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Research Article

The Challenges of Understanding Fluid in Fluid Density

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Abstract

Teachers' understanding of science concepts must be deeper than just factual knowledge. They need to understand how the facts are connected and relate to the natural world. Weather, ocean currents, and tectonic movement are all phenomena listed in the Next Generation Science Standards (NGSS). Although understanding density of fluids within fluids is not directly mentioned in the NGSS, students need to understand fluid density in order to explain these common yet complex phenomena. We extended a familiar science activity of making a density column in order to help teachers understand the expectations of NGSS. Understanding the causes of the phenomena is critical for teachers. We found when students do not understand, they are more likely to substitute concrete or active causal factors, such as weight or force. We issued to our teachers the following challenge: "Make a density column with these 4 mystery liquids." As our students were in the process of determining the correct order to add the liquids, we noticed they confused mass and viscosity with density. In light of the expectations of the NGSS, we need to change the way teachers are prepared. They need time and space to practice connecting the concepts in practice. Therefore, teachers need help to connect the concepts to past experiences as well as time to reflect and revise. Teachers need to develop a mindset as a lifelong learner powered by their reflections and drive to help students understand science.

Keywords: Professional Development; Density; Next Generation Science Standards; Science Concepts; Fluid Density; Domain Knowledge

1. Introduction

Education is a keystone of our culture. Education can prepare students to become contributing members of society. However, in order for the education system to be successful, teachers must be prepared to teach the required curriculum. Their understanding of the concepts must be deeper than just factual knowledge (Harlen & Holroyd, 1997); they need to understand how the facts are connected. Teachers' domain knowledge affects the quality of their teaching (Fritsch et al., 2015) and subsequently their students' achievement.

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This study is from one part of a long-term professional development designed to prepare teachers to use the Next Generation Science Standards (NGSS). Professional development is the most efficient and successful way to prepare teachers for changes in enacted curriculum (Desimone, Smith, & Ueno, 2006) and has been directly linked to student achievement (Darling-Hammond, 2000; National Research Council, 1996). Teachers participating in professional development are continuing their professional growth and actively taking responsibility for their learning (National Research Council, 1996). This professional development gave the teachers the opportunity to interact with material and collaborate with others, which contributed to their overall learning (Bransford, Brown, & Cocking, 2000). Our goal was to prepare the teachers to successfully implement the NGSS.

1.1 The NGSS

What makes warm and cold weather fronts? What causes ocean currents? Why are some clouds tall, while others are short and plump? What causes subduction zones between continental and oceanic plates? These are all phenomena listed in the middle school NGSS, the suggested science standards in the United States. Although understanding density of fluids within fluids is not directly mentioned in the NGSS, students need to understand fluid density in order to explain the common yet complex phenomena mentioned above. We addressed this concern with teachers during the professional development. We deliberately took a familiar science activity of making a fluid density column and extended it to help our teachers understand the expectations of NGSS. This demonstrated to the teachers how fluid density is part of such processes as hot air rising, convection currents of molten rock, formation of layers of water in oceans and lakes, and characteristics of matter. Understanding density, a property of matter, is important for not only understanding the previously mention phenomena but also learning about other concepts of science (Hadenfeldt, Neumann, Bernholt, Liu, & Parchmann, 2016).

The NGSS were released in April 2013. These standards were written with contributions from 26 state representatives along with the National Science Teachers Association, the American Association for the Advancement of Science, National Research Council, and Achieve (NGSS, 2013). The goals of the NGSS were to create common standards among the states in the United States, develop greater interest in science, and support ways to cover fewer standards with in-depth expectations (NGSS, 2013). The NGSS have three dimensions that act as a framework for their design: (a) core ideas, or specific content; (b) science and engineering practices, which means methodology of scientist or engineers; and (c) cross-cutting concepts, which are underlying concepts common to multiple science topics. Most states are predicted to adopt these standards by 2021. This is a new way to frame science standards with the emphasis on sense making and not memorizing (National Science Teachers Association, 2013). This change in emphasis requires training teachers to implement the standards in their classrooms. Unlike previous standards, which were a checklist of individual concepts, the focus is on systems and how phenomena are part of many basic science concepts. Teachers need to be able to understand the underlying concepts that contribute to natural phenomena to understand how the system functions and how the systems work together. In the professional development we wanted to help the teachers reach this understanding, but first they needed to realize their current understanding of fluid density.

1.2 Density

The education literature generally has recognized that promoting students' understanding of density has a long and problematic history (Hitt, 2005; Libarkin, Crockett, & Sadler, 2003; Maclin, Grosslight, & Davis, 1997). We have found students do not understand density as a contributing factor in everyday phenomena. This difficulty in understanding increases students' tendencies to substitute concrete or active causal factors, such as weight or force (Driver, Newton, & Osborne, 2000), rather than density. Ultimately, these naïve conceptualizations hinder students from understanding more advanced science topics such as weather patterns, plate tectonic movement, and convection currents. As density is not obvious in these phenomena, students find it challenging to understand and connect density to phenomena. Most students think of weight and density as the same thing (Smith, Carey, & Wiser, 1985; Smith, Maclin, Grosslight, & Davis, 1997; Smith, Snir, & Grosslight, 1992). Students tend to focus on a single feature of an object (weight, size, or shape) or the material of the object (Smith et al., 1985). This focus is usually found when students try to explain sinking and floating. Typically, they focus only on the object that they are testing to see if it sinks or floats, ignoring the liquid (Houghton, Record, Bell, & Grotzer, 2000).

Another issue with understanding density is students explaining differences in objects with the same volume but a different mass posit it is because one object is "filled with air" (Grotzer et al., 2005, p. 9). Although this is one possible explanation, students often do not realize the possibility that the object is not hollow but is made of a substance of lesser density. Various possible explanations, both from a perceptual and cognitive sense, would require students to pay attention to the weight of an object or focus on the sinking or floating object and thereby locate the cause of sinking or floating of the entity itself.

Density is an intensive quantity, meaning that one cannot directly see or measure it. It must be inferred by holding either volume or mass constant and assessing the implications for the other variable (Inhelder & Piaget, 1958). This typically creates huge difficulties for students (Bliss, 1995). Experiences with natural phenomena do not offer opportunities for students to hold the mass or volume of an object constant in order to make density obvious. Weight and surface features, however, can be evaluated instantly, which attracts students' attention, making it unlikely that they will look beyond these features to infer the existence of density (Grotzer, 2015; Grotzer et al., 2005).

In much the same way, understanding the role of density in sinking and floating or liquid in liquid, students need to reason about the relationship between the densities involved, either between object and fluid or between fluid and fluid. This relational causality indicates that an effect is caused by the relationship between elements of a system. Neither element is the cause by itself. Thinking about relational causality demands a different approach than linear or unidirectional forms of causality, where one object or entity acts as a causal agent on another (Grotzer, 1993).

The phenomena listed earlier, warm and cold weather fronts, ocean currents, and cloud shapes, are all connected to relative density; the relationship between two or more densities causes the outcome. The understanding of relative density begins with an even more basic relationship—the relationship of mass to volume. Understanding density as a relationship is important for students along with being able to grasp the generative concept of relative density. Density is given some attention in science—unfortunately, fluid density is less emphasized and fluid in fluid density lesser still.

Issues with density do not reside only with the learner. The challenges of fully understanding density are amplified by a number of teaching practices. For instance, we have found common practices include teaching specific densities for various materials without letting students know that density can change. We also have seen instances of teachers referring to certain objects as “sinkers” and others as “floaters” without reference to the nature of the liquid. In classroom observations, we noted one activity in primary grades where students are asked to make a list of objects that sink and objects that float. Although seemingly benign, this type of activity neglects the fact that most objects will sink in some liquids and float in others, thereby supporting a linear static model. This contributes to a range of difficulties for students later. For instance, it makes it difficult for students to understand such everyday phenomena as weather patterns, mineral content of rocks, and tectonic plate movement.

Our teachers had earned 12 undergraduate credit hours of science instruction from the College of Natural Sciences. However, we found that they faced the same challenges with fluid density as many students.

2. Main Research

2.1 Research Question

Our study was guided by a single research question. What difficulties do the teachers have in understanding fluid density?

2.2 Participants

We have done this activity in six different professional development sessions (*N* = 120 teachers, 12 males) with different cohorts. A typical cohort consists of approximately 20 teachers, and all the teachers were concurrently teaching. Our sample had 30 different laboratory groups. We looked specifically at the lab groups rather than the individual students. The teachers were always working in lab groups. The teachers were all new to the profession; none of the participants had more than 3 years of teaching experience.

2.3 Methods

The professional development for this research was part of a series of professional developments attended by each cohort. The cohort met weekly for several weeks. Therefore, these teachers were comfortable with each other and familiar with inquiry-designed activities. We began this session of the professional development with the challenge. The only review of density was showing the teachers examples of density columns. The teachers agreed that they were familiar with density columns, and most had previously done a similar lab (Riegle-Crumb et al., 2015). We issued the following challenge: “Make a density column with these four mystery liquids” using any of the equipment or tools available in the classroom except computers or their phones. Teachers were told that they needed to know the density order of the liquids in the column before they began adding the liquids into the column. The lab was performed at room temperature with all liquids at room temperature. For the challenges we used light corn syrup (d = 1.37 g/mL, blue colored), distilled water (d = 1 g/mL, green colored), glycerin (d = 1.26 g/mL, colored red), and castor oil (d = 0.959 g/mL, natural colored). We choose common liquids so that the teachers would have access to the supplies if they did this activity in their classroom. Teachers were given an open environment to determine the methods and equipment needed to solve the challenge and the time to implement their plan. For data, the researchers observed the teachers, took observational notes, analyzed the teachers' notes, and analyzed the postlab explanations. By mutual agreement the researchers determined the coding of the data.

We were interested in the process the teachers would use to solve the challenge and whether their process was successful. The teachers had minimal guidance from the professional development team. The design of this research was to observe emergent understanding and misunderstanding of density. This information guided the rest of the professional development. We wanted the teachers to develop a better understanding of density and how density is a contributing factor of phenomena in the natural world.

3. Results

Despite variations in equipment and methods used, we were able to identify five general types of methods employed (Table 1). Every group's process could be categorized into the five general methods. The groups tried the different methods in various orders (Fig. 1). Table 1 shows the number of lab groups that tried each method to determine the density of the mystery liquids. Whereas 30 lab groups participated in professional development, several groups tried more than one method.

Table 1 Number and Percentage of Lab Groups (*N* = 30) Trying Each Method

Method	*n*	%
Rate of solids sinking in the liquids	4	13
Flow of the liquids	25	83
Droplets rate	26	87
Comparing relative density	3	10
Solving for density	2	7

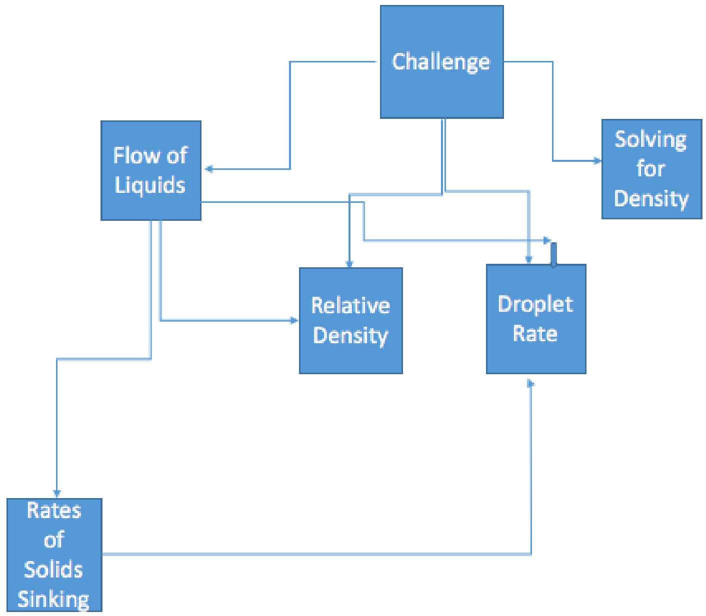

Fig. 1. The different pathways that lab groups took to solve the challenge.

3.1 Rate of Solids Sinking in the Liquids

Four groups (13%) dropped a marble in each beaker full of the liquids and timed with a stopwatch how long it took the marble to hit the bottom of the beaker. Each of the four groups abandoned the process because they were unable to measure the time with accuracy. Another group in another cohort had a similar idea but used a plastic ball and the liquids in cups (Fig. 2). They realized that the plastic balls would not sink in the liquids. This method did not give the teachers the correct sequence of the liquids for the density column.

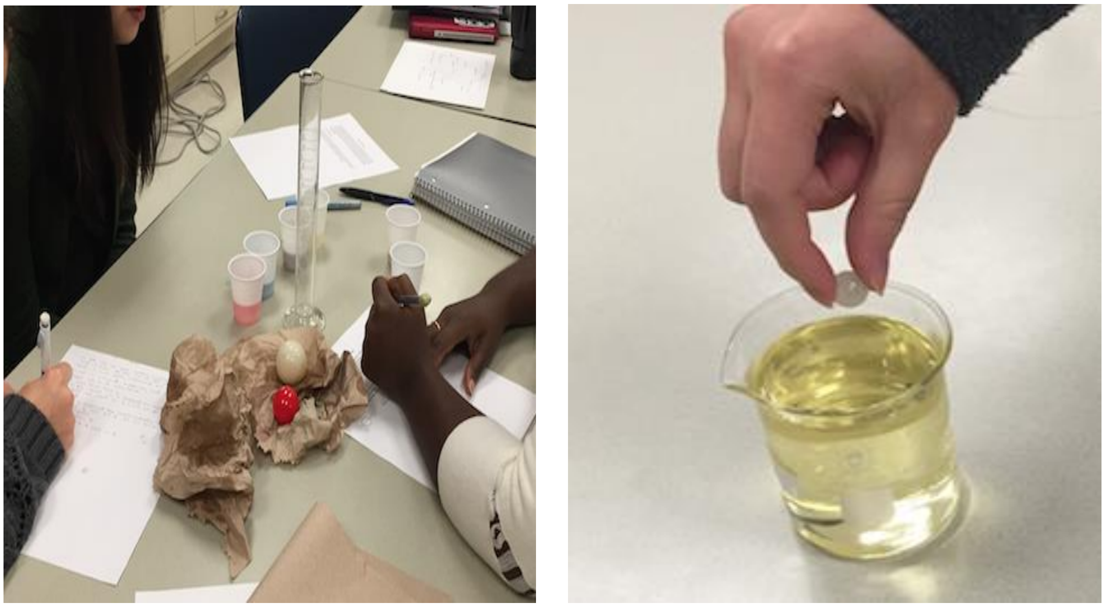

Fig. 2. These lab groups tested how long it took a marble to reach the bottom of each cup. The group first tried the plastic balls but discovered that neither would sink so they switched and used a marble.

3.2 Flow of the Liquids

Twenty-five groups (83%) swirled the liquid in beakers. As one group explained, "To predict and compare the density of the four liquids, we tilted each of the beakers side to side to see how quickly or slowly the liquid would react." Swirling and observing the movement of the liquids in the beakers was the first process most groups tried. Those groups that stopped with just these data did not come to a correct solution of the sequence of the liquids in the density columns. These groups assumed that oil is denser than water because the oil was more viscous. However, when we asked them to "explain how an oil spill in the ocean looks," they answered the oil is on top of the water or that the oil creates a layer on top of the water. These teachers hypothesized that the slower the liquid moved, the denser the liquid.

3.3 Droplets Rate

The most common method, tried by 87% of the groups, was a variation of putting drops at the top of a piece of paper and timing how fast the drop flowed to the bottom of the paper. Some groups used paper towels or notebook paper, and one group used an individual white board. This also led to a predictable incorrect hypothesis of the order of the liquids in the density column.

3.4 Comparing Relative Density

Three groups dropped water droplets into the mystery liquids to determine the relative density. They understood that water was a constant and therefore compared water to the other mystery liquids. When asked why, they said, "We were just comparing the density of the liquids to that of water." When we probed the group about the density of water, they were not sure, but one person thought it might be zero. Another lab group wrote in their postlab,

> We tested two liquids at a time. We started predicting that blue [corn syrup] was denser based on its consistency. We tested the green liquid [distilled water]. … We talked about using the formula, but we compared the way other groups were figuring out the density and did the same.

Both of these groups determined the correct order of the liquids in the density column before they added the liquids to their column.

3.5 Solving for Density

Two lab groups in the six professional development cohorts did start by using the formula D = m/V; see Fig. 3. One of the two lab groups that took the mass of each liquid painstakingly made sure they had the same volume for each liquid. They wrote, "We put exactly 7 mL of each liquid into the same cylinders and compared the four cylinders on a balance scale. We determined the order from least heavy to most heavy." This shows a lack of understanding that volume changes proportionally with mass and that mass and density are not the same (Gomez-Zwiep & Harris, 2007).

3.6 Debrief

After the challenge, we debriefed. The first question was, "What is the formula for density?" In every cohort, the teachers were able to recite, "Density equals mass over volume." This result was similar to what Deich (2015) found with sixth graders. Some of the teachers said they thought of the formula while they were doing the challenge, but they either did not know how to use the formula or did not know what equipment would give them the density. One group wrote in their lab debrief, "We have never used the formula in real life, so it didn't occur to us to use it in the lab." Another group wrote, "You could see how dense something was based on how thick it was, but after we did this lab, we realized why when we make pasta in boiling water the oil always floats on top." When the teachers were asked about what units were used for density, the most common response was grams, demonstrating the teachers did not understand that density is a ratio (Smith et al., 1985).

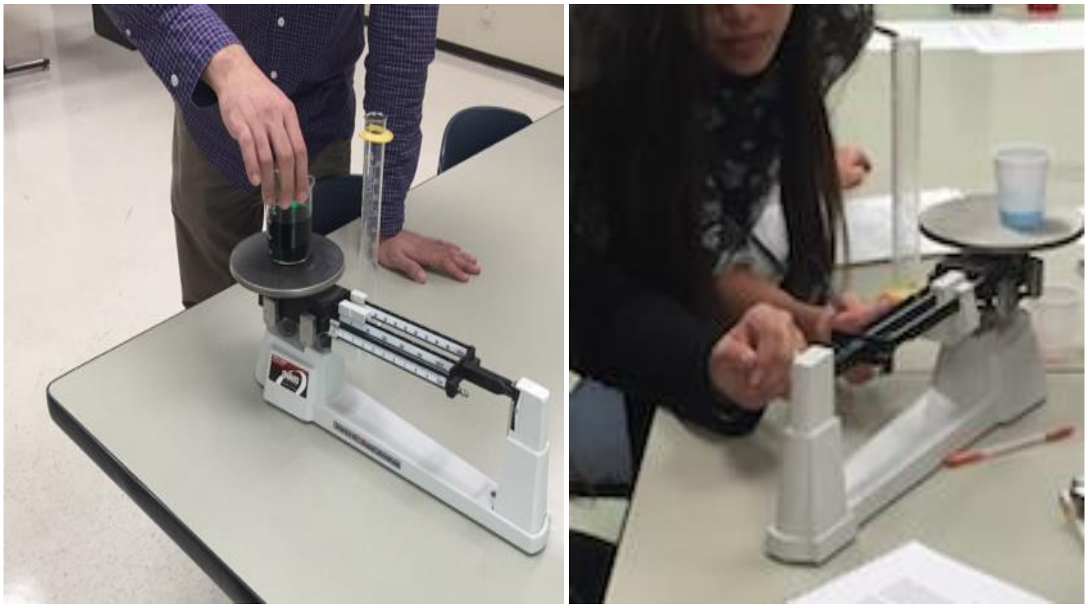

Fig. 3. Some lab groups used the density formula to determine the density of the liquids.

4. Conclusions

We have done this activity with six different cohorts, and only two lab groups observed (7%) reached for a balance to determine the mass of the mystery liquids. Yet, each cohort said they had made a density column previously. These teachers found difficulty in connecting the multiple density algorithmic problems they have previously solved with the actual act of determining density of a fluid, similar to students in middle school (Deich, 2015). Some groups were comparing relative density of each fluid; the groups that dropped the marble into each fluid and the groups that were measuring the mass of the fluids were looking at density and subsequently buoyancy. The students in these groups had some understanding of density. The groups that were looking at the flow of the liquids and the rate the droplets flowed down a piece of paper were examining viscosity. These teachers were confusing the two concepts, which made it important to investigate further fluid density and its properties along with exploring viscosity. We also found evidence that the teachers confused density with mass or did not understand density as a ratio; they mentioned the units of density as grams, and lab groups attempted to keep the volumes of the mystery fluids constant. This activity clearly showed us that teachers need more experiences in actual science or they might pass on some of the same misconceptions to their future students (Maclin et al., 1997). Teachers also need expanded lab experiences with the properties of weight and volume to be able to understand the concept of density (Lehrer, Schauble, Strom, & Pligge, 2001). Finally, teachers might know the algorithmic formula but might not be able to attach that understanding to activities in the classroom context (Deich, 2015).

This educational dilemma sounds challenging, but part of the solution is beginning this conversation. We have great expectations of science teachers, and yet many are not trained as experts in the disciplinary content of science (Fuentes, Bloom, & Peace, 2014; Howitt, 2007; McLaughlin, 2015). Therefore, teacher preparation programs need to change the way teachers are prepared. First, teachers need time and space for hands-on labs to connect the concepts in practice. Second, as professional development mentors, faculty need to help them connect the science concepts to past experiences. Third, faculty need to model how to accomplish this in the classroom. Finally, teachers need time to reflect and revise.

Teachers need a mindset as a lifelong learner powered by reflections and drive to help students understand science. In our case, we had the teachers use their reflections to design a lesson to be used with their middle school students. Now that they were aware of their misconceptions, we wanted them to design a lesson that would teach their students about density. Being aware of the misconceptions people have about density will help teachers be able to guide their students. Teachers will be able to connect density to such processes as hot air rising, convection currents of molten rock, formation of layers of water in oceans and lakes, and characteristics of matter.

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