the pilot study showed that students must be instructed about what a good concept map is and how to construct a hierarchical concept map. This includes instructing students about what constitutes a concept and a proposition and about how to adequately link propositions with arrows so that a meaningful concept map can be scored. The researcher determined that this instruction was necessary because as many as 30% of student responses to concept maps in the pilot study featured meaningless information that was related to procedures used in the lesson but not relevant to the concept maps and should not have been included. Instruction about concept maps prior to using them helped students avoid such information on their concept maps.

The majority of student teachers had very little knowledge about density prior to the study: 27 out of 43 (63%) responses on pre-concept maps had a score of zero. This number of zero correct propositions was reduced partially to 17 out of 43 (40%) on post-concept maps after student teachers received instruction. On average, the number of correct propositions used by students teachers was below one correct proposition on pre-concept maps ($M = 0.57$; $SD = 0.81$) and only increased to one correct proposition on post-concept maps ($M = 1.00$; $SD = 0.14$). Although the t-test showed a statistically significant increase with a small Cohen's d effect size in students' scores, results from pre- and post-concept maps indicate that student teachers still need to improve their content knowledge about the concept of density. Student teachers' scientific content knowledge is crucial because lack of content knowledge ultimately causes these teachers to transfer misconceptions to students in the classrooms where student teachers are assigned. Moreover, teachers must possess accurate scientific literacy and must use correct scientific vocabulary for students to receive adequate instruction. In keeping with Vygotsky's (1987) recommendations for concept development, instruction is crucial to help students progress from concrete to abstract thinking. After they received instruction, many students (30%) used the concrete experiences that they had witnessed in the lesson activity to describe the concept of density. For example, some students used procedural information on post-concept maps, information that either described how volume or mass was measured (using a ruler

or the water-displacement method and using a balance). Preservice teachers also used coping strategies derived from the lesson activity that formed emerging concepts about density. Emerging concepts are based on concrete experiences and depict students' complex, not abstract, thinking. These emerging concepts reflect learners' complex thinking but edge learners toward scientific understanding of the scientific concept. Examples of emerging concepts in this study involved using the density formula or compactness to define density.

Overall, these results demonstrate that preservice teachers who participated in this study used concrete experiences to explain density and were still struggling to report abstract concepts, such as defining density as property of matter. Only 4% of students used the correct scientific concept of property of matter to define density. Results about lack of comprehension of density as a property of matter coincide with similar research findings reported in the literature (Dawkins et al., 2008). The concept of density as a physical property of matter is addressed in general chemistry classes. The researcher analyzed the transcripts of student teachers who participated in this study and found that only three participants had taken a general chemistry class. Therefore, the research recommends that student teachers be required to enroll in a general chemistry course as part of the curriculum of teacher preparation programs for elementary science education.

Misconceptions Exhibited by Preservice Elementary Teachers

Some misconceptions proved to be weak and were removed by instructional intervention, such as density is volume, is a change of state, or involves a chemical reaction. All three misconceptions were reduced to zero appearance on student post-concept maps, which indicates that addressing these misconceptions during the course of instruction did succeed in removing the misconceptions from students' responses. Other misconceptions related to density as heaviness or mass were reduced from 33% to 23%. Participants used these misconceptions to erroneously predict that heavier objects will sink and that lighter objects will float, a misconception that has been cited in the literature as being used by K-12 students (Knel et al., 1998; Smith et al., 1985; Smith et al., 1997; Smith et al., 1992). The results indicate that further instruction is needed to address this misconception, which proved to be one of the more robust misconceptions that the researcher examined in this study. Overall, the most robust misconception was the concept of associating density with the phenomena of sinking and floating, a misconception which persisted in some students' post-concept maps (42%). Kohn (1993) showed that students as young as 4 can relate density and buoyancy. However, preservice elementary teachers who participated in this study still struggled with relating density to buoyancy. This finding corresponds with other findings in the literature about preservice teachers (Greenwood, 1996; Stepan et al., 1988).

Students continue to confuse density and buoyancy and to have problems recognizing the relationship between the two concepts (i.e., buoyancy, not density, explains sinking and floating). The Archimedes principle is what explains the relationship between density and buoyancy and, based on the results of this study, seems to be what is lacking in students' understanding of the two interrelated concepts of density and buoyancy in explaining the phenomena of sinking and floating. Buoyancy and the Archimedes principles are taught in a required class in science concepts. Although the majority of students (72%) scored an A or a B in that class, they could not distinguish density from buoyancy. This implies that further effort is needed to address misconceptions related to the Archimedes principle.

Categorization of Misconceptions Exhibited by Elementary Preservice Teachers

Categorizing students' misconceptions using Vygotsky's (1987) theory of concept development showed that the majority of students who participated in this study were thinking at the complex phase and were using pseudo-concepts to explain density. Vygotsky (1987) defined pseudo-concepts as spontaneous concepts derived from everyday experiences that students encounter. Pseudo-concepts seem like scientific concepts. Pseudo-concepts may be based on partial knowledge of a concept, but this knowledge is not unified knowledge and can be exposed as pseudo-concepts when students apply it in the wrong contexts. In this study, the concept of density as floating and sinking is a pseudo-concept. Student teachers confused

the concept of density with the concept of buoyancy and erroneously used density to explain the phenomena of sinking and floating. Instructors must clearly make the distinction between the two concepts by pointing to the fact that buoyancy is the correct scientific word to use to explain the observed phenomena of sinking and floating. Vygotsky (1987) emphasized the role of language in transferring knowledge. Therefore, instructors must also use the most accurate and precise terminology when instructing students to avoid misconceptions and to develop the correct scientific vocabulary to be used by prospective teachers.

Finally, 67% of the student teachers who participated in this study used emerging concepts, such as using the density formula, to define the concept of density, and 5% students used compactness to define density. Although students could recite the density formula, they did not conceptually understand density. This shows that these students are still thinking at the complex level and have not developed conceptually to the abstract level. Results about students defining density as compactness of particles in objects is similar to results from other studies reported in the literature (Hewson, 1986). Although explaining density with compactness may be treated as conceptually adequate, this explanation still falls short of understanding that density is a physical property of matter, indicating that students' thinking probably revolves around macro concepts that are sensory in nature (e.g., how thin or thick a particular substance is). Only 4% of students used the correct scientific concept of property of matter to define density. This indicates that instruction about the concept of density in content classes must emphasize this definition.

Implications for Improvements in Teacher Preparation Programs

This study was conducted at a higher education institute in the U.S., an institute with a large teacher preparation program that certifies 300 teachers a year. Based on the results of this study, this research recommends that future researchers continue to use concept maps to identify common misconceptions associated with student teachers' understanding of important scientific concepts to be taught in their prospective programs. Further insight into students' conceptual understanding can be achieved using Vygotsky's (1987) theory of concept development. Furthermore, the results of this study show the need to address specific content knowledge of student teachers about critical concepts, such the concept of density. More emphasis is needed in both content courses and in science methods courses for teaching the Archimedes principle and how it is used to explain sinking and floating and in teaching density is a property of matter. Also, prospective student teachers should be required to enroll in a general chemistry class as part of their coursework for teacher certification at the elementary level.

References

- [1]. Akerson, V. L. (2005). How do elementary teachers compensate for incomplete science content knowledge? *Research in Science Education*, 35, 214–268.
- [2]. Au, K. H. (1992). Changes in a teacher's view of interactive comprehension instruction. In L. C. Moll (Ed.), *Vygotsky and Education: Instructional Implications and Applications of Sociocultural Psychology* (pp. 271–286). Cambridge, England: Cambridge University.
- [3]. Ausubel, D. P. (1963). *The Psychology of Meaningful Verbal Learning*. New York, NY: Grune & Stratton.
- [4]. Boyatzis, R. E. (1998). *Transforming Qualitative Information: Thematic Analysis and Code Development* (2nd ed.). Thousand Oaks, CA: Sage.
- [5]. Bransford, J., Brown, A. L., & Cocking, R. R. (Eds.). (1999). *How People Learn: Brain, Mind, Experience, and School*. Washington, DC: National Academy Press.
- [6]. Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, 3, 77–101.
- [7]. Brooks, D. W., & Shell, D. F. (2006). Motivation and teacher-initiated learning. *Journal of Science and Technology*, 15(1), 17–30.
- [8]. Chi, M. T. H. (2005). Commonsense conceptions of emergent processes: Why some misconceptions are robust. *The Journal of the Learning Sciences*, 14(2), 161–199.
- [9]. Dawkins, K. R., Dickerson, D. L., McKinnet, S. E., & Butler, S. (2008, September/October). Teaching density to middle school students: preservice teachers' content knowledge and pedagogical practices. *The Clearing House*, 21–26.
- [10]. Esiobu, G. O., & Soyibo, K. (1995). Effects of concept and Vee mappings under three learning modes on students' cognitive achievement in ecology and genetics. *Journal of Research in Science Teaching*, 32(9), 971–995.

- [11].Francisco, J. S., Nakhleh, M. B., Nurrenbern, S. C., & Miller, M. L. (2002). Assessing student understanding of general chemistry with concept mapping. *Journal of Chemical Education*, 79(2), 248–257.
- [12].Greenwood, A. (1996). When it comes to teaching about floating and sinking, preservice elementary teachers do not have to feel as though they are drowning! *Journal of Elementary Science Education*, 8(1), 1-16
- [13].Hewson, M. G. (1986). The acquisition of scientific knowledge: Analysis and representation of student conceptions concerning density. *Science Education*, 70(2), 159–170.
- [14].Heyworth, R. M. (1999). Procedural and conceptual knowledge of expert and novice students for solving of a basic problem in chemistry. *International Journal of Science Education*, 21, 195–211.
- [15].Hoz, R., Bowman, D., & Chacham, T. (1997). Psychometric and edumetric validity of dimensions of geomorphological knowledge which are tapped by concept mapping. *Journal of Research in Science Teaching*, 34(9), 925–947.
- [16].Kohn, A. (1993). Preschoolers' reasoning about density: Will it float? *Child Development*, 64, 1637–1650.
- [17].Krnel, D., Watson, R., & Glazar, S. A. (1998). Survey of research related to the development of the concept of matter. *International Journal of Science Education*, 20(3), 257–289.
- [18].Libarkin, J. C., Crockett, C. D., & Sadler, P. M. (2003). Density on dry land. *Science Teacher*, 70(6), 46–50.
- [19].Liu, X., & Hinchey, M. (1993). The validity and reliability of concept mapping as an alternative science assessment. Paper presented at the Third International Seminar on Misconceptions and Educational Strategies in Science and Mathematics of the Misconceptions Trust, Ithaca, NY.
- [20].Markow, P. G., & Lonning, R. A. (1998). Usefulness of concept maps in college chemistry laboratories: Students' perceptions and effects on achievement. *Journal of Research in Science Teaching*, 35(9), 1015–1029.
- [21].Mason, C. L. (1992). Concept mapping: A tool to develop reflective science instruction. *Science Education*, 76(1), 51–63.
- [22].Novak, J. D., & Canas, A. J. (2008). *The theory underlying concept maps and how to construct and use them* (IHMC Report Cmap Tools 2006-01 Rev 01-2008). Retrieved from Florida Institute for Human and Machine Cognition website: <http://cmap.ihmc.us/publications/researchpapers/theorycmaps/theoryunderlyingconceptmaps.htm>
- [23].Novak, J. D., & Gowin, D. B. (1984). *Learning How to Learn*. New York, NY: Cambridge University Press.
- [24].Novak, J. D., & Musonda, D. (1991). A 12-year longitudinal study of science concept learning. *American Educational Research Journal*, 28(1), 117–153.
- [25].Park, K. (1993). A comparative study of the traditional calculus course vs. the calculus & mathematica course (Doctoral dissertation). *Dissertation Abstracts International*, 54, 119A.
- [26].Penner, D. E., & Klahr, D. (1996). The interaction of domain-specific knowledge and domain-general discovery strategies: A study with sinking objects. *Child Development*, 67, 2709–2727.
- [27].Roletto, E., Regis, A., & Albertazzi, P. G. (1996). Concept maps in chemistry education. *Journal of Chemical Education*, 73, 1084–1088.
- [28].Roth, W.-M., & Roychoudhury, A. (1993). The concept map as a tool for the collaborative construction of knowledge: A microanalysis of high school physics students. *Journal of Research in Science Teaching*, 30, 503–534.
- [29].Ruíz-Primo, M. A. (2000). On the use of concept maps as an assessment tool in science: What we have learned so far. *Revista Electrónica de Investigación Educativa*, 2(1), 29-53.
- [30].Ruíz-Primo, M. A., & Shavelson, J. R. (1996). Problems and issues in the use of concept maps in science assessment. *Journal of research in science teaching*, 33(6), 569–600.
- [31].Ruíz-Primo, M. A., Schultz, S. E., Li, M., & Shavelson, R. J. (2001). Comparison of the reliability and validity of scores from two concept-mapping techniques. *Journal of Research in Science Teaching*, 38(2), 260–278.
- [32].Smith, C., Carey, S., & Wisner, M. (1985). On differentiation: A case study of the development of the concept of size, weight, and density. *Cognition*, 21, 177–237.
- [33].Smith, C., Maclin, D., Grosslight, L., & Davis, H. (1997). Teaching for understanding: A study of students' preinstruction theories of matter and a comparison of the effectiveness of two approaches to teaching about matter and density. *Cognition and Instruction*, 15(3), 317–393.
- [34].Smith, C., Snir, J., & Grosslight, L. (1992). Using models to facilitate conceptual change: The case of weight-density differentiation. *Cognition and Instruction*, 9, 221–283.
- [35].Stepans, J., Dyche, S., & Beiswenger, R. (1988). The effect of two instructional models in bringing about conceptual change in the understanding of science concepts by prospective elementary teachers. *Science Education*, 72(2), 185–195.

- [36]. Stoddart, T., Abrams, R., Gasper, E., & Canaday, D. (2000). Concept maps as assessment in science inquiry learning: A report of methodology. *International Journal of Science Education*, 22(12), 1221–1246.
- [37]. Tasdere, A., & Ercan, F. (2011). An alternative method in identifying misconceptions: structured communication grid. *Procedia-Social and Behavioral Sciences*, 15, 2699–2703.
- [38]. Williams, C. G. (1998). Using concept maps to assess conceptual knowledge of function. *Journal for Research in Mathematics Education*, 29(4), 414–421.
- [39]. Wilson, J. M. (1994). Network representations of knowledge about chemical equilibrium: Variations with achievement. *Journal of Research in Science Teaching*, 31, 1133–1147.
- [40]. Vygotsky, L. (1986). *Thought and Language* (A. Kozulin, Trans.). Cambridge, MA: MIT Press. (Original English translation published 1962)
- [41]. Vygotsky, L. S. (1987). Thinking and speech. In R. Rieber & A. Carton (Eds.) and N. Minick (Trans.), *Collected Works* (Vol. 1, pp. 39–285). New York, NY: Plenum.
- [42]. Yin, Y., & Shavelson, R. (2008). Application of generalizability theory to concept map assessment research. *Applied Measurement in Education*, 21, 273–291.
- [43]. Yin, Y., Vanides, J., Ruíz-Primo, M. A., Ayala, C. C., & Shavelson, R. J. (2005). Comparison of two concept-mapping techniques: implications for scoring, interpretation, and use. *Journal of Research in Science Teaching*, 42(2), 166–184.