Investigating Density in the Spirit of Eureka!

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"*The king of Syracuse (in nowadays Sicily, Italy) gave some gold to a goldsmith and ordered him to make a new crown. After some weeks, the goldsmith came back and brought a new crown to the king. The crown was massed. The mass of the crown was the same as the gold given to the goldsmith. The king examined the crown skeptically and he was suspicious. Could the goldsmith have stolen some gold from the gold given to him? The king wanted to investigate the truth to find how much gold might have been stolen.*"

Ana, a fifth grade science teacher, retold an age-old story about the king and his new crown with much enthusiasm. She understands the importance of engagement in learning and is convinced that using the true historical account of Archimedes and his experiment is the best way to introduce this lesson. Ana did not finish the story on purpose because it was used as an opening to the science lesson. After the brief introduction the teacher said, "Class, we now have a problem. We need to help the king find out if gold had been stolen in making the new crown. Do you have suggestions?"

"I think the goldsmith is honest and nothing has been taken." said Tom. "What is your reason for saying that?" the teacher asked. "Well, the mass of the crown and the mass of the gold given to him is the same. Isn't it?" the student replied. "That is correct Tom. However, is it possible that two substances that have the same mass can be different in volume?" Ana pressed on. The class was very puzzled. "What is the difference between one kilogram of iron and one kilogram of feathers?" Ana asked again. Now the class was divided. Some students claimed that they are the same because they had the same mass. Other students said that they were different because one kilogram of iron had to be much smaller in volume than an equal mass of feathers. The iron-feather discussion slowly but surely led the class to investigate a very important physical property of matter – density.

"The king ordered his court scientist Archimedes (287-212 BC) to find the truth. Archimedes thought about the problem for a long, long time and he had no answer. One day he was ready to take his tub bath. The tub was filled to the brim with water. Archimedes slid into the bathtub and a large volume of water overflowed the tub. The spilling water caught his attention. Suddenly, he thought through the new crown problem. He jumped out of the bathtub, shouting Eureka! Eureka!" Ana continued with the story and explained that Eureka in Greek means "I have found it."

Figure 1. Archimedes (287 – 212 BC).

Source: http://www.google.com/imgres?imgurl=http://twistedphysics.typepad.com/cocktail_party_physics/images/2007/07/16/archimedes.jpg

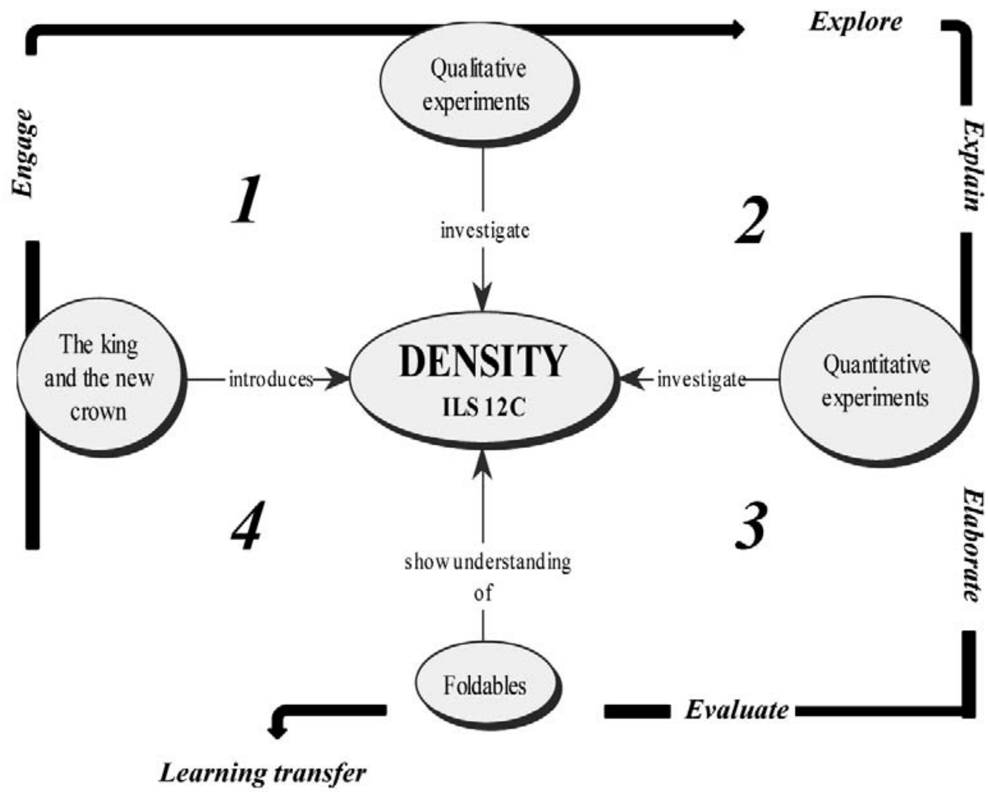

Figure 2. The Learning Quadrants: A Modification of the Learning Cycle.

"Archimedes took two identical vessels and filled them to the brim with water. He then placed each container separately in the middle of another large container. Archimedes submerged the crown in one vessel. Similar to the bathtub experience, water overflowed from the vessel to the outer container. Archimedes repeated the water submersion procedure with a lump of pure gold that had the same mass as the gold crown. Again, the water overflowed and collected in the outer container. Archimedes compared the volume of overflow water in the containers. If the crown and the lump of gold had the same mass, they should have displaced the same volume of water. He found that the crown displaced a larger volume of water than the lump of gold. Therefore, Archimedes concluded that the crown must have some other metals mixed in it, thus taking up more volume in the water than pure gold. Finally, the goldsmith confessed that he had taken some gold from the crown and replaced it with other metals." Ana finished the story and reinforced the concept of density one more time by comparing the pure gold as the "one kilogram of iron" and the gold crown as the "one kilogram of feathers."

Density in science is often difficult for elementary grade students to understand. Elementary grade students can easily understand single properties of matter such as color, texture, and volume. Understanding density poses two conceptual challenges. The first is knowing the difference between mass (a property of matter) and weight (a force on a mass due to gravity). The second challenge is that two properties, mass and volume, are combined to make a third property, density.

Realizing the challenge of teaching density, Ana meticulously prepared a lesson framework that included concrete hands-on and computer simulated experiences. Figure 2 describes the four quadrants of the lesson framework. Comparable to the learning cycle, the first quadrant is designed to motivate students. The motivation phase sets the stage similar to the engagement phase of the learning cycle (Wong 2008). The engagement phase of the quadrant framework invites students to find out and learn. "We need to help the king to find if gold had been stolen in making the new crown. Do you have suggestions?" Many teachers often pay only lip service to motivating students, not appreciating that the impact of the engagement goes a long way in sustaining the learning process from beginning to end. For that reason, investing in engagement to learn is well worth the time.

Learning by using a historical case study like Archimedes's experiment effectively addresses Illinois Learning Standard (ILS) 13A that says "know and apply the accepted practices of science." The Illinois Standard Assessment Test (ISAT) has questions on historical and contemporary scientists. A good way to study the scientists is to retrace their work and contribution to science, not learning the scientist as just a famous name out of context.

Density is the mass per unit volume; all the molecules are distributed in some fashion in the matter. A high density object has molecules distributed closer together than another object that has low density. When liquids of different densities are put together, in most cases the one with lower density will be on top. Note that polar liquids, such as rubbing alcohol and water (density = 0.860 and 1.000 g/ml, respectively), will mix because they are attracted to each other and their densities are similar. If water and honey are mixed, even though they are both polar and therefore attracted to each other, they will not initially mix due to their different densities (1.000 versus 1.480 g/ml). The same holds true for nonpolar liquids. Polar and nonpolar liquids repel each other, and will stay separated even if their densities are nearly alike, for example water and corn oil (1.000 versus 0.930 g/ml). The understanding of density helps students understand the common phenomenon of sinking and floating.

There are numerous sink or float activities that teachers can use to teach density. Some can be as simple as predicting and testing whether selected common objects will sink or float in a medium such as water. Compare a can of regular soda versus a can of diet soda. Which one will sink and which one will float in water, and why? To challenge the students further, the predicting and the testing of the sinking or floating of objects can be done in a different medium with a different density than water such as oil. Students will gain a deeper understanding of the density concept if they can successfully transfer the sink or float concept from water to oil.

Ana gave her class two density take-home experiments that are qualitative in nature. The experiments are qualitative because they do not require students to do any numerical calculation or measurement. The first experiment asks students to demonstrate that they can separate fluids into distinct layers. The second experiment asks students to demonstrate that they can float different solids in the layers of liquid from the first experiment.

In the first experiment, students were asked to put five different household liquids (making sure that instructions were provided so that students used safe substances, and so that they did not mix hazardous solutions together) in a tall glass so they may separate into layers. Students reported that they used generally two approaches. The first one was trial and error. Students using this method simply found liquids from around the house and placed them in a tall glass with the hope that they would form into layers. A lot of frustrations were generated from this trial and error method. The other approach was more effective. Students first researched the density of five household liquids before they were put in a glass. Several students reported that they were successful after finding from the internet the densities of the following liquids: baby oil (0.830 g/ml), rubbing alcohol (0.860 g/ml), corn oil (0.930 g/ml), water (1.000g/ml), and corn syrup (1.380 g/ml). Knowing the densities, the students put corn syrup into the glass first followed by water, corn oil, rubbing alcohol, and baby oil. The second method was very systematic and a prior knowledge of liquid densities through research was required.

The second experiment was a continuation of the first experiment. It was prompted by asking students to predict and test how they could float three objects (for example cork stopper, candle, and steel bolt) in the layers of liquid from the first experiment. Most of the students learned well from the first experiment; therefore, they found out the densities of the three objects. The densities of the objects follow: the cork was 0.24 g/ml, the candle (wax) was 0.91 g/ml, and the steel bolt was 7.81 g/ml. Knowing the densities of the objects and the liquids, students were able to predict what object would float in which liquid layer with great precision. The cork stopper floated in water, the candle floated between the rubbing alcohol and the corn syrup, and the steel bolt would be at the very bottom of the corn syrup layer.

By the conclusion of the two qualitative experiments the students were well into the second

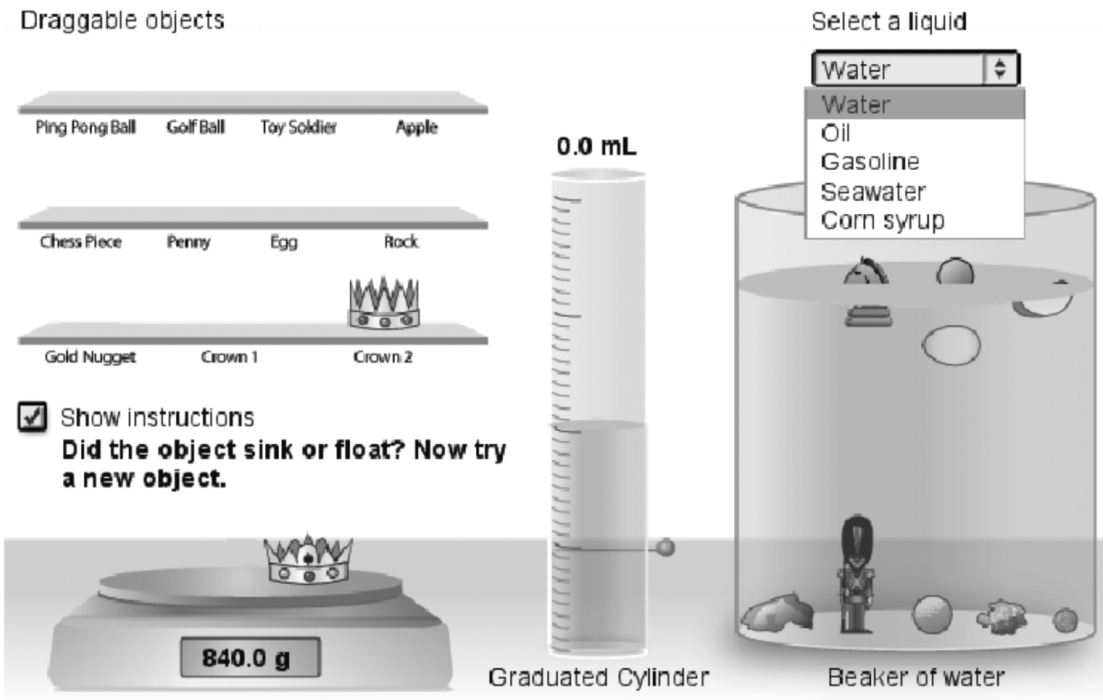

Figure 3. Density Experiment (used with permission from explorelearning.com).

quadrant of learning, exploring, and explaining (Figure 2). Beyond the initial exploring and explaining, students were now ready to do computer simulated lab activities. These activities were instructional by design and are optimized for learning. They were chosen for this segment of the instructional delivery to support the learning of density much like the science learning center in a classroom.

Figure 3 is a screen shot of the experiment from Explorelearning (www.explorelearning.com). Explorelearning is a subscription, web-based program and it is not free. Figure 3 shows eleven draggable objects on the shelf, a scale for massing, a graduated cylinder with water, and a large beaker also with water. The experimenter can drag any objects using the computer mouse from the shelf to the beaker of water. The screen shot shows that certain objects float while others sink in water. Why? Students can actually calculate the density of the object by finding the mass (from the scale) and the volume (by submerging it in the graduated cylinder of water). For example, the mass of the apple wedge is 33 grams and the volume of the apple is 44 ml. The density of the apple slice is therefore 33 g /44 ml = 0.75 g/ml. The density of water is 1.000 g/ml. No wonder an object of less density (apple) floats in a fluid of higher density (water). The mass of the golf ball is 45 grams and the volume is 36 ml. The density of the golf ball is therefore 45 g/36 ml = 1.25 g/ml. No wonder the golf ball sinks in water.

There is a drop down menu in the upper right corner of the screen shot that says "Select a liquid." Click the arrow and choose a different liquid such as oil, gasoline, seawater, or corn syrup. Students will be in for a surprise! Objects that were in water before will change their sink or float status in a different liquid. Why?

Do you see the two crowns? One is sitting on the bottom shelf and one is on the scale in Figure 3. Which is the fake crown and which is the real crown made of pure gold (hint: the density of gold is 19.30 g/ml)? A density comparison of the crowns is a very good investigation where a teacher can challenge students to apply their conceptual understanding of density to bring closure to the king and the new crown story. In learning quadrant 3

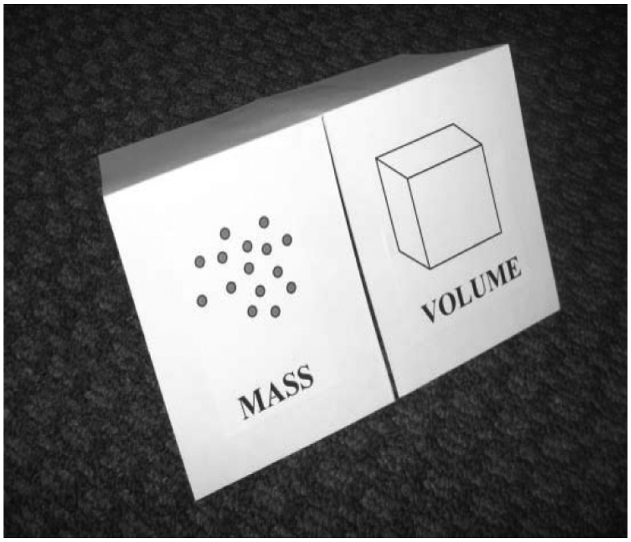

Figure 4. Foldable (A).

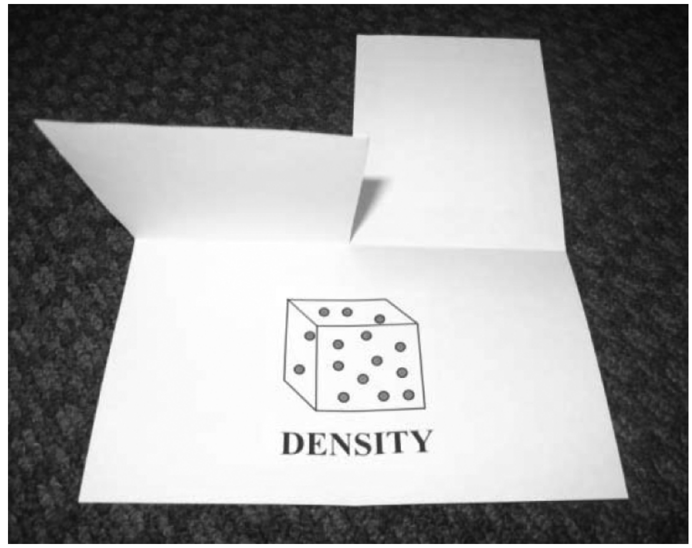

Figure 5. Foldable (B).

(Figure 2), activities to extend, apply, and transition in different situations are the elaboration phase of the learning cycle (Wong. 2008).

There are many ways to evaluate what students know and what they can do in science. The teacher can administer a paper and pencil assessment similar to the Illinois Standard Achievement Test. Sample test items are found in http://metacat2.com/iltestlinks.html. Or, the teacher can administer a performance based assessment and ask students to calculate, compare, and evaluate the properties of density using real-world objects and liquids. Wait. There are still other ways of assessment such as the foldables (Zike D. 2001). Students are asked to present their conceptual understanding in a visual format using a piece of 8" x 11" paper with foldable sections. Foldables divide a concept such as density into parts (that is, mass and volume). A three dimensional foldable allows a student to interact with the concept kinesthetically. Figure 4 shows a scissors cut between mass and volume on the front flap. Flipping open the front folds, one can see a graphic representation of density combining mass and volume in Figure 5. When asked how using the foldable diagram may show the same object with a lower density, the student answers "Simply reduce the amount of mass with the same volume." How can one argue that the student did not understand density visually and conceptually?

Teaching science to children is extremely exciting. The effectively teacher can creatively use various methods of delivery to engage the students. Has any teaching of discovery learning ever made you forget about yourself with extreme joy like Archimedes? Eureka!!

References

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Author Information

Ovid K. Wong is an associate science education professor at Benedictine University in Lisle, Illinois. He is the author of twenty-five books. His most recent book titled *Elementary Science with Classroom Experiments for ISAT* (Phoenix Learning Resources) is dedicated to coaching teachers and students to effectively prepare for the state-mandated science examination in Illinois. Different versions of the book were developed and written for New York and other states to prepare students for their respective state science examination.