TEACHING FOR CONCEPTUAL CHANGE IN A DENSITY UNIT TAUGHT TO 7TH GRADERS: COMPARING TWO TEACHING METHODOLOGIES - SCIENTIFIC INQUIRY AND A TRADITIONAL APPROACH

by

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A DISSERTATION

Presented to the Department of Educational Methodology, Policy, and Leadership
and the Graduate School of the University of Oregon
in partial fulfillment of the requirements
for the degree of
Doctor of Education

June 2012

DISSERTATION APPROVAL PAGE

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Title: Teaching for Conceptual Change in a Density Unit Taught to 7th graders: Comparing Two Teaching Methodologies- Scientific Inquiry and a Traditional Teaching Approach

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June 2012

Title: Teaching for Conceptual Change in a Density Unit Taught to 7th graders: Comparing Two Teaching Methodologies- Scientific Inquiry and a Traditional Teaching Approach

This mixed methods study was designed to compare the effect of using an inquiry teaching methodology and a more traditional teaching methodology on the learning gains of students who were taught a five-week conceptual change unit on density. Seventh graders ($N = 479$) were assigned to five teachers who taught the same unit on density using either a traditional or an inquiry teaching methodology. Data from five pre-post quantitative and qualitative assessments were used to determine student learning gains. Analysis of the data occurred at four levels: (a) overall student learning, (b) comparing methodologies across all students, (c) comparing methodologies across matched teachers, and (d) comparing methodologies across matched classes. Matching was based on scores from the statewide large-scale assessment of mathematics. Findings were mixed. At level 1, all students made statistically significant learning gains for the density unit. At level 2, results were ambiguous. There were no significant differences found between teaching methodologies for three of the pre-post assessments, but for two of the pre-post assessments, the inquiry group had statistically larger learning gains. When the analysis was performed at level 3, students taught using the inquiry methodology outperformed students taught using the traditional methodology. At level 4, students in high-performing math classes had statistically larger learning gains with the traditional methodology and students in low-performing math classes had greater learning gains with the inquiry methodology. When a multi-level model was used to account for the nested structure of the data, it was found in the inquiry methodology that students with the lowest math scores had the greatest learning gains, while in the traditional methodology, the students with the highest math scores had the greatest learning gains. This cross level interaction was a major finding of the study.

Students' content and conceptual understanding of density improved over the course of the density unit, with students in both groups making statistically significant learning gains, moving away from misconceptions about density to accurate qualitative and quantitative explanations. Students in traditional classes made the greatest learning gains at the qualitative level of density explanation, while more students in the inquiry group had a quantitative understanding of density at the end of the study than students in the traditional group.

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ACKNOWLEDGMENTS

I would like to thank Professors Zvoch, Kame'enui, Hollenbeck, and Anderson-Inman for their insight, feedback, and expertise in supporting me through the process of finishing this dissertation. Special thank you to Dr. Ed Kame'enui who spent countless hours reading and editing my first two chapters, Dr. Keith Zvoch who helped me to understand the power and beauty of statistics, and Dr. Julie Alonzo who first showed me that I could write academically and encouraged me as I worked to complete this gargantuan task. I am deeply grateful to the College of Education Doctoral Awards committee who awarded me the Ken A. Erickson Memorial Award and the UO Graduate School Award that allowed me to purchase the supplies to run my research study. I could not have completed this work without the love and support of my family and friends.

DEDICATION

To my parents for creating a home where creativity was encouraged and where we were taught to think. To Timothy, my loving husband of 31 years who has stood by my side every minute of our marriage, supporting me and encouraging me to chase after my dreams. Now it is his turn to follow his dreams. To my children, never give up. Follow your dreams wherever they may take you.

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CHAPTER I

LITERATURE

The Changing Needs of Science Education in the United States

Today's world is influenced by science and technology (National Science Board, 2010). Understanding scientific discoveries and methods is relevant for citizenship in a democracy that is dependent on scientific products and technologies (Bencze, 2006). A science-literate citizenry and greater numbers of students pursuing careers in science are needed to keep a competitive edge in the global economy (Carter, 2007; National Academy of Sciences [NAS], 1996; Phillips, 2007; Rutherford, 1990) and are arguably important to our national security (Gonzalez et al., 2004). In order to understand and help form public policy on topics such as global warming, genetic engineering, depletion of fossil fuels, deforestation, population growth, ozone depletion, and pandemic virus infections, citizens must have basic science literacy (Phillips, 2007).

The U.S. Department of Education is beginning to invest more in science education in order to maintain U.S. preeminence in science, technology, engineering and mathematics (STEM) (U.S. Department of Education [USDE], 2007). The National Science Foundation (NSF) Science and Engineering Indicators Report (2010) noted that U.S. research and development expenditures outpaced the overall expansion of the U.S. economy, with business responsible for 73% of that expenditure. The American Recovery and Reinvestment Act (ARRA) of 2009 included a one-time $18.3 billion increase in science research and development funds (NSF, 2010), with Race to the Top specifically targeting educational reform (Duncan, 2009). Never before has the amount of federal funds dedicated to school improvement been so large (USDE, 2009). Regardless, the current economic decline has brought increasing anxiety over the loss of U.S. global competitiveness (USDE, 2009). As President Obama stated, "The relative decline of American education is untenable for our economy, it's unsustainable for our democracy, it's unacceptable for our children – and we can't afford to let it continue" (CSA, 2009, p. 39).

Many other countries are making similar investments to improve their own science educational systems (Gonzalez et al., 2004), most notably Singapore and Chinese Taipei (Phillips, 2007). While the U.S. is still the top spender in the world on science and engineering research and development (R&D) with Asia and Europe a close second, the U.S. is only eighth in the world if this spending is compared with the Gross National Product (GNP) (National Science Board [NSB], 2010). Israel, Sweden, Finland, Japan and South Korea all have an R&D/GNP ratio at or above 3%; the U.S. is at 2.7% (NSB, 2010). As a result, the U.S. will need to work harder in order to maintain its competitive edge (USDE, 2007).

21st Century Skills

A report by the National Research Council (2010) suggested that "21st century skills such as adaptability, complex communication skills, and the ability to solve nonroutine problems—are valuable across a wide range of jobs in the national economy" (p. 12). However, concerns about the ability of our current K-12 educational system to teach these skills to students is even more in debate now than it was when the 1983 report, *A Nation at Risk,* was released (NRC, 2006). While *A Nation at Risk* detailed the declining state of the American education system and the potential for our country to lose its global competitive edge as innovators in technology, industry, and science, 37 years later U.S. students' current declining performance on national and international science and math achievement tests have once again gotten the attention of Congress and the federal government (Labov, 2006). International data collected from the 2003 Trends in Mathematics and Science Study (TIMSS) showed that the highest performing countries were also the countries that granted the largest proportion of college degrees in science, mathematics, engineering, and technology (Phillips, 2007). Questions about the United States' ability to produce citizens literate in science, technology, engineering, and mathematics (STEM) have been asked (Department of Education, 2007):

> The prosperity the United States enjoys today is due in no small part to investments the nation has made in research and development at universities, corporations, and national laboratories over the last 50 years. Recently, however, the federal government expressed concern that pressures on the science and technology enterprise could seriously erode this past success and jeopardize future U.S. prosperity. (NAS *et al.*, 2005, page vii)

Declining Performance of U.S. Students as Measured by NAEP and TIMSS

In order to address this problem, the current state of science education in the United States needs to be examined. The *Deficit Reduction Act of 2005* (P.L. 109-171) established the American Competitiveness Council (ACC). The ACC, led by Secretary of Education Margaret Spellings, initiated a one-year study to assess programs aimed at improving America's competitiveness in STEM (DOE, 2007). To perform its work, the

ACC formed three working groups, each focused on an education category: K–12 Education, Postsecondary Education, and Informal Education and Outreach. Based on these evaluations, the ACC's review revealed that, "despite decades of investment in science and math education, there is a general dearth of evidence of effective practices and activities in STEM education" (DOE, 2007, p. 3). The ACC then made six recommendations based on this analysis. One of them was that the federal government should promote practices that are effective and implement proven and effective, research-based instructional methods and materials if they wished to strengthen our national competitiveness.

The National Assessment of Educational Progress (NAEP) is the only federally-funded national assessment of student science achievement (National Center for Education Statistics [NCES], 2006). The NAEP report informs the public about the academic achievement of students in the United States. NAEP has collected data for grades 4, 8, and 12 for over 30 years and is the only continuing and nationally representative measure of achievement in science over time (Bennett, 2007). In 2005, approximately 305,000 students from 15,800 schools participated in the NAEP assessment (NCES, 2006). This represents about 12% of schools in the U.S. For each grade tested, the National Assessment Governing Board (NAGB) adopted three achievement levels: *basic*, *proficient*, and *advanced*. When comparing scores between the years 2000 and 2005, 4th grade students made some gains in science and middle school students made no gains, with only 29% of students considered proficient. Scores for 12^{th} grade have been declining since 1996, a trend that continued in 2005, with only 19% of students considered proficient (NAGB, 2006).

In addition, gaps between whites and minority students still persist (NAGB, 2006), although the 2005 NAEP reported that fourth grade minority students' scores improved. The score gap between white and Black students narrowed from a 38-point gap in 1996 to a 33-point gap in 2005, and it narrowed between white and Hispanic students from a 34-point gap in 1996 to a 28-point gap in 2005. At 8th grade, where overall science scores remained unchanged, the gaps between minority and white students also remained unchanged since 1996 (White /Black gap = 37 points, White/Hispanic gap = 32 points). In the 12th grade, science scores declined for all groups when compared to 1996 scores, and gaps between whites and minority groups (White/Black gap = 36 points; White/Hispanic gap = 28 points) did not narrow.

American students' understanding of science was reported to be slipping by TIMSS—the Trends in International Math and Science Study —an international project that measures the math and science abilities of students around the world (Gonzalez et al., 2004). In 1995, U.S. 4th graders were outperformed by their peers in four countries; eight years later, seven other countries had 4th graders who performed better than U.S. students in science (Gross, 2005). At the same time that US student performance on the science and math components of national and international tests is declining relative to other countries, the world is becoming increasingly technological. When these students become adults, they will need to make evaluative decisions on topics that are science related.

U.S. Adults Must Have the Capacity to Make Decisions on Complex Issues

Science issues facing adults all over the world are complex in nature. Adults need to be able to make evaluative decisions that require careful questioning, gathering of evidence, and critical reasoning (Phillips, 2007), yet according to the National Science Board (2010), relatively few Americans have a generalizable understanding of experimental design that they can apply to different situations. The National Research Council (NRC) (1996) suggested that teaching scientific inquiry in schools would help create a workforce that was capable of being good problem-solvers.

New federal science education standards (American Association for the Advancement of Science [AAAS], 1990; NRC, 1996), as well as pending state adoptions, emphasize and require inquiry learning as part of the science curriculum (NRC, 1996), justifying this stance by explaining that "Inquiry is the foundation for the development of understandings and abilities of the other content standards" (NRC, 2006, p. 104). Implementing these new standards will require major changes in much of this country's science education (NRC, 1996). If the United States wants to set a national goal of changing how science is taught and it recommends the use of inquiry as a primary tool for children's understanding of science, we need to know what methods best help students develop knowledge of inquiry (Conley, 2003). To understand what role scientific inquiry can play in how we teach children science, we need to understand what scientific inquiry is and what it is not, and if it is effective.

Children as Naive Scientists

Two theories of children as naive scientists will be discussed in the following sections: Piaget's Theory (1946) of children as naive scientists and the Core-Knowledge Theory (Kail, 2006) of children as scientists. Both theories suggested that children naturally engage in inquiry and that their capacity to understand scientific concepts varied by age.

Piaget's Theory

Children can use inquiry to explore the properties of the world in which they live. They are very curious and try to make sense out of their experiences (Piaget, 1947). In the process of their explorations of the world, they construct knowledge and build theories about how the world works, acting like scientists. When they acquire new information, it is integrated into their existing theories (Sigelman & Rider, 2006). Sometimes, however, a child's theory cannot accommodate the new information, and the theory needs to be modified in order to make sense of the new information. Piaget (1947) believed that these *disequilibrium events* occur three times over the course of a life, at the ages of 2, 7, and 11 years. Using these disequilibrium events, he divided human cognitive development into four stages: the sensorimotor stage (birth – 2 years); the preoperational stage (age 2-6): the concrete operational stage (age 7-11); and the formal operational stage (ages 11-adult) (Kail, 2006; Sigelman & Rider, 2006).

Piaget thought that infants as young as 12 months old were active experimenters; they drop different objects to see what will happen; they shake objects to see which one makes a louder noise. They actively explore the world around them (Sigelman & Rider, 2006). Baillargeon (2004) suggested that an infant could act as a naive physicist, by being able to detect height differences in objects where height was a relevant variable. Walden, Kim, McCoy, and Karrass (2007) found that infants have knowledge of physical principles such as numerosity and occlusion. Hood, Carey, and Prosada (2000) suggested that physical properties could be understood at many different levels. An infant's idea of the world is obviously different that an adult's idea. Although infants' ideas are not complex, they do understand that unsupported objects will fall. Middle school students would be able to add an explanation for this event, as they might state the scientific concept that objects fall due to gravity (Kail, 2006). As children age they are able to explore the world in increasingly abstract ways until they reach the formal operational stage where they are capable of understanding the scientific method as it is taught in school. This ability to draw conclusions from facts is key to scientific thought (Sigelman & Rider, 2006).

Core-Knowledge Theory

Another theory of cognitive development is the core-knowledge theory. This theory proposes that the brain has developed specialized systems for knowledge that are important to human survival. The systems for acquiring language and knowledge of objects, people, and living things are developed early in life (Kail, 2006). Because this knowledge is so essential, it is suggested that these mental structures in the brain evolved so that learning would be easier. Although the nature of these mental structures is in debate (Kail, 2006), core-knowledge theorists believe that children act as scientists and create informal theories of the world. For example, they can create informal theories of physics and biology. Acquiring knowledge in these areas has been essential to human existence. "Naive physics allows children to predict where and how objects will move in the environment; naive biology is important for avoiding predators and in maintaining health" (Kail, 2006, p. 184). One key biology concept is the distinction between living and nonliving things. Babies can distinguish between animate objects and inanimate objects. Preschool children understand that living things have offspring, move, grow, have internal parts, get sick and can heal. They can learn this both from observing animals and from their parents. Although young children have these theories, they are not complete. For example, preschoolers do not know that genes are the biological basis for inheritance (Springer & Keil, 1991).

Children's Cognitive Ability to Understand Science Concepts Varies by Age

It appears that from a young age children experiment with the world. However, they are not capable of correctly interpreting what they learn in a true scientific way until they are around 10 years old and are mentally capable of a sequence of logical reasoning (Ravanis & Bagakis, 1998). In a study conducted by Bar (1989) on the heating and evaporation of water, 10-13 year olds were capable of understanding the process of liquid water turning into water vapor. However, five year olds could not offer any accurate scientific thinking about what was happening. Ravanis and Bagakis (1998) proposed that science teaching of young children should not focus on content knowledge and laws as would teaching of older children, but rather on organized experiences with the physical world. They found that younger children were more suited to exploration and inquiry, where students handled materials and the teacher provided explanations as needed. This fit in with a Piaget-like approach rather than an empiricist approach where the focus was on a teacher's transfer of knowledge.

Cognitive research reveals that children of different ages are capable of understanding science concepts at different cognitive levels. Thus, inquiry activities need to be differentiated according to the cognitive abilities of the children participating in the activity. Inquiry activities for young children should focus on lower-level activities like description, observation, and measurement of objects. Older students can look more at cause and effect, which involve higher cognitive thinking (Kuhn, Black, Keselman, & Kaplan, 2000).

Kuhn et al. (2000) raised the possibility that students at the middle school level, and even into high school, have formed incorrect mental models of the physical world. These models can prevent students from correctly analyzing the results of inquiry experiments, especially experiments with multiple variables such as are common in the higher grade levels. The mental models that students possess may be resistant to change. If students lack the necessary skills, inquiry learning may not be effective. So choosing inquiry experiences that are cognitively appropriate to a child is vitally important to his/her understanding of concepts.

Scientific Inquiry Engages Higher-Level Thinking Skills

According to Gallager (2007), the primary paradigm in science education today is the transmittance of science knowledge through memorization and summative testing on student retention of that information. This is perceived as learning by both teachers and students, but learning, in fact, requires more than the transmittance of information from someone who knows it to someone who does not (Wenning, 2005). Gallager (2007) asserts, "teachers can not 'give' understanding" (p. 9). Science education reformers, such as Gallager, proposed that students must be engaged in a much more complex process that allows them to be active participants in the development of understandings that lead to an application of scientific processes. An idea central to the book *Science for All Americans* (Rutherford & Ahlgren, 1990) is the need to shift away from the memorization of complex science terminology towards the understanding of scientific ideas and their relationship to each other and to the real world. "The understanding of, and the ability to apply knowledge cannot be simply transmitted. Factual knowledge can be transmitted rather easily, but understanding and application are more complex " (Gallager, 2006, p. 6). At the heart of the scientific experience is finding connections between investigations, finding patterns in data, and forming explanations that interpret that data and relate it to science concepts. These practices can be found in the laboratory experience.

Science labs are a key component of any well-designed science course. Looking at the type of lab experience that students are having becomes important. Are our schools giving students the most effective lab experience they can? Are the labs engaging students in critical thinking and problem solving? Two distinct types of labs will be reviewed. The first, step-by-step labs, is the traditional lab type taught in most schools in the United States. The other, inquiry labs, is the focus of the recent curriculum improvement efforts (American Association for the Advancement of Science ([AAAS], 1998). There is some variation in inquiry lab types, which will be discussed.

Step-by-Step Labs

Teacher-centered instructional methods are common in schools and have been at the heart of American science classes for many years (Wise, 1996). Students read textbooks, take notes, memorize information, and perform workbook-style labs (Hassard & Dias, 2008). Most textbook ancillary materials come with a large quantity of labs with step-by-step instructions that support this traditional process (Peters, 2005). An example of a step-by-step lab for the determination of the density of a set of objects follows. Students are: (a) given an explicit set of objects, (b) told exactly how to weigh them and are provided a data table to record those results, (c) told how to take the volume and where to record that information, (d) told how to use the mass and volume measurements to calculate density, and (e) asked specific questions about the experiment that they need to answer.

The purpose of step-by-step labs is for students to focus on verifying information previously communicated in class. They are used for content support and are essentially a confirmation activity (Gengarelly & Abrams, 2008). Using step-by-step labs, students can learn how to follow directions (Hodson, 1996), which can be a worthwhile learning objective. But this objective does not engage higher-level thinking skills, as often there is one correct answer to be found, of which the student may be aware before experimentation begins. "Recipe-like activities often short circuit opportunities to stimulate thinking by students" (Germann, Haskins, & Auls, 1996, p. 477). Students focusing on steps may not be able to step back and clearly see the big concept that the lab is trying to convey. Students can have difficulty constructing meaning from step-by-step labs (Peters, 2005).

Step-by-step labs can provide an active and physical learning experience that is engaging to students, especially when compared to reading a textbook and taking notes, but they do not require mental participation, which is the key to deep understanding of science concepts (Lord & Orkwiszewski, 2006). Many teachers find that when students use step-by-step labs there are limited opportunities for higher-level thinking. For example, students are seldom asked to be critical of procedural flaws and potential sources of error. Students are told which variables to hold constant, which variables are independent, and which are dependent. As the entire purpose is to have students successfully complete the lab as it is written, the procedures are so refined that they seldom fail (Backus, 2005).

The National Research Council's ([NRC], 2006) publication, *America's Lab Report,* states that most science students in the United States are participating in laboratory experiences that emphasize procedures with little integration of critical thinking. This causes students to leave high school with little idea that science is a process that requires ongoing testing and revision (Carey & Smith, 1993; Smith et al., 2000). Step-by-step labs show science to be an unrealistic linear process; such a process is not authentic and does not mimic the scientific processes that are performed by scientists who must struggle with the interpretation of unexpected outcomes. "In general, most high school laboratory experiences do not follow the instructional design principles for effectiveness…students participate in a limited range of laboratory activities that do not help them to fully understand science processes" (NRC, 2006, p. 6). Most lab experiences do not integrate well with other classroom instruction and infrequently include teacher and student analysis and discussion (NRC, 2006). Bennett (2007) found that even when students do step-by-step labs, 37% of students never talk to the class about their results, and 28% never write up the result of an experiment. In fact, in the United States, 29% of students never carry out a science experiment at all and 42% only do so less than once a month. This lack of experimentation makes it difficult for students to connect learning about science content with the learning processes of science (Gengarelly & Abrams, 2009).

Inquiry in the Classroom

Teachers vary considerably in how they attempt to engage students through inquiry; some advocate more structured methods (Igelsrud & Leonard, 1988) while others advocate providing students with few explicit instructions (Tinnesand & Chan, 1987). Regardless of how teachers specifically structure the student experience in the classroom, a focus on inquiry should involve the collection and interpretation of information in response to student curiosity, wondering, and exploring. Wenning (2005) proposed a continuum to delineate six levels of inquiry based on the level of pedagogical practice. Table 1 shows the relationship between (a) intellectual sophistication, and (b) locus of control in inquiry-orientated teaching practices. The locus of control shifts from the teacher to the student moving from left to right on the continuum. In discovery learning the teacher has most of the control, and in open inquiry the work depends almost entirely on the student. Intellectual sophistication also varies across the continuum, increasing from a low level in discovery learning to the highest level in open inquiry. "The thought processes required to control an activity are shifted from the teacher to the student as practices progress from the right along the continuum" (Wenning, 2005, p. 4).

Inquiry Activities

In general, inquiry activities are a form of inquiry-based teaching. These types of teaching practices were developed when the definition of inquiry was translated into the classroom (Gengarelly & Abrams, 2009). These are not full inquiry labs, but they have many of the components of inquiry and do engage students in higher-order thinking, so they have been included.

Table 1

A Basic Hierarchy of Inquiry Oriented Science Teaching Practices

Inquiry Activities			Inquiry labs		
Discovery Learning	Interactive Demonstration	Inquiry Lesson	Structured Inquiry	Guided Inquiry	Open Inquiry
Low	← Intellectual Sophistication →				High
Teacher	← Locus of Control →				Student

Adapted from Wenning (2005)

Discovery learning. Discovery learning is the most fundamental form of inquiry learning, most often employed at the elementary school level. It was largely triggered by the perceived threat of Soviet scientific supremacy in the 1960s driving U.S. curriculum reform in an effort to get students to think like scientists and actively engage in science lessons (Cohlburn, 2005). The Elementary Science Study, conducted by the National Science Foundation, brought hands-on discovery learning to students in the 1960s and 1970s. The focus was on students constructing knowledge from experience (Wenning, 2005) and using reflection to help in their understanding. The teacher asked about students' prior knowledge on a topic, and then introduced an experience that related to their prior knowledge. The teacher then used a sequence of questions to help students make meaning of the experience, guiding them to a specific conclusion. Shymansky, Hedges, and Woodworth (1990) found that students who were taught using discovery learning liked science more and were better at *doing* science than were peers taught using other approaches. A drawback to discovery learning in elementary schools is the lack of science expertise by generalist teachers, as it can require that teachers have a broad background of science content knowledge.

An example of discovery learning would be a teacher asking students about experiences students have had while swimming or manipulating objects in water (rocks, balls, toy boats, etc). The teacher might then ask students to submerge a block of wood in water, where students would notice that the wood would always rise to the top of the water. The teacher through questioning strategies would introduce the idea of buoyant force. Then the teacher would have students try a variety of objects to see if they sink or float. Together the students with the guidance of the teacher would come up with rules about the properties of objects that sink and those that float. The teacher might even go as far as introducing the concept of the density of objects as it relates to the density of water.

Interactive demonstration. An interactive demonstration generally consists of a teacher in the front of the room, manipulating a piece of scientific apparatus, and then asking students to make predictions about what would happen next (Wenning, 2005). The teacher controls the discussion by asking questions that elicit student misconceptions, confronting them, and then resolving them in a demonstration of the scientific process. An example would be the demonstration of the buoyancy of a piece of wood in water. The teacher might ask a guiding question about the relationship between the weight of an object suspended in air, the weight of an object suspended in water, and the buoyant force. The teacher might then take out a spring scale and propose using it as a way to take measurements. The teacher can move the discussion from one that is qualitative to one that is quantitative. Students, through careful guidance from the teacher, would realize that buoyant force is the relationship between the weight of the object in air and the weight of the object in water. They could then define that relationship mathematically.

Inquiry lesson. An inquiry lesson is very similar to an interactive demonstration. The primary difference being the guidance from the teacher is more indirect. Students are given more responsibility in identifying and controlling variables. While the teacher still guides the process through questioning, the teacher now “speaks about scientific process explicitly by providing an ongoing commentary about the nature of inquiry” (Wenning, 2005, p. 5).

Inquiry Labs

Inquiry-based instruction represents a broad range of instructional possibilities. From this continuum, Herron (1971) broke down inquiry labs into three major categories, which vary in the degree of sophistication and the amount of teacher control. At one end, students make few independent decisions and the teacher plays a central role in guiding the process (teacher-directed) (Bell, Smetana, & Binns, 2005; McComas, 2005). At the other end, students make all of the decisions and the teacher does not have a prominent role in the decision-making processes (student-directed) (Colburn, 2000). The three categories are guided inquiry, structured inquiry, and authentic inquiry and they are defined by asking the following questions, *Does the student or teacher decide?:* (a) the question to investigate, (b) the procedures to follow in addressing the question, and (c) the data to collect and analyze (see Table 2).

When choosing which inquiry type to use, it is important to link the type of inquiry with the educational goal for the student (Olson & Loucks-Horsley, 2000). Sometimes, however, it can depend on a teacher’s preference, training (Waight & Abd-

El-Khalick, 2007), the balance of time available to devote to inquiry in relation to other classroom goals (Bencze & Di Giuseppe, 2006), and the availability of resources and materials (Pine et al., 2006). These varying types of inquiry also suggest that inquiry in the classroom differs in goals and practice from inquiry as practiced by scientists in the field (Gengarelly & Abrams, 2008). It has a broader purpose (Chiappetta & Adams, 2004), which includes providing a working understanding of the scientific discipline to students and an "opportunity to see how scientific knowledge is constructed" (Gengarelly & Abrams, p. 75).

Table 2

Levels of Inquiry

Level of inquiry	Question	Procedure	Analysis
Step-by-Step	X	X	X
Structured Inquiry	X	X	
Guided Inquiry	X		
Open Inquiry			

The "X" marks what the teacher provides

Structured inquiry. Structured inquiry is typically easier for the teacher to implement and less time-consuming than the other types of inquiry labs (Colburn, 2000). The teacher generally gives pre-lab instructions, puts constraints on the area of science content that students are allowed to explore, and provides the question that students will test (Berg, Bergendahl, & Lundberg, 2003). Students may only perform one or two parts of a lab as inquiry in conjunction with teacher scaffolding (Dass, Kilby, & Chappell, 2005). Typically the teacher will tell the students what materials to use, and they may suggest a procedure. Even when a teacher imposes certain limitations on student explorations, students can still experience a degree of wonder (Haury, 1993). They still have the opportunity to be critical of procedural and design flaws. Analysis of data and interpretation of results can still be very open-ended and require higher order thinking.

Some students may in fact benefit more from a teacher-directed inquiry approach (Berg, Bergendahl, & Lundberg, 2003). When and where appropriate, students' questions and ideas can still be considered in making the inquiry experience relevant to the student, even in structured inquiry (Enger, 1998). This type of inquiry is the most commonly used type (Zion, Cohen, & Amir, 2007), especially in schools with scarce monetary resources; limited instructional time due to an emphasis on reading, writing, and math; and in schools that focus on high-stakes assessment (Lee, Buxton, Lewis, & LeRoy, 2006).

Guided inquiry. In guided or bounded inquiry labs, students are given a performance objective, but they are expected to design the experiment without a detailed pre-lab orientation or teacher-provided questions (Wenning, 2005). Students are entirely responsible for the experimental design, with the teacher being present to guide them in the process. Teacher assistance may not be direct. They may use questioning strategies that force the student to think and figure out solutions to the problems that they are encountering. Teachers often, however, provide the materials for the inquiry. As a result, even though most students in a class are investigating similar questions, their procedures, results, and analysis will vary. If those differences are discussed in class, then a deeper understanding of the processes of science can be learned (Colburn, 2000). Both structured and guided inquiry are effective in conveying content because the teacher is able to lead the student into discovering specific content (Zion, Cohen, & Amir, 2007).

The engagement of students in inquiry can allow a deeper understanding of that content to occur (Wenning, 2005).

Open inquiry. Open-ended inquiry is based on the type of activities that scientists actually carry out. In essence, it asks the students to think about what they know, why they know it, and how they have come to know it (Olson & Loucks-Horsley, 2000). Students determine all aspects of the investigation, including the content that they are going to study. In open inquiry, students begin with defining a question. Then they formulate a testable hypothesis, where they generally look at the effect of a single independent variable on a single dependent variable (Wright & Wright, 1998); design and subsequently perform a procedure; and finally, analyze their data looking for possible explanations that relate to known science concepts. It is a multifaceted process that requires logical thinking and the consideration of alternate explanations (Olson & Loucks-Horsley, 2000). However, students are not expected to do all of this work completely on their own. Teachers play a pivotal role by "facilitating, focusing, challenging, and encouraging students to engage in this kind of activity" (Zion, Cohen, & Amir, 2007, p. 424).

Open inquiry encourages student creativity in developing and testing ideas; communicating their understanding in a variety of formats, including written, oral, and graphic so that it can be evaluated by peers, teachers, and even perhaps outside experts; and developing action plans to put the learned content to use in real-life situations (Dass, Kilby, & Chappell, 2005). If inquiry is not authentic, then science can be falsely viewed as "simple, certain, and algorithmic" (Chinn & Malhotra, 2002, p. 175). Because of the relatively complex nature of authentic inquiry, it may not be performed as often in the classroom as teacher-directed inquiry (Bencze & Di Giuseppe, 2006). "Experiences that vary in 'openness' are needed to develop inquiry abilities…Guided inquiry can best focus the learning on the development of particular science concepts. More open inquiry will afford the best opportunities for cognitive development and scientific reasoning" (National Research Council [NRC], 2000, p. 30). Typical knowledge-level questions found on multiple choice assessments will not adequately assess student learning of the inquiry processes; "assessments therefore need to gauge the progress of students in achieving the three major learning outcomes of inquiry-based science teaching: conceptual understandings in science, abilities to perform scientific inquiry, and understandings about inquiry" (NRC, 2000, p. 75). Table 3 summarizes the key differences between step-by-step labs and inquiry labs.

Obstacles to Open Inquiry

There are several obstacles that prevent widespread implementation of inquiry in the classroom. Some of these are student-based obstacles and some of these are teacher-based obstacles

Student-based Obstacles

To fully engage in the higher levels of inquiry, students need to have learned the process by having participated in guided or structured inquiry (see Table 1). If this has not occurred, students may become frustrated by their lack of understanding of the processes involved, and confusion in the classroom may ensue (Wennig, 2005). Problems can occur because students are not used to figuring out scientific processes on their own and they may wonder why the teacher will not just tell them the correct answer (Colburn, 2000). Students may develop ideas that are difficult to investigate in school laboratory conditions, have difficulty in creating suitable methods, and not know how to handle equipment (Zion, Choen, & Amir, 2007). When they obtain an unexpected result from an experiment, they may have difficulty in determining if it is due to technical error or a design flaw in the procedure. Lastly, many students lack the scientific writing skills to communicate their process.

Teacher-based Obstacles

Many teachers themselves do not understand or value the inquiry process (Wenning, 2005), perhaps because they lack their own authentic inquiry experience (Windschitl, 2004). Such lack of understanding or valuing inquiry may result in the minimal implementation of inquiry in the classroom (Gengarelly & Abrams, 2009). Teachers' misconceptions of the inquiry process can affect the implementation of open inquiry (Keys & Bryan, 2001). They may lack the confidence to facilitate it, as it is pedagogically difficult because results (a) are sometimes unexpected, (b) cannot be predetermined, and (c) may lead to further investigations (Singer, Marz, & Krajcik, 2000). Teachers may feel that they are not in control over what is happening in their class (Uno, 1997). Open inquiry takes longer to perform than other types of labs (Zion, Cohen, & Amir, 2007), as time must be found for students to research their question, design their experiment, carry it out, and then analyze their results. Finally, grading inquiry can be a time-consuming process for teachers (Colburn, 2000). While there are both teacher-based obstacles to inquiry, overcoming them through teacher professional development and support would provide benefits to students, allowing students access to the higher-level thinking skills found in inquiry.

Table 3

Comparison of Step-by-Step Labs and Inquiry Labs

Step-by-Step Labs	Inquiry Labs
Driven by step-by-step instructions requiring minimal intellectual engagement of students; promotes rule-conforming behaviors (e.g. students are told what to do in a cellular respiration experiment. They soak 10 beans with 10 ml of water and put them in a 100 mL container. After three days students measure the CO_2 and O_2 output of the beans for 45 minutes. They then answer 5 questions. Deviation from the procedure is not encouraged. Students are expected to get similar results. The answers to the questions are expected to be the same for all students)	Driven by questions requiring ongoing intellectual engagement using higher order thinking skills; promotes independent thought and action (e.g. students notice that aquatic plants in the aquarium often have bubbles on them. They wonder what might be causing them. After exploring a number of possibilities, they decide to investigate the O_2 and CO_2 output of the plants. They find that the bubbles are O_2. Students then investigate other plants both aquatic and terrestrial to see if they produce similar results. Different students explore different plants. Independent exploration is encouraged. Every analysis is different.)

Table 3

Comparison of Step-by-Step Labs and Inquiry Labs (Continued)

Step-by-Step Labs	Inquiry Labs
The focus is on verifying information that had been presented previously in class; moves students from abstract toward concrete	Focus is on collecting and interpreting data to discover new concepts; moves students from concrete toward abstract
Constants are given, variables are defined (e.g. the teacher tells the student to weigh 5g, 10g, and 15 g of salt to make a predetermined solution that has a predetermined concentration)	Students determine variables and constants (e.g. the teachers instructs the students that today they will be investigating the relationship between the amount of solute and solvent in the determination of the concentration of a solution. Each student uses different solutes, solvents, and has different concentrations that they produce)
Presumes students will learn about the nature of science implicitly through their structured lab experience.	Students learn about the nature of science explicitly by designing and performing labs
Rarely allows students to confront and deal with error or uncertainty; does not allow students to experience failed	Commonly allows for students to learn from their mistakes; students are

experiments	encouraged to identify sources of error
Uses practices that are not consistent with actual scientific processes; Shows the work of science to be a linear process	Employs procedures that are more consistent with authentic scientific practice; shows work of science to be recursive and self-correcting

Adapted from Weening (2005)

Higher-level Thinking Skills Facilitate Conceptual Understanding

Deeply rooted in best practices, inquiry-based teaching is designed to help students learn to think independently and gain problem-solving skills that will help them throughout their entire life (Colburn, 2005). Gallagher (2007) found that students needed help developing inquiry understanding at three levels: (a) the inquiry process itself; (b) the identification of patterns and meaning in the data; and (c) the formation of explanations based on experience. This can be a demanding process for students. When students engaged in inquiry, they needed to have time to explore topics in depth, build conceptual understanding, and make connections among concepts (Bybee & Van Scotter, 2000). The understanding of, and the ability to apply, knowledge cannot be transmitted simply, as understanding and application are higher-order processes. Factual knowledge, on the other hand, can be transmitted in more direct ways using lower-levels of cognitive engagement (Pine et al., 2006).

Scientific Inquiry Promotes Higher Level Thinking Skills

Afra, Osta, and Zoubeir (2009) conducted a study that examined an interesting phenomenon. It appeared that ninth grade students in the country of Lebanon were able to successfully apply formulas to calculate voltages, currents, resistances, or power, but were unable to predict or justify the behavior of real electric circuits. The researchers stated that inquiry was not typically found in textbooks or used in classrooms there. The investigators conducted a mixed method study of 12 9th Lebanese students and found that the students who received the inquiry-based teaching approach had more enhanced conceptual understanding of circuits after the study than students who were taught with a traditional approach. During the course of this investigation, researchers confronted student misconceptions through discrepant events. The need to address student misconceptions during the learning process was emphasized. Results, however, are not very generalizable due to the small sample size and the fact that students were from one of the most elite schools in Lebanon.

Two different sets of strategies used to promote conceptual change were investigated in a meta-analysis conducted by Guzzetti, Sydner, and Gamas (1993). The effect of different reading and science teaching strategies on student conceptual change on a variety of science topics was analyzed. Reading strategies were investigated because it was recognized that textbooks and the materials that accompany them dominate science instruction (Yore, 1991) and they "are the most criticized instructional strategy" (Guzzetti, Sydner, & Gamas, 1993, p. 118). Science books have been particularly criticized for their inability to affect conceptual change (Blakslee, Anderson, & Smith, 1991), as most text structures found in textbooks do not promote the "cognitive dissonance" that is needed to promote conceptual change (Guzzetti, Sydner, & Gamas, 1993, p. 118). As a result of these criticisms related to textbooks, researchers in the reading education field tested the effects of alternative types of text or text-based strategies that were designed to compensate for the inadequacies of ordinary text on conceptual change. These strategies were designed to promote the "change, incongruity, or surprise that must occur in the mind of the learner to affect new learning " (p. 118). The results of these investigations on alternate reading strategies were analyzed in the meta-analysis. A second set of investigations into the effect of different types of science education on conceptual change was included in a separate analysis. The results of these two different sets of strategies were then compared.

For the reading strategies analysis, 23 experimental and quasi-experimental studies conducted between 1982 and 1991 were analyzed. In all, 74% of the studies had random assignment, and the majority were replication studies. On the basis of the evidence provided by the meta-analysis, Guzzetti, Sydner, and Gamas (1993) reported that text could affect conceptual change when it causes cognitive conflict. In their meta-analysis, the researchers assigned a Bloom's taxonomy level to the assessments that were used in each investigation they analyzed. At Bloom's taxonomy level 3 the dependant variables were effective. Results showed no effect, however, when the text did not refute misconceptions either directly or indirectly or when students were engaged at Bloom's levels 1 or 2.

For the second analysis, researchers included 70 studies conducted between 1981 and 1991 in their analysis of the effect that science teaching strategies had on conceptual change. The most common threat to internal validity was the lack of random assignment (in 65% of the studies) and the lack of a pretest (in 70% of the studies). Most of the science education studies (81%) studied some form of cognitive dissonance. The length of the studies included one hour or less (32%), 2 to7 hours (30%), 10 to 34 hours (22%) and 40 to 90 hours (16%). One of the main comments of Guzzetti, Sydner, and Gamas (1993) was that science investigators implemented a combination of strategies and then evaluated their combined impact, "rather than testing effects of a single intervention against a single control or comparison" (p. 145).

As a consequence, because the meta-analytical determination of the effect of a single strategy became impossible, investigators used a cluster analysis. Results show that three strategies in science instruction have an effect on conceptual change. They are: (a) *Learning cycle* – which is a form of inquiry where students explore a topic, organize the data looking for patterns, and then apply the principles that they have learned to other situations; (b) *Bridging analogies* – once target problems in conceptual understanding are identified, teacher-led discussions challenge students to provide the rationale for their concept, then the teacher provides students the scientific view; and (c) *Conceptual conflict* –after a diagnostic of students' current concepts is completed and alternate conceptions are exposed, a variety of strategies such as experiential demonstrations and guided experiments are implemented by the researcher to confront misconceptions. When a non traditional, inquiry lab approach was combined with any of these three strategies, the effect of the strategy increased. If a traditional lab was included, no increase in effect was measured. One science education strategy that did not have an effect on conceptual change was the traditional lecture and lab combination that is found in most science classrooms.

When comparing the results of the two fields (reading and science education), Guzzetti, Sydner, and Gamas (1993) noted that the strategies that had the largest effects all included some form of cognitive conflict and higher-order thinking skills. The format of the effective strategy was not as important as the fact that the student was engaged in cognitive conflict. Some limitations to the meta-analysis as proposed by the authors were:

(a) the variance in the types of misconceptions that were studied, (b) the inconsistent definitions of the term *misconception*, and (c) the measurement and definition of conceptual change.

Scientific Inquiry Improves Student Outcomes

Methods and Validity Influences

In this section, I review 20 empirical investigations and two meta-analysis studies in an effort to answer the following questions: (a) *What types of studies have been conducted on scientific inquiry?* and (b) *What is the empirical evidence that scientific inquiry produces positive student outcomes?* Articles were located using ERIC, PsychINFO, Dissertation Abstracts, reference lists, and searching on-line journals of interest, most notably the *Journal of Research in Science Teaching*. Search terms included: scientific inquiry, conceptual understanding, middle school, technology in science inquiry, meta-analysis, step-by-step labs, direct instruction, student attitude, national standards, and science reform. Table 4 displays some general information about the 20 papers that will be reviewed in this section. All articles were published in peer-reviewed journals.

An Analysis of the Research on Science Instruction

Internal validity refers to the possibility that the conclusions that are drawn from an experiment may not accurately reflect what has gone on in the experiment itself. It is concerned with quality issues that might influence the outcome of the study and is present whenever anything other that the experimental stimulus can affect the dependent variable (Babbie, 2007). In the Schroeder et al. (2007) meta-analysis, three variables related to internal validity were examined: (a) Publication Type, (b) Type of Study, and (c) Test

Type. The results of the regression analysis indicated that there was a significant relationship between these internal validity variables and the effect size. The results of this analysis are shown in Table 4.

Similar internal validity issues may affect the studies that I reviewed. Only one investigation in my search, authored by Bennett, Persky, Weiss, and Jenkins (2007), used an experimental methodology. This is 5% (n = 1) of the total articles reviewed. In all, 65% (n = 13) were quasi-experimental. Schroeder et al. (2007) found a similar dearth of experimental investigations in their meta-analysis, with 4.8% of articles experimental and 95.2% quasi-experimental. The lack of experimental studies is most likely due to the difficulty of conducting randomized studies with students and teachers in a school setting. Regardless, the lack of experimental studies with true random assignment is an area that needs to be addressed if a true causal relationship between scientific inquiry as an instructional strategy and student-learning outcomes is to be established.

Table 4

Internal Validity Influences on the Effect Size of Science Instruction Strategies

Internal Validity Influence	Mean Effect Size
Publication Type	
Refereed journal article	0.91
Dissertation	0.28
Unpublished report	1.03
Type of Study	
Experimental (complete randomization)	0.83
Quasi-experimental (randomization used)	0.53
Quasi-experimental (no randomization)	1.00
Test Type	

Standardized	0.73
Other type test (teacher- or researcher- constructed	0.75

Adapted from Schroeder et al. (2007)

Only two of the 20 studies used standardized tests as an outcome (Geier et al., 2008; Pine et al., 2006). The remaining 90% (*n* = 18) of assessment measures were either teacher or researcher generated. Schroeder et al. found similar results, with 75% of the measurements in the meta-analysis being teacher or researcher constructed. Only 35% of studies included in my analysis reported validity or reliability information for assessments (Bennett, Persky, Weiss, & Jenkins, 2007; Dalton, Morocco, Tivnan, & Meed, 1997; Geier et al., 2008; Krajck et al., 2000; Marx et al., 2004; McCarthy, 2005; Pine et al., 2006). The potential for measurement unreliability compromises the results reported and the conclusions drawn. As Babbie wrote, "the reliability of instruments is a fundamental issue in social research" (p. 146). Although the form of assessment for most studies was not standardized, for the purpose of this paper, the lack of information about the technical adequacy of the measurement instruments used in these studies should be kept in mind as one interprets the results. For the standardized tests, the validities and reliabilities were well within recommended guidelines. Table 5 summarizes the research studies that were reviewed.

Generalizability

Shadish, Cooke, and Campbell (2002) define external validity as the "inferences about the extent to which a causal relationship holds over variations in persons, settings, treatments, and outcomes" (p. 83). External validity addresses generalization issues, which can be diverse. The meta-analysis performed by Schroeder, Scott, Tolson, Huang, and Lee (2007) looked at four external variables: (a) publication year, (b) test content, (c) grade level, and (d) treatment categories. They used a weighted least-square multiple regression analysis to determine the influence of these variables on effect-size data and found that there was no statistically significant relation between these variables and effect size. Thus, for the purpose of this paper, these external variables are assumed not to have influenced the outcomes of the studies reviewed.

Twenty-five percent (n = 5) of the studies examined had small sample sizes between 0-49 student participants (Echevarria, 2003; Khishfe, 2008; McCarthy, 2005; Rowell, 2004; Waight & Abd-El-Khalick, 2007). With too few participants in a sample, a potential exists that the confidence interval on the outcome does not permit strong assertions about generalization. Fifty percent (n = 10) of the studies had large sample sizes, including a study by Marx et al. (2004) that had 8,000 student participants, and a study by Geir et al. (2008) that had 5,000 students in the experimental group and 17,500students in the comparison group. As sample size increases, standard error

Table 5

Research Studies Reviewed

Type of Study	Number of Articles	Percent (%)
Experimental	1	5
Quasi-experimental	13	65
Qualitative	1	5
Mixed	5	25
Type of Measure		
Standardized Test	2	5
Pre- Post- Assessment	11	30
Teacher Interview or Observations	6	16
Student Interview or Observations	10	27
Student Product or Performance Assessment	4	11
Survey	4	11
Measure Evaluation		
Validity/Reliability Information Provided	7	35
No Validity/Reliability Information	13	65
Number of Student Participants		
0-49	5	25
50-199	3	15
200- 499	2	10
Over 500	10	50
Year Published		
1980-1999	2	10
2000-2008	18	90

decreases. This helps improve the quality of inferences that can be made about external validity.

In summary, most papers that were reviewed that compared inquiry and step-by-step labs were current research articles published within the last three years in peer-reviewed journals. Although many studies had large sample sizes, the research design of the majority of the studies was not ideally developed to examine a true causal relationship between inquiry and student outcomes as only one experimental study was found. Relatively few studies used measurements that were normed or included reliability or validity information. While the National Research Council suggests that open inquiry is best suited for meeting national goals of science literacy, it appears to be the least performed type of inquiry. These shortcomings provide an area of focus for future research in this area.

For the purpose of comparison, the 20 studies were placed into four categories: (a) meta-analysis investigations; (b) large-scale and multi-year studies; (c) small-scale studies; and (d) studies that support evidence for under-represented groups. I chose these categories because different types of evidence relevant to my own research interests was derived from each grouping. I did not use the traditional categorizations of experimental, quasi-experimental, mixed, and qualitative, as the investigations were not equally distributed across these categories. As a result, interesting patterns could not be derived from analyzing them in this way. The rationale for my choice of these four categories follows:

1. The two *meta-analysis* investigations allowed me to compare the patterns that were reflected in meta-analysis group of investigations to those that I chose to analyze. I

was able to conclude that the investigations that I reviewed are representational of a larger body of work.

2. *Large-scale investigations* allowed me to see the impact of inquiry, when an inquiry-based curriculum is implemented across an entire district or at multiple schools across the country. Effectiveness was measured using state or nationally normed-tests. The multi-year studies allowed me to see the patterns of these same research projects as they were implemented over time, allowing me to focus on the types of difficulties that are encountered and the types of modifications that are needed to create a research design that accurately measures inquiry's effect. Generalizability and validity were highest in this category.

3. The category of *Small-scale investigations* contains the largest number of investigations overall. These studies are interesting because their methodologies more closely resemble what I was implementing. However, the generalizability and validity of these studies varied greatly.

4. *Under-represented groups* allowed me to analyze if there was a measurable effect on different sub-groups of students when scientific inquiry is used as a teaching methodology. The reason that this is important to me is that the district where I work faces increasing numbers of minority, low-income, and special needs students.

Within each category, I have related both the benefits and limitations of current research. The majority of studies measured student academic gain, with 94% of the studies reporting a significant gain in achievement.

Meta-Analysis Studies

Two major meta-analyses that compare the effectiveness of alternate teaching strategies, including inquiry and traditional teaching strategies, have been conducted. The first was conducted by Wise (1996) who looked at the association between teaching strategies and student achievement in science. He analyzed 140 articles published between the years 1965 – 1985. These articles were drawn from major science education journals, doctoral dissertations, and ERIC documents. Half of the studies were conducted in middle schools and half were conducted in high schools with a broad range of science content represented. A majority of the studies involved 100 or more students, with an equal representation of urban, rural, and suburban school research settings. Assessment of student knowledge was primarily through subject knowledge tests, but there were also problem-solving, attitude, and science thinking skill measures. No mention was made in the meta-analysis of how the quality of the research was determined, what the criteria were for inclusion in the analysis, whether the studies were experimental or if other research methodologies were used, and if the assessments were researcher developed or normed-tests. No confidence interval estimates were calculated. Such lack of information lessens the overall quality of the meta-analysis.

The research studies used by Wise (1996) yielded 375 effect sizes, as most investigations used two or three student achievement measures where effect size was calculated. Wise defined traditional methodologies as "knowledge to passive student audiences, with textbooks alone constituting the science curricula; students rarely involved in direct experiences with scientific phenomena" (p. 1). Wise (1996) considered this to be the predominant strategy used in middle and high schools. The eight alternate teaching strategies he analyzed were: (a) questioning, (b) focusing, (c) manipulation, (d) enhanced materials, (e) testing, (f) inquiry, (g) enhanced context, and (h) instructional strategies. Table 6 lists the effect size for each strategy Wise (1996) analyzed, comparing them to Schroeder's (2007) meta-analysis results.

All alternate teaching strategies were shown to have a positive effect, ranging from the largest effect of +.58 for questioning strategies to the smallest effect of +.18 for instructional media strategies. Although inquiry strategies did show a medium positive effect of +.28, there were five strategies that Wise found to be more effective. The average effect size was +.32, with inquiry falling below the average. Wise (1996) defined inquiry strategies as:

> Student centered, inductive instruction that is less step-by-step and teacher directed than traditional instruction. This category includes strategies referred to as the inquiry or discovery type. Examples include: facilitated inquiry activities, guided discoveries, inductive laboratories, or indirect instruction. (p. 3)

Overall, Wise (1996) found that students using the eight alternate teaching methods scored, on average, one-third standard deviation or 13 percentile points better on achievement measures than students who were taught using traditional teaching methodologies. The feature that distinguished the eight alternate strategies that Wise analyzed from traditional strategies was that they were all "inquiry-oriented instruction" (p. 4) in which students used higher-order thinking skills in order to gain new knowledge. Even though the category of inquiry did not have the largest effect size, Wise felt that all the categories had a component of inquiry in them and, in fact, defined the other categories. In the conclusion of his meta-analysis, Wise (1996) made the recommendation that “teachers should use inquiry strategies as the predominant approach to science instruction in middle and secondary schools” (p. 5).

The Schroeder et al. (2007) meta-analysis study addressed the question: *What teaching methodologies have been shown to improve student achievement in science in the USA?* The acquisition of studies was thoroughly documented. It began with 390 articles, published between the years 1980 – 2004, obtained from journal articles, conference papers, books, dissertations, and government reports. Listed are some but not all of the criteria used for selection: (a) experimental or quasi-experimental (no correlational studies), (b) K-12 general education students were participants, no special populations, (c) effect sizes were reported or the statistics for calculating them, (d) used student achievement as the dependent variable, and (e) used science education teaching strategies as the independent variable. Sixty-one studies were eventually analyzed, predominantly quasi-experimental studies from refereed journals published between the years 1995 – 2004. Table 6 compares the effect size results from the Wise (1996) and Schroeder (2007) meta-analysis studies.

One-third of the studies lasted less than a month, and another third lasted between 1 and 7.5 months. Assessments used to determine student achievement were primarily on general science, biology, and chemistry. The dependent variables in the studies were measured in a variety of ways: 4.8% included national standardized multiple science content, 9.7% included national standardized single science content, 3.2% included local standardized multiple science content, and 6.5% included local standardized single science content. These assessments were all reported to have had good reliability and validity evidence because they were all widely-used assessments. In 78.5% of the studies, other types of tests were used, primarily local teacher- or researcher-developed. It was assumed by Schroeder et al. that these were relevant assessments because they were created to match the instructional units that were being studied.

Table 6

Comparing the Effect Size of Nine Alternative Teaching Strategies as Published in Two Meta-Analysis Studies

	Wise (1996)	Schroeder (2007)
Questioning strategies	+.58	+.74
Focusing strategies	+.57	
Manipulation strategies	+.56	+.57
Enhanced materials strategies	+.52	+.29
Testing (assessment) strategies	+.32	+.51
Inquiry strategies	+.28	+.65
Enhanced context strategies	+.26	+1.48
Instructional media strategies	+.18	+.48
Collaborative learning strategies		+.95
Average effect size	+.32	+.71

Schroeder et al. (2007) analyzed the following seven teaching strategies that Wise (1996) also analyzed: (a) questioning, (b) manipulation, (c) enhanced materials, (d) testing, (e) inquiry, (f) enhanced context, (g) instructional strategies, and an additional strategy that Wise (1996) did not study (h) collaborative learning (see Table 6). Schroeder et al. (2007) did not study focusing strategies as Wise (1996) did. In the Schroeder et al. (2007) meta-analysis, enhanced context strategies had a very large effect size of +1.48. Enhanced materials strategies had the lowest effect size, at +.29. The

Schroeder meta-analysis gave inquiry a large effect size of +.65, ranking it fourth out of eight different teaching strategies. While the meta-analysis generated empirical evidence that alternate teaching strategies were more effective than traditional teaching strategies when teaching science, Schroeder et al. also found that "no one strategy is as powerful as utilizing a combined strategies approach" (p. 1452). In the conclusion, Schroeder et al. (2007) stated that when students have an opportunity to "experience collaborative scientific inquiry under the guidance of an effective teacher, achievement will be accelerated" (p. 1452).

When reviewing the two meta-analyses, it is interesting to note the differences in the average effect size reported. The average effect size for the Wise (1996) analysis was +. 32, while for Schroeder (2007) it was +.71. Every value for the seven alternate teaching strategies was larger in the Schroeder et al. (2007) analysis, except for enhanced materials strategies, which sharply declined. Although it is not possible to provide a definitive explanation for these differences, an interesting change in the definition of terms was noted. Wise (1996) defined *instructional media strategies* as strategies that "involve instruction based on media, such as showing films on a topic or using pictures, photographs, or diagrams" (p. 6). Note there is no mention of computers. Schroeder et al. (2007) changed the term to *instructional technology strategies* and defined it as when "teachers use technology to enhance instruction (e.g., using computers, etc., for simulations; modeling abstract concepts and collecting data)" (p. 1446). In this definition, computer technology is the focus. Of the eight instructional inquiry strategies included in the two meta-analysis studies, this was the only definition that changed.

Critique of studies. A significant problem with current research in this area highlighted by the Schroeder et al. (2007) meta-analysis is the lack of operational definitions for critical science teaching strategies. An example that was given was the variable definitions for direct teaching. In one paper, direct teaching was defined as a "highly scripted instructional model used primarily in early reading and mathematics instruction" (p. 1453) and in another it was defined as "a wide range of teacher-controlled talking, showing, questioning, and demonstrating" (p. 1453). This lack of clear definitions is an area that needs significant improvement. Another concern that was raised was the potential "file drawer problem" where studies that do not show an effect are not published. The authors attempted to account for this by creating a statistical estimate for the number of *file drawer* studies that would be needed before a statement of no-effect would be given. They called this variable the *Failsafe* N_s, defined as the number of studies that would be needed to decrease the effect size below .05. This number was calculated for each of the eight alternate teaching strategies. For the total papers (n = 61) that were part of this meta-analysis, the authors reported N_s = 756, a pretty large number of studies.

Although these meta-analysis studies showed that alternate teaching methodologies could increase student achievement in science, a study by Krajcik et al. (2000) found that teacher differences in the delivery of inquiry caused large effects on outcomes in students. Although an overall mean effect size of +.87 was recorded for the inquiry units that were taught, great variation occurred due to teacher experience, making this an important factor that must be considered. Is the teacher being measured, or is it the strategy? It should also be remembered that the categories of teaching strategies in a science classroom will overlap, and it will always be difficult to separate the strategy of inquiry from the other teaching strategies that are in use by a teacher.

Large-Scale, Multi-Year Studies

Four sequential studies (Geier et al., 2008; Krajcik et al., 2000; Marx et al., 2004; Songer, Lee, & Kam, 2002) conducted in Detroit's public school system used the same project-based science curriculum developed by the Center for Learning Technologies in Urban Schools (leTUS) at the University of Michigan. The curriculum was aligned with national, state, and Detroit Public School curriculum standards. The project unit topics were: (a) What is the Quality of Air in my Community? (b) What is the Water Like in my River? and, (c) Why Do I Need to Wear a Helmet When I Ride My Bike? These 8- to 10-week inquiry units were reported to be highly engaging to students. A total of 34,942 middle school students participated in these four studies. Overall, they showed significant academic gains at the end of the unit. The refinement of methods over the course of these studies, the use of standardized state and national science assessments that had reported reliability and validity indicators, and the large sample sizes for all four studies, made these findings especially important.

Looking deeper, Geier et al. (2008) performed a three-year study with 5000 sixth through eighth grade student participants in the treatment group and 17,500 students in the comparison group. Academic gain was measured using the Michigan Educational Assessment Program (MEAP). Students who participated in the project-based teacher-directed inquiry program for all three years showed the largest gains on the MEAP. Students who participated for two years showed the next highest level of gain, with students participating for one year showing the lowest level of gain. However, while a significant effect could be seen as students participated for multiple years in the inquiry program, these gains were coupled with intensive teacher training, which was a prerequisite for success in all four studies. This training perhaps confounded the results, because it is difficult to determine which item was responsible for increasing student learning: teacher training or the inquiry curriculum. Results showed that without teacher training and commitment, student-learning gains were not as great. In fact, taking it one step further, teacher resistance proved to be a large obstacle to using inquiry as a teaching methodology as Bencze and Di Giuseppe (2006) noted.

Limitations of the urban setting were discussed in detail in a paper by Songer (2002) who found that it was hard for urban teachers to implement inquiry for the following reasons: (a) inadequate space, (b) large class sizes, (c) little prep-time for teachers to prepare for labs, (d) teachers' low science content knowledge, (f) high teacher mobility, (g) high student mobility, and (h) lack of administrative support. These limitations were also discussed in the papers by Geier et al. (2008), Krajcik et al. (2000) and Marx et al. (2004). Similar findings were reported in other studies: limited lab materials and lack of lab space affected teachers' ability to use scientific inquiry as a teaching methodology (Dass, Kilbey, & Chappell, 2005; Enger, 1998). So although content gain using inquiry methods can be demonstrated to be statistically significant, there are likely many obstacles to implementing inquiry that must be overcome in the school setting.

Bybee and Van Scotter (2007) investigated a national field test of the Biological Sciences Curriculum Study (BSCS) inquiry approach. They demonstrated that the 1,600 student participants located in 10 states had a 20-25% improvement in content knowledge over students who did not participate. This study drew 9th and 10th grade participants from urban, suburban, and rural schools and found that in order for the inquiry curriculum to be effective, it needed to have rigor, focus, and coherence. Students who showed the greatest gain were the general-ability and high-ability groups. Khishfe (2008) noted that an explicit and reflective inquiry-oriented approach was more effective than an implicit inquiry-oriented approach. Results did not support the assumption that students would automatically learn through engagement in science-based inquiry activities. Students must be engaged in reflective processes during inquiry (Dalton, Morrocco, Tivnan, & Meed, 1997).

Smaller Scale Studies

Lord and Orkwiszewski (2006) used a science attitude instrument developed by Novodvorsky (1993) and found that when students had the same science content delivered, but performed either inquiry or step-by-step labs, they had different attitude and learning gain outcomes. Students engaged in inquiry learned more science content as evidenced by higher quiz scores than students who were taught in classes where proscribed labs were used. Students who developed their own inquiry labs also had more positive attitudes about science. Ornstein (2006) found that students enrolled in science classes that regularly had labs had a more positive attitude toward science than students who were in classes that infrequently did labs. Students in classes that engaged in higher level questioning in inquiry style labs, during which they drew their own hypothesis and formed their own conclusions, were more positive about science than students who were in classes that had proscribed labs with little student input.

A study performed by Berg, Bergendahl, and Lundberg (2003) compared student outcomes for open inquiry, teacher-directed inquiry, and a traditional step-by-step approach for 190 students enrolled in a chemistry lab course. They found that students who performed open and teacher-directed inquiry labs could describe the experiments better than the students who did the traditional labs. Students who were in the traditional group could not suggest changes to the lab, while those in the inquiry labs could. Academic gains for students in inquiry were higher than gains seen for students in traditional labs. Inquiry showed positive effects on all ability groups, even students who were categorized as low performing. Students were shown to be more willing to put effort into the open inquiry labs over the traditional step-by-step labs. This was illustrated by the increased time they spent preparing for the experiment, time spent in the laboratory, and also in their judgment of how valuable and interesting they found the experiment. Harmer and Cates (2007) showed that inquiry worked best when teachers chose an authentic task, which had broad societal impact and emphasized how the problem would impact a student or his/her family or friends. They also suggested using an inquiry task that allows for many possible solutions.

In contrast, Pine et al. (2006) found no statistically significant differences between three out of four inquiry units when compared to similar material delivered using a textbook approach. Physical science tasks composed the three inquiry units that showed no improvement. Pine et al. stated that the tasks were too easy and thus did not actually engage students in higher-order thinking that is characteristic of inquiry labs. However, an 11% difference was seen in the fourth unit, where students performed observations of flatworms. According to the authors, the greater amount of time that students took doing the observational study over a textbook reading of flatworms accounted for the improvement. It seems to be a general trend and understanding in the literature that if the inquiry task is not engaging or rigorous, then it will not be a more effective way of teaching students science. This observation about student engagement needs to be further investigated, as it is a common conclusion in the research and it needs to be teased out. Specifically, what component of the science inquiry methodology is contributing to student learning gains? Is it the higher levels of thinking or is it the amount of time spent on the learning that allows for deeper understanding?

Four quasi-experimental studies revealed that students who were taught using scientific inquiry performed better on science achievement tests than students who were taught using other methods (Backus, 2005; Bybee & Van Scooter, 2007; Echevarria, 2003; Lee, Buxton, Lewis, & LeRoy, 2006; McCarthy, 2005). However, there were limitations to this group of studies, the primary one being non-random assignment of students to research groups. Bachus (2005) self-reported data from her own high school classroom, where she suspended traditional teaching methods for one year. Her findings had no control or comparison group other than her own recollections of her previous year of teaching, where she used a more traditional approach. Lee et al. (2006) had a very small sample size of 25 elementary students. Although learning gains were demonstrated for this small group of students, the generalizability of these findings is limited. Lee (1990) found limitations that were similar to those seen in the Detroit schools (Geier et al., 2008; Krajcik et al., 2000; Marx et al., 2004; Songer, Lee, & Kam, 2002): lack of support from the district and lack of experience of teachers with the inquiry method requiring extensive training before the study could be implemented. Even after training occurred, teachers reported difficulties using inquiry methods in helping their students construct scientific understandings.

Scientific Inquiry Benefits Under-Represented Groups

NAEP has recently developed an assessment method called Technology-Rich Environments (TREs) that assesses science inquiry skills in students using an interactive computer program. Several field studies have been performed and results show variability for student inquiry scores based on a number of factors (Bennett, Persky, Weiss, & Jenkins, 2007). Table 7 illustrates TREs inquiry scores for different student populations. While no differences can be seen due to gender (a finding confirmed in Geier et al., 2008), differences did occur by ethnicity and socio-economic status (SES).

Table 7

Mean TRE Inquiry Scores, by Student Characteristics, Grade 8: 2003 (Bennett et al., 2007)

Characteristic	Number of Students	Scientific Inquiry Score
Total	1,077	150
Gender		
Male	517	149
Female	560	150
Race/ethnicity		
White	643	160
Black	185	125
Hispanic	188	137
Eligibility for School Lunch		
Not eligible	656	158
Reduced-price	70	148
Free lunch	300	131

Scientific inquiry was found to benefit underrepresented groups: minorities (Geier et al., 2008; Lee et al., 2006; Marx et al., 2004; Songer, Lee, & Kam, 2002), students with learning disabilities (Dalton et al., 1997), students from low SES backgrounds and ELL students (Lee et al., 2006); emotionally disturbed students (McCarthy, 2005), and high achieving students (Lee et al., 2006). Scientific inquiry reduced gender differences seen in science scores (Geier et al., 2008).

Four studies attempted to address the gap seen in students with minority status and low SES. The large studies performed in the Detroit Public School System that have already been discussed looked specifically at closing this gap (Krajick et al., 2000; Marx et al., 2004; Songer, Lee, & Kam, 2002). Lee et al. (2006) found that students who were lower achieving, had minority status, were ELL, or had low SES had the greatest overall improvement.

Several studies specifically focused on addressing the gaps seen in scientific inquiry skills in special education populations. For example, students with disabilities who were mainstreamed received about 29 minutes of science instruction a week in grades 4-6, while 38% of students with disabilities who were in self-contained settings received no science instruction at all (McCarthy, 2005). For those who received instruction, 60% occurred using a textbook regardless of the fact that these students are the most likely to have difficulty with the text. McCarthy (2005) found that 18 students with significant emotional and behavioral disabilities did significantly better using an inquiry approach than students who used textbooks. Dalton, Morocco, Tivan, and Meed (1997) found that students with learning disabilities showed improvement, as did their general education classmates, when using inquiry methods. According to the authors, this improvement occurred through the use of higher-level thinking and questioning strategies.

Although gaps exist in science performance between certain populations as measured by nationally normed-tests, scientific inquiry is being used in an effort to reduce that gap in science achievement. Limitations to these studies are that students were not randomly assigned or selected, so a true causal relationship cannot be inferred from the results of these studies. Self-reporting of data by teacher researchers who do not have comparison groups is another issue that needs to be addressed.

Improvements to Inquiry Research Needed

Overall, while the bulk of the research supports science achievement gains in students who were taught using inquiry, there are many aspects that need improvement and many factors that may have affected the outcomes of these studies. There is still debate over how inquiry is defined and what is “true” inquiry. The range of inquiry is large, varying from being completely student driven to completely teacher directed. Many inquiry tasks that are given to students do not reflect the core attributes of authentic scientific reasoning (Chinn & Malhotra, 2002). Many teachers do not understand what inquiry is and, therefore, cannot teach it (Marlow, 1999). Enger (1998) argues that directed inquiry is not true inquiry. The misunderstanding of inquiry can extend to the district level. Rowell (2007) found that the district guide for inquiry used in a Canadian school was not really inquiry at all. Educational leaders need to be sure what the concept of inquiry is in order to move people to change teaching methodologies.

It is difficult to measure learning gains in inquiry on state and national student performance assessments. Inquiry is a complex construct that requires use of higher-order thinking skills that are not easily reduced to multiple choice style tests. For example, The New York State's Living Regents Exam was determined to be inadequate for inquiry measurement (Day & Matthews, 2008). Trying to address this need is the TRES test, which is currently in the process of being tested for large-scale interactive assessment of scientific inquiry (Bennett et al., 2007). Although there is hope that the TRES test will be able to objectively measure science inquiry and content skills, it is still in the pilot stage. Additionally, it is a test that is done on computers, and this may be an obstacle to schools without reliable technology.

Empirical evidence supports the assertion that scientific inquiry can play a role in increasing student achievement in science. Multiple studies, including two large meta-analyses, showed that inquiry can have a positive effect on learning outcomes. However, there are many limitations that must temper interpretations of these studies, including: (a) the role of other methodologies used in the classroom during inquiry instruction, (b) the role of teacher experience, support, and even content knowledge of inquiry, (c) the role of resources in the classroom, (d) the lack of large scale assessments to measure growth, (e) and of course, the lack of experimental studies using randomization.

Although inquiry shows promise as a teaching methodology and an approach in the classroom that allow students to engage in higher order thinking and problem solving, students also need to confront misconceptions that they hold so that learning can occur. Conceptual understanding of a science topic is important for students, so they can advance to more complex understandings. One of the topics that is commonly taught in middle school that many students hold misconceptions on is density (Smith et al. 1987). Identifying those misconceptions and then teaching to them will allow students to develop an understanding a fundamental science topic.

Teaching Density for Conceptual Understanding Requires a Non-traditional Approach

In middle school, students are introduced to one of the central concepts in modern science, the particulate model of matter. This model explains that all things are made of atoms, that atoms move in perpetual motion, and that they attract each other when they are a small distance apart and repel each other when they are in close contact with each other (Snir, Smith, & Raz, 2003). This concept is first taught in middle school science (Penner & Klahr, 1996) because it is thought to be too conceptually difficult for younger students to understand (Smith, Frenette, & Gard, 1985; Smith, Snir, Grosslight, & Frenette, 1986). Even middle school and high school students can have difficulty learning this concept, as it conflicts with many "intuitive ideas that students have about matter and about models" (Snir, Smith, & Raz, 2003, p. 796). Despite having instruction on the nature of matter, students of all age groups can still retain their naive views (Osborne & Cosgrove, 1983). Until students confront their misconceptions, conceptual change will not occur (Driver & Erickson, 1983; Kang et al., 2005). Naive views can interfere with student understanding of a broad range of science topics later in their schooling (Lee et al., 1990), as many topics in chemistry, physics and biology depend on a student's understanding of this model of matter.

Learning about density can help a student understand the particulate nature of matter, yet density is conceptually difficult for middle school students to master because it is abstract, unobservable, and must be inferred from knowledge about weight and volume (Smith, Snir, & Grosslight, 1987). Definitions of density can have both a formal and a nonformal component. Integration of these two components is believed to be essential (Smith, Maclin, Grosslight, & Davis, 1997). Density is formally defined as the ratio between an object's mass and its volume. It is calculated using the formula d = m/v (d = density, m =mass, and v = volume). Density is defined as a unique characteristic of matter. Informally, students have learned through their interactions with various materials that solid objects can have the same volume but have different weights (a steel ball and a wooden ball) or that a very small object can weigh more than a larger object. If two objects of similar size are made of different materials, students can infer that some objects are made up of heavier materials than others. These nonformal concepts need to be taken into account when a student is learning about density (Smith et al., 1997).

Students can enter a classroom with intuitive ideas of density that can be at odds with the formal concepts that are taught in the classroom. Typical instruction usually revolves around teaching "definitions for concepts, equations, formulas, and practice in how to apply these formulas in standard problem solving situations" (Smith et al., 1997, p. 319). Yet after traditional instruction "many students will have an undifferentiated concept that mixes characteristics of both weight and density" (Smith, Snir, & Grosslight, 1987, p. 1). Instructional methodologies that help students differentiate between density and weight need to engage students' higher-level thinking skills and their prior knowledge of these concepts (DeMeo, 2001).

Smith, Snir, and Grosslight (1987) assert that if students are taught density in a traditional way, they will not make a conceptual change and will instead modify the lesson to fit their own "intuitive framework" (p. 1). Further, giving students lists of formulas or definitions of density to memorize does not encourage them to relate the new material to their existing conceptions. Smith et al. (1987) suggest four activities that should be included in a curriculum that will teach for conceptual change in density: (a) analyze student starting points and expert end points so that the needed conceptual change can be defined; (b) have students make predictions about real world phenomenon, the teacher then selects situations that are puzzling to students in order to challenge them; (c) use a modeling approach so that students can visualize their ideas and conceptual relationships; and (d) use assessment tools that allow a teacher to effectively evaluate a student's progress toward expert understanding.

Hewson and Hewson (1983) presented a chart that lists scientific and alternate conceptions of mass, volume, and density, reproduced as Table 8. They conducted a study using 137 high school students from South Africa that compared an established traditional instructional methodology using a textbook and worksheets, with an alternate instructional strategy that used the same textbook, teacher-led discussions, inquiry experiments, and demonstrations designed to promote conceptual change. A pretest was given to all participants to determine students' prior conceptions of density, mass, and volume. It was determined that there were no statistically significant differences between the traditional and alternate instructional groups at the time the pretest was given. Misconceptions that students held were used to develop the alternate instructional materials. At the end of the intervention, a post-test was given to the traditional and experimental treatment groups and a change score was calculated. Results showed that the experimental groups gained more scientific conceptions and lost more alterative conceptions than the control group.

Table 8

Scientific and Alternative Conceptions of Mass, Volume, and Density

	Scientific conceptions	Alternative conceptions
Mass	Mass is a measure of the amount of matter in an object	Mass//weight = heaviness
	All matter has mass	Some objects have mass/weight (brick), while others do not (pin, hair)
	Units o measurement are grams, kilograms	Change shape = change mass
		Mass/weight = density
Volume	Volume is the amount of space occupied by matter	Volume = size or quantity
	All matter has volume	Volume = capacity
	Units of measurement are milliliters or cubic centimeters	Some objects have volume (water in cup) while others do not (cup, pin)
		Change shape = change volume
Density	Density is the ratio of the mass per unit volume of a substance	Density = mass/weight
	Units of measurement are grams per cubic centimeter	Density = denseness or crowdedness
		Density = packing of particles i.e. closely packed = dense, loosely packed = not dense

Adapted from Hewson & Hewson (1983)

The Smith et al. Investigations

Carol Smith, Department of Psychology, University of Massachusetts, was the primary investigator for a series of four studies on student conceptual change on the concept of density. These investigations were conducted between 1985 and 1997. A comparison of the studies is summarized in Table 9. The studies become increasing stronger as they move from a qualitative approach in 1985 to a mixed methods approach in 1997: the number of participants increases, reliability data are provided (Smith et al., 1997), and the length of the study increases. There is a refinement in the way that density is modeled. These studies were very useful in helping frame this dissertation. Although three of these studies used a computer modeling approach (Smith, Frenette, & Gard, 1985; Smith et al. 1986; Smith, Snir, & Grosslight, 1987), many of the visuals that were used to illustrate the particulate nature of matter as it relates to density were incorporated into this dissertation, as were sections of the pre-post assessments and interview strategies of Smith, Snir, and Grosslight (1987) and Smith et al. (1997). As the Smith et al. (1997) paper is the most rigorous of the four investigations, I will perform a more in-depth analysis on this paper.

Smith et al. (1997) used a mixed methods approach in their investigation of teaching students about density. Thirty 8th-grade participants, in two different classes in a large urban middle school, were studied. The investigators looked at both students' theories of matter prior to instruction and the effect of two different teaching methodologies on student understanding of density. In order to determine the pre-instructional theory of matter that a student held, students were asked to complete a series of tasks. Two separate coders independently coded data with a reliability of ≥ 90% and analyzed them using the Mann-Whitney *U* test. Students' pre-instructional ideas were consistent with one of two theories of matter: (a) *Commonsense Matter Theory 1*, a naive theory where matter ceases to exist when it becomes too small to see or touch. This theory does not promote students' differentiation of weight and density, or (b) *Commonsense Matter Theory 2*, an accurate theory where matter is fundamentally continuous and maintains the properties of the larger piece, no matter how small each piece is. Understanding of this theory promotes students' understanding of density. A further breakdown of pre-instructional knowledge was made into the following four categories: (a) full differentiation of weight and density, (b) limited differentiation of weight and density, (c) transitional differentiation of weight and density, and (d) hard-core lack of differentiation of weight and density. This pre-instructional analysis showed that students held a wide range of starting conceptions of density.

In the second part of the investigation, researchers compared the effectiveness of two teaching approaches. One emphasized quantitative reasoning, formal definitions, and measurements before qualitative understanding was in place. The second was a modified curriculum that forced students to confront the difference between their starting conceptions and the formal, desired understanding of density, using visual models to help them confront their misunderstandings. Although both curricula were effective in promoting understanding of density, the modified version that forced students to restructure their naive ideas was more effective at promoting an integrated understanding of density.

A "more text-centered approach that focused exclusively on quantitative comparisons and calculations produced negligible change in qualitative understandings and larger gaps between students' qualitative and quantitative understandings" (Smith et al., 1997, p. 385). Smith et al. (1997) asserted that qualitative restructuring took a considerable amount of time and mental effort on the part of students. It also took a longer period of time to change their qualitative reasoning about density than it did to teach students how to use a formula to calculate density. Even though students did better overall with the modified curriculum, not all students were successful in achieving an integrated understanding of density by the end of the study. Some of these unsuccessful students were in the lowest-performing group and could not distinguish between weight and density at the beginning of the investigation. It was suggested that they needed more time to restructure their innate theories. Another interesting observation was that some students were frustrated by the open-ended nature of the modified curriculum, wanting to be told the right answers so that they could get good grades. These students may not have been "epistemologically prepared " (p. 387) to negotiate conceptual change.

A weakness of Smith et al.'s (1997) study was that two different teachers taught the two different methodologies. It would have been a stronger study if the same teacher had taught both classes. To minimize this effect, teachers were observed by the curriculum developers. The sample size was also fairly small. This was due to the large amount of qualitative data that needed to be coded. The study had several strengths. It used multiple assessments for determining outcomes and used statistical analysis to determine the significance of results. The study was long term and was done by a research group with experience in the area. This study has had the benefit of many refinements of experimental procedures from previous investigations, as it is an ongoing area of research for this group.

Many aspects of the research by Smith et al. (1985, 1986, 1987, 1997) were incorporated into this dissertation: (a) multiple assessments, (b) qualitative coding of student responses, (c) instructional use of modeling, (d) some of the assessment and interview task items, and (e) probing for weight/density differentiation. Other researchers have also made important contributions to the field of student conceptual understanding of physical science topics and these studies will be discussed next.

Table 9

Comparison of Four Papers by Smith et al.

Study	Smith, C., Frenette, M. & Gard. (1985)	Smith, C., Snir J., Grosslight L., & Frenette, M. (1986)	Smith, C., Snir, J. & Grosslight, L. (1987)	Smith, C., Maclin, D., Grosslight, L., & Davis, H. (1997)
Type of study	Qualitative, observations, interview, matched pairs, no control	Qualitative, no control group, all participants received the treatment	Mixed methods, no control group- all participants received the treatment	Mixed methods
Independent variable	Order of tasks. One group given hands-on problems then computer model, other group given computer model then hands-on problems. Both groups did a play dough task for the 3rd session.	None – all students were given the same series of lessons on density. Computer modeling of density was key component, some structured lessons on modeling were given, some hands-on manipulation of objects	None – all students were given the same series of lessons on density. Use of discrepant events, hands-on activities, and computer modeling of density were key components of lessons	Comparing two different curriculums, one a standard curriculum on density and the other a modified one.
Dependent variable	Language used in describing density	Conceptual change of density	Conceptual change of density	Conceptual change of density
Assessment(s)	Interview and recording of student conversations	Pre- post-instructional interviews	Clinical interview, pre-post-written test	Pre- post interview and pre- post written test (multiple)
Reliability and validity	No	No	No	Yes > 90% reliability
Length of study	3 sessions	A series of 8 45-minute lessons	Density lessons presented over 10 40-minute class periods	10 weeks
Participants	Matched pairs of students in grades 2,4, and 6. 12 2nd graders, 10 4th graders, and 10 6th graders	Pilot study: 4 4th graders, 4 5th graders, 4 6th graders Teaching study: 19 6th grade students	20 6th grade students, 17 7th grade students	30 8th grade students,
Outcome	1) Younger students used less accurate, ambiguous language in describing density 2) Order of lessons mattered, students who received computer model first did much better than other group.	1) Understanding of density increased with age. 2) 66% of students could articulate the difference between weight and density	1) Five levels of student understanding of density were determined. 66% of students moved from the lowest level to a mid level. 2) High level of correlation between interview and written test	1) Students taught with modified approach that identified misconceptions did better on assessments

Other Investigations

Lee et al. (1990) used a mixed methods approach in a two-year study that looked at the effect of teaching strategies and curriculum materials on students' conceptual understanding of the nature of matter. The sample size for this study was much larger than the Smith et al. (1985, 1986, 1987, 1997) investigations, with 735 ethnically mixed sixth-grade students taking the pre-post assessment and 48 students interviewed. The reliability for the two measurement instruments (clinical interview and pre-post assessment) was calculated at 73%. The researchers explained that the reliability value was relatively low and close to the low cutoff threshold because the analysis was conducted by multiple coders on information that was collected from multiple sources. Results showed that students who were given the curriculum that was designed to: (a) promote conceptual understanding; (b) get them actively involved in using "scientific knowledge to describe, explain, predict, and control the world around them" (p. 4); and (c) apply their knowledge, did statistically significantly better than students who were taught using a traditional approach. Although student misconceptions were directly confronted in this study, in the next study it was found that young students may design inquiry experiments that only confirm their naïve ideas or may disregard information that is contrary to their novel theories. This suggests that in the classroom teachers should be deliberate in how they are guiding students in inquiry to ensure that misconceptions are confronted.

The Penner and Klahr (1996) qualitative study on the floating and sinking rate of different objects investigated the development of scientific reasoning skills that encompass "two types of knowledge: (a) domain-specific knowledge about the natural world, and (b) domain-general procedures for generating, assessing, and integrating that knowledge" (p. 2709). It differs from the Smith studies in two ways: (a) density is only one of several factors that influences the sinking rate of objects and (b) it investigated how emergent knowledge affects or is affected by a student's experiments in a domain. Thirty participants in three age groups: 9- to 10-year olds, 11- to 12-year olds, and 13- to 14-year olds were given pairs of objects to drop in water. The objects were chosen to vary in three attributes: weight, material, and shape.

During the investigation, participants were asked to summarize what properties they thought influenced the rate at which the object dropped. Data were collected through interview and observation. The younger students chose to do predictive experiments that supported their idea that heavier objects sink faster more often than the older students, who tried to test a particular hypothesis. Nearly all students, regardless of the evidence that shape can affect the rate an object sinks, concluded that heavy objects sink faster, even though they had direct evidence to the contrary. Prior beliefs had a strong influence on how participants interpreted the outcome.

This experiment provided evidence that older children will try to investigate the effect various attributes (like shape and size) have on sinking and floating when confronted with a novel experience if their results are different than their initial beliefs. Younger students preferred to design experiments that supported their naive ideas. The investigation further demonstrated that unless teachers confront students' misconceptions, even when students are presented with direct evidence that is contrary to their view of the world, they may not change their naive views. One of the weaknesses of the study was that all the participants were girls from a private girls' school, making the findings less generalizable. The sample size was also small.

Kang, Scharmann, Noh, and Koh (2005) studied the conceptual change in density concepts in 159 seventh graders in Korea. A similar study conducted by Kang, Scharmann, and Noh (2004) sampled 350 seventh grade girls in Korea. In both investigations, students had no previous instruction on density. A pre-instructional test was administered that examined student cognitive conflict as triggered by a discrepant event. Prior studies have shown that the need to reduce cognitive conflict is a powerful human motivation and is considered necessary for learning (Posner et al., 1982). Indeed, Guzzetti et al. (1993) who conducted an analysis on the qualitative research that had been conducted on the cognitive processes of students who are undergoing conceptual change report that students must create their own meanings and struggle with ideas on their own. Simply listening to a lecture that did not challenge their ideas did not feel like learning (Dickie & Kato, 1993).

Computer-aided instruction that was designed to change an undifferentiated weight-density concept into a differentiated scientifically accurate concept was given. A post-test was administered and the results for Kang et al. (2005) indicated that the only dependant variable that was statistically significant that correlated with the degree of cognitive conflict was field dependence/independence (FDI), which is a student's ability to "dis-embed relevant information from complex and potentially confusing events" (p. 1040). A multiple regression analysis indicated that logical thinking ability, FDI, and failure tolerance (the ability to keep working on a challenging task despite failure) were statistically significant predictors of higher density conception test scores.

Kang, Scharmann, and Noh's (2004) results indicated that there was a significant correlation between cognitive conflict and conceptual change. *T* -test results showed that there were statistically significant differences in the degree of cognitive conflict and the level of students' logical thinking ability and FDI teaching. Implications from both studies are that teachers need to address students' misconceptions on density prior to teaching it. Traditional teaching methodologies that assume students do not have misconceptions about conceptually difficult topics like density are not as effective as those that create cognitive conflict. It was recommended that teachers create "alternative classroom environments that encourage academic risk taking" (Kang et al., 2005, p. 1053) if students are going to learn to differentiate weight and density. One of the limitations of these two investigations is the fact that both used an all girl sample. The statistical analysis used in both studies was a strength.

Conclusion

The Smith et al. (Smith, Frenette, & Gard, 1985; Smith et al., 1986; Smith, Snir, & Grosslight, 1987; Smith et al., 1997) studies provide a strong body of evidence that non-traditional teaching methods that address students' pre-instructional knowledge of density are needed to drive conceptual change in density. Further evidence of the value of non-traditional approaches versus traditional approaches in teaching topics related to density is provided by the research into floating and sinking by Penner and Klahr (1996) and the nature of matter by Lee et al. (1990). These investigations, which compare the traditional approach versus the nontraditional hands-on approach, provide further evidence that teaching density, as it is usually taught in middle school, will not produce the conceptual change needed for true understanding. The Kang et al. (2005) and Kang, Scharmann, and Noh (2004) investigations show that cognitive conflict promotes conceptual change and allows students to distinguish between weight and density. Although there is strong evidence for teaching for conceptual understanding of density in nontraditional ways, there have been no large scale studies on using a combined approach of guided inquiry and methods that promote conceptual change. This is the area of research addressed by this dissertation.

Research Question

Do seventh grade middle school students who learn about density using a guided inquiry methodology have higher levels of conceptual understanding and content knowledge of density than students who are taught using a traditional teaching methodology, as measured by a pre- and post assessment and a pre- and post-task assessment of high and low learners?

Hypotheses

H_1 = Students who are taught using the scientific inquiry method will have a higher level of content knowledge gain and conceptual understanding of density than students who are taught using a traditional methodology, as measured by quantitative and qualitative pre- and post-assessments and student interviews..

H_o = There will be no statistically significant difference in content knowledge gain or conceptual understanding of density between students who are taught density with a scientific inquiry teaching methodology versus students who are taught with a traditional methodology, as measured by quantitative and qualitative pre- and post-assessments and student interviews.

CHAPTER II

METHODOLOGY

Overview of Research Design

For this investigation I used a quasi-experimental pre-test post-test comparison group design with teachers and their classes assigned to treatment and comparison groups. Teacher assignment was based on their preference for an inquiry or traditional teaching methodology. The independent variable for this investigation was the teaching methodology used to deliver a four-week unit on density to seventh and eighth grade students. The treatment involved an inquiry-based teaching methodology delivered via a researcher-developed unit that used discovery, hands-on activities, discrepant events, modeling, and guided inquiry labs. The comparison group used a unit that incorporated teaching strategies such as reading, lecture, notes, demonstrations, worksheets, and step-by-step procedural labs that are associated with a more traditional teaching methodology. The learning objectives, scope, and sequence of the series of eight lessons and culminating three crime-solving labs were identical. The change in the dependent variables was determined using researcher-developed assessments that measured student content knowledge gain, conceptual understanding of density, ability to differentiate weight and density, and growth from a qualitative understanding of density to a quantitative one. Several assessments were based on those developed by Smith et al. (1987).

Study Participants

Sampling Frame and Procedures

The participants for this study were drawn from a large (38,500 student) suburban public school district located in Oregon. This school district has eight comprehensive middle schools, five option middle school programs, and three K-8 schools. Three comprehensive middle schools and one K-8 school participated in the study. Table 10 displays the number of students attending these schools and the school-wide demographic data for the year of the study, 2010-2011. These data were obtained from the school district website. A convenience sample was used. Teachers were assigned to either the treatment or the comparison group. Student participants were drawn from the classes of the participating teachers. Although participating schools had a lot in common, there were also some differences. The percentage of minority students varied from a high of 56% at school 4 to a low of 31% at school 1 (district average = 46%). The percentage of English Language Learners (ELLs) varied from 8% at school 2 to 16% at schools 1 and 4 (district average = 14%). At school 3, the percentage of students eligible for free or reduced-price lunch (51%) was much higher than the district average of 38%.

Five seventh grade middle school teachers with a district-wide reputation for excellence in science teaching volunteered to participate in this study, making this a convenience sampling. Each teacher earned a $200 stipend for participating. Two of the 7^{th} grade teachers were from the same middle school, two additional teachers were from two different comprehensive middle schools, and one teacher taught both seventh and eighth grade students in a K-8 school.

Table 10

School Demographics for Participating Middle Schools- 2010-2011

School	Number of students in school	% Minority	% ELL	% SPED	% Free and reduced lunch	% TAG
1	516	31	16	13	39	7
2	830	39	8	14	32	11
3	897	45	12	15	51	7
4	869	56	16	14	43	15
District Average	NA	46	14	12	38	11

Teacher Participants

The five participating teachers were all classified by the district as "highly qualified" to teach science and had expressed an interest in implementing best practices in their classrooms. Most had taught for more than 10 years (M = 10.2, SD = 3.11). Three of the teachers in comprehensive middle schools taught three science classes a day with approximately 90 students total per teacher (M = 92.33, SD = 8.14). The fourth teacher in a comprehensive school taught 109 students in four classes a day. The teacher in the K-8 school taught 88 students in two classes of seventh grade students (n = 42) and two classes of eighth grade students (n = 46). Class sizes varied between teachers and between the classes for any given teacher, ranging from a low of 20 students to a high of 34 students (M = 27.81, SD = 4.75).

Teacher participant information and treatment assignment are presented in Table 11. Each teacher taught either the treatment or the comparison lessons on density to all of their students, to reduce the threat of treatment diffusion. Teacher assignment to either the treatment or the comparison group was based on teacher responses to a researcher-developed questionnaire titled *Teacher Methodology Preference Survey* (Appendix G).

Table 11

Teacher Participant Information

Teacher	School	Gender	Years Teaching	# Science Classes	Total # Students	Average Class Size	Teaching Methodology Assignment
1	1	F	10	4	88	22	Inquiry
2	2	F	13	3	98	33	Traditional
3	2	M	5	3	96	32	Inquiry
4	3	M	12	3	83	28	Traditional
5	4	F	11	4	109	27	Inquiry

Student Participants

In all, 428 seventh graders and 46 eighth graders participated in this study. Student ages ranged from 12-14 years. Several student characteristics that could conceivably affect the comparability of the different groups (treatment and comparison) should be mentioned. Most science classes are heterogeneously mixed for reading and math ability. However, sometimes the enrollment in science classes is affected when a higher-level math class is being taught by one of the teachers on the teaching team. When a higher level of math is taught, generally, the other classes taught by that middle school team are composed of students who are lower performing in math. Student math ability is an important consideration for this investigation, as students with higher math ability might perform better on a unit on density regardless of the method of content delivery.

Another factor that could contribute to nonequivalent groups were the proportion of ELL, SPED, and TAG students in a given teacher's class. In addition, reading ability could conceivably affect the outcome of the study, as the traditional teaching methodology used reading assignments to provide students with density information. Table 12 illustrates performance on the 2010-2011 Oregon Assessment of Knowledge and Skills (OAKS) statewide large-scale assessment of mathematics and reading and literature for all the seventh grade students at participating schools. Students participating in this study were a subset of these students. There was greater variability between the four schools for mathematics scores (M =68.83, SD = 5.43) than there was for reading scores (M = 78.65, SD = 3.75). This variability between schools might influence the comparability of the groups and will be taken into account during analysis.

Table 12

OAKS Test Scores for Schools in Study and for the District, School Year 2010-2011

	Total # 7th Grade Students	# 7th Grade Students in Study	% Students Meets/Exceeds in Mathematics	% Students Meets/Exceeds in Reading and Literature
School 1	42	42	62	74
School 2	291	194	73	82
School 3	279	83	67	78
School 4	293	109	74	81
District	2923	428	73	83

Note: data were obtained from the ODE website.

http://www.ode.state.or.us/data/schoolanddistrict/testresults/reporting/pagrsurpressed.aspx

To determine if there were statistically significant differences between the classes of a given teacher, I performed an Independent Samples *t*-test using SPSS, comparing student performance on the OAKS Mathematics assessment. Teacher 1's two seventh grade classes did not differ significantly from one another: Class 1 (M = 234.10, SD = 9.74) and Class 2 (M = 233.05, SD = 7.45) $t(40) = 3.92$, $p = .70$. There were also no statistically significant differences between Teacher 1's two eighth grade classes: Class 3 (M = 241.78, SD = 11.16) and Class 4 (M = 241.83, SD = 11.48), $t(44) = .013$, $p = .99$. However, as expected there was a statistically significant difference between Teacher 1's 7th and 8th grade students' OAKS scores. The 8th grade students for Teacher 1 will not be used in any comparisons with 7th grade students of other teachers in the study. *T*-test analysis of other classes in the study indicated that teachers 2, 3, and 5 each had one class with statistically significant lower performance scores on the OAKS Mathematics assessment than other classes for that teacher (See Table 13).

When comparing the overall OAKS Mathematics performance scores for students across teachers using SPSS and an Independent Samples *t*-test, there were no statistically significant differences between: (a) the two teachers at School 2, Teacher 2 (M = 232.41, SD =12.28) and Teacher 3 (M = 229.86, SD = 11.38) $t(194) = 1.51$, $p = .13$; (b) the two teachers at Schools 2 and 3, Teacher 3 (M = 229.86, SD = 11.38) and Teacher 4 (M = 226.85, SD = 8.01) $t(182) = 2.046$, $p = .06$; and (c) the two teachers at Schools 1 and 4, Teacher 1 (M=237.88, SD = 10.80) and Teacher 5 (M = 239.39, SD = 10.02) $t(195) = 1.016$, $p = .31$.

Table 13

Independent Samples T-test – Checking for Differences Between Classes on Student ODE Math Performance

Teacher	Classes being compared	Mean	Standard deviation	t	*df*	*p*	Conclusion
1	1	234.10	9.74	2.42	42	<.05	For Teacher 1, 7th grade classes (1, 2) had statistically significantly lower scores on OAKS Math Assessments than 8th grade classes (3, 4)
	3	231.78	11.16				
	2	233.05	7.45	3.02	42	<.05	
	3	231.78	11.16				
	1	234.10	9.74	2.40	42	<.05	
	4	241.78	11.48				
	2	233.05	7.45	3.00	42	<.05	
	4	241.78	11.48				
2	5	227.09	9.16	2.34	65	<.05	For Teacher 2, 7th grade class 5 had statistically significantly lower scores on OAKS Math Assessments than classes 6 & 7.
	6	233.86	13.42				
	5	227.09	9.16	3.38	61	<.05	
	7	236.26	12.20				
3	8	231.29	11.93	2.32	64	<.05	For Teacher 3, 7th grade class 9 had statistically significantly lower scores on OAKS Math Assessments than classes 8 & 10.
	9	225.03	9.71				
	9	225.03	9.71	3.02	61	<.05	
	10	232.97	11.07				
5	14	240.85	9.98	3.82	54	<.05	For Teacher 5, 7th grade class 16 had statistically significantly lower scores on OAKS Math Assessments than classes 14, 15, & 17
	16	231.97	7.30				
	15	240.85	8.20	4.21	53	<.05	
	16	231.97	7.30				
	16	231.97	7.30	5.33	54	<.05	
	17	244.48	10.15				

Because student reading ability could also affect the outcome of the study (as the traditional teaching methodology had student participants reading to gain understanding of density), groups were also compared for reading performance. Using SPSS, an Independent Samples *t*-test was performed to see if there were statistically significant differences in the OAKS Reading performance scores between the classes of each participating teacher. Only two classes had statistically significant differences, with lower scores than other classes for the same teacher: (a) Teacher 3, Class 9 (M = 225.68, SD = 8.24) and Class 10 (M = 231.47, SD = 10.87), $t(61) = 2.38$, $p < .05$; and (b) Teacher 5, Class 16 (M = 229.59, SD = 8.33) and Class 14 (M = 236.78, SD = 9.96), $t(54) = 2.94$, $p < .05$. Both of these classes also had lower OAKS Mathematics performance scores. Interestingly, teacher 1's seventh and eighth grade did not differ in terms of reading ability. When the OAKS Reading performance scores were compared across teachers, there were no statistically significant differences between students assigned to teacher 1 (M = 236.38, SD = 10.38) and students assigned to teacher 5 (M = 236.16, SD = 10.78), $t(195) = .144$, $p = .87$. However, the mean reading scores for these two teachers' students were statistically significantly higher than the scores of students assigned to Teachers 2, 3, and 4. The reading performance of the students assigned to these three teachers were statistically equivalent.

The nonequivalent classes were taken into consideration during the analysis of results. The data that was obtained from students that had no statistical matches was not used in order to determine the effectiveness of the treatment, only classes that were matched between the treatment and comparison were compared in order to determine the effectiveness of the treatment. No statistically significant differences were seen between teachers or between classes based on the number of students who were identified as ELL, SPED, and/or TAG, so these variables were not considered separately in analyzing the results.

Intervention

The teaching intervention was a four-week unit on density consisting of eight lessons and three labs. Student gains were measured using a pre-post multiple choice assessment of all participating students, a pre-post task assessment for the measurement of density for three objects completed by all students, an interim density assessment that measured conceptual understanding, and an in-depth interview and task assessment of a select group of students. Both the inquiry (treatment) and the traditional (comparison) lessons were designed to be engaging and cognitively challenging to students. The researcher developed the lessons, labs, and activities.

One of the guiding principles of the intervention unit was to try to expose students' misconceptions about weight and density through a series of hands-on activities. In the inquiry lessons, these explorations were more open-ended. Students were given guiding questions, made material choices, and designed their own procedures. In the traditional lessons, students were given set procedures and told what materials to use. Another guiding principle of the study was to try to move students from a qualitative understanding of density where they could distinguish that one object was heavy for its size or light for its size, to a quantitative one where they were able to describe how much denser one material was than another. A qualitative understanding usually occurs first (Smith et al., 1987), where students are able to rank materials by density, determining that steel is denser than aluminum and aluminum is denser than wood. In a quantitative description, they would be able to determine that steel is about three times denser than aluminum and that aluminum is about four times denser than wood. Lessons 2-6 were designed to build student qualitative understanding of density. Lessons 7-8 *Determining Density* and *Density* and *Applying What You Have Learned* focused on developing students' quantitative understanding of density.

Lesson Overview

Lesson 1 through Lesson 6 shared common elements between the treatment and the comparison groups. All content was similar, with similar learning objectives, materials, sequence, and timing. The variability was in the approach that was used to teach students density and the concepts relating to density. For example, in Lesson 1- *Properties of Matter*, both the treatment and the comparison group of students were given the same background information on the properties of matter. Both groups were asked to define the terms *matter* and *characteristic property of matter*. However, the inquiry group was asked to define the vocabulary based on their experience in the lab and the traditional group was asked to write the definition down as notes in a graphic organizer. Another example was in Lesson 5- *Measuring Matter*, where both the inquiry and the traditional group were asked to rank objects from heaviest to lightest. Students compared this ranking with data that they collected in Lesson 2 - *Sinking and Floating* to see if there was a correlation between the heaviness of an object and sinking, or the lightness of an object and floating. The inquiry groups did this after they had performed a guided inquiry lab, and the traditional group did this after a procedural lab.

After Lesson 6, an interim assessment was given that evaluated students' qualitative understanding of density. It was an open-ended assessment that asked the following questions: (a) Does mass alone explain why an object sinks or floats when placed in water? (b) Does volume (or size) alone explain why an object sinks or floats when placed in water? (c) Does density alone explain why an object sinks or floats in water? (d) What is density? (e) Is it possible to combine two materials that have different densities (one sinks and one floats) in water into a new object that has a density that is different from the original materials? (f) Can objects that float in water sink in another type of liquid? (g) True or False, when an object sinks or floats, it is dependent on the relationship between the density of the liquid and the density of the object. For each question, students were to explain their thinking. This interim assessment was placed before the final three problem-solving labs to determine if there was any difference between the groups prior to the final assessments.

Lesson 7 - *Calculating Density,* was exactly the same for both the treatment and the comparison groups because it introduced density in terms of a formula that was a ratio of mass to volume. Students of both groups completed the same set of density problems using the density formula: Density (D) = Mass (M) ÷ Volume (V).

In keeping with Smith et al. (1987), a modeling approach was used to help students with their conceptual understanding of density. Students were asked to draw the density concepts that they learned. For example, in Lesson 3 - *Mixing Materials* students in both the treatment and the comparison groups created neutrally buoyant objects by combining high-density materials and low-density materials. During the reflection at the end of the lesson, both groups were asked to interpret a set of drawings that were made of dark and light colored boxes. The phrase "heavy for its size" was associated with dark-colored squares and the phrase "light for its size" was associated with light-colored squares. Students were then asked to rank a set of drawn objects that had different ratios of dark to light squares. Objects with a greater proportion of dark to light squares had a greater density and objects with a greater proportion of light to dark squares had a lower density. By seeing these ratios expressed as abstract models, students could make the connection that most objects in the world are mixtures of different substances. By understanding that changing the ratio of materials will change the average density of an object, students develop a more complex conceptual understanding of density.

Lesson 8 developed students' quantitative understanding of density by asking them to write six comparison statements about objects for which they had determined the density. In the inquiry lab, students were asked to choose their own objects and to develop their own procedures. They were told to choose ten objects that were comparable – controlling their own variables, from all the materials that they had used in the previous lessons. In the comparison lab, students were told which ten objects to use from a set of density cubes (all cubes were the same size, but made of different materials) and density cylinders (all cylinders were the same weight, but made of different materials). Students were also told the procedures to use.

Once the students completed the eight hands-on lessons, they performed three quantitative density labs that were based on mysteries where students solved a crime using what they had learned about density. In this way, all students had experiences of applying what they had learned in an authentic task. Both the treatment and the comparison groups had the same crime scenarios for these final labs. The first lab was on the density of regularly shaped objects (the mystery was an art theft that students had to solve), the second lab was on the density of irregularly shaped objects (the mystery was a murder that students had to solve), and the third lab was on the density of liquids (the mystery was an illness that students had to diagnose). The materials for these labs were identical in both the treatment and the comparison groups.

Materials

The materials for lessons 1-8 were carefully chosen so that students would informally explore a variety of density comparisons throughout the course of the intervention. It was important that students were exposed to these different types of material categories so they could begin to distinguish between weight and density and to move from a qualitative understanding of density to a quantitative understanding (Smith et al., 1987). For example, students using materials in category 1 – *same material, different size, same density* – could see that density is not dependent on the size or the mass of an object alone. A large piece of wood floats as well as a small piece of wood. From this, a student could make the inference that a large tree that weighs 1,000 pounds or more will also float. Perhaps the student has even seen this at the beach or at a river. In category 6 *same size, same shape, different materials, different density* category, students could see that a wooden ball floats, but a golf ball that is the same size sinks. In fact, the inference can be made that while the golf ball will sink, it is much smaller and weighs much less than a log that floats. These kinds of examples help students develop qualitative ideas of density before they are exposed to a density formula. All the material categories that were used in this investigation to help advance student conceptual understanding of density are listed and described in Table 14. Every lab used at least one of these categories and many used multiple categories. The same materials were used in both the treatment and the comparison lessons so both sets of students had the same exposure to all the material categories (see Figure 1).

Treatment Lessons

The first eight lessons were designed so that students could build measurement and observational skills as well as content knowledge and conceptual understanding of density. Table 15 briefly describes these lessons. All treatment lessons, teacher notes, and lesson keys are found in the appendix. Extensive teacher notes were created to increase the likelihood that the lessons were implemented with fidelity, as the researcher was not be able to observe teachers teaching every lesson. Throughout the treatment lessons, students were introduced to the basic concepts of density using guided inquiry and a student exploratory approach.

Formative assessments developed by Keeley and Harrington (2010) and tied to National Science Education Standards (1996) and Benchmarks for Science Literacy (AAAS, 1993) were used to challenge student understanding of density concepts and to reveal student misconceptions. The use of these formative probes was a key difference between the treatment and the comparison lessons. Lessons 1-3, 5 and 6 used the formative assessment probes.

Once the students completed the eight hands-on lessons, they performed three quantitative density crime-solving inquiry labs. For each lab, students wrote their own question, a paragraph on relevant background information, and their hypothesis, materials, and procedures. Students created their own data table and graph, and analyzed their own data.

Table 14
Material Categories and Objects Used in Density Lessons

Category	Material/Density Comparison	Objects Used
1	Same material, different size, same density	A variety of wooden objects made from pine (floats), sets of cylinders (steel, brass, aluminum, and plastic) that are the same materials but different lengths, fishing weights (sink), marbles (sink), aluminum foil and candle holder, different sizes of Styrofoam balls (float), different sizes of plastic (sink)
2	Same size, different density, same external material	Small ball of clay (sinks), small ball of clay with a half of a cork inside (neutrally buoyant), small ball of clay with a full cork inside (floats). A set of three Styrofoam balls that have weights inside to give them different densities (one floats, one sinks, and one is neutrally buoyant)
3	Same size, different density, appears to be the same materials	A square of white Dial bar soap (sinks), a square of white Ivory bar soap (floats)
4	Same size, different density, similar material	Pumice (floats), basalt (sinks), white balls (sink or float), plastics and acrylic beads (sink or float)
5	Same size, different density, different material	Density cube set
6	Same size, same shape, different materials, different densities	Set of balls that are the same size but have varying densities (Some float, some sink)
7	Different size, different density, different material, same weight	A set of cylinders all with the mass of 15 grams
8	Different size, same material, same density	Density set of cylinders made of same material but with different sizes and masses
9	Different size, similar material, same shape, different density	Set of rectangles that are made from five different types of plastic each with a different density.
10	Same solid material, different liquids with different densities	Candle, alcohol (candle sinks) and water (candle floats)
11	Appears to be same colorless liquid, different densities	Water, alcohol, mineral oil, baby oil, glycerin corn syrup

Figure 1. Material basket of density objects for lesson 1

Table 15
Inquiry Lessons- Briefly Described

Lesson #	Lesson Title	Objective/Description
1	Properties of Matter	Students: (a) learned that everything that they touch, taste, and see is made of matter and that matter has characteristic properties, (b) sorted objects according to characteristic properties, (c) sorted same set of objects for a different property. • Formative assessment: Comparing Cubes • Framework for density as a property of matter • Properties of Matter Sorting Activity worksheet • Properties of Matter Wordsearch
2	Sinking and Floating	Students: (a) predicted and tested an object's ability to sink and float, and (b) developed rules for sinking and floating • Mini inquiry: Does the size of an object affect it ability to sink or float? • Make a visual representation of 3 objects that sink, float, and are neutral • Qualitative understanding of density

Table 15 (continued).

Lesson #	Lesson Title	Objective/Description
3	Mixing Materials	Students: (a) created three objects out of clay and cork: one object sank, one floated, and one remained neutrally buoyant; (b) made a visual representation of the 3 objects that are made of the same materials, yet had different floating behaviors; (c) explained how mixing the ratio of heavy for its size materials with lighter for its size materials changed how an object sank or floated. • Mini inquiry: How does changing the ration of two different materials in an object affect its ability to sink or float? • Formative assessment: Floating High or Low? • Teacher demonstration on neutral buoyancy • Students use models to understand ratios and how mixing materials of different densities create objects with new densities. • Qualitative understanding of density
4	Changing the Liquid	Students: (a) used the same set of objects from previous lessons and explored the sinking and floating properties of some of these objects in three different liquids – alcohol, fresh water, and salt water; (b) observed that objects put into different liquids sank or floated depending on the liquid. • Mini Inquiry: How does changing the liquid an object is put into alter how an object sinks or floats? • Create a model of a neutrally buoyant object and demonstrating how that objects looks different depending on the density of the liquid • Qualitative understanding of density
5	Measuring Matter	Students: (a) determined the mass of an object, and (b) discovered that the density of an object is not determined by mass alone. • Mini Inquiry: Does the mass of an object affect its ability to float? • *Practice Reading the Balance* worksheets • Formative assessment: Solids and Holes • Differentiate between weight and density • Qualitative understanding of density
6	Exploring Volume	Students: (a) determined the volume of objects using 3 methods: i) water displacement in a graduated cylinder, ii) water displacement in an overflow can, iii) using a ruler for three-dimensional rectangular solids and the volume formula. • Formative assessment: *What Will Happen to the Weight?* • *Practice Reading the Volume* worksheets • Building laboratory skills needed for determining the density of objects by measuring volume three ways – complete *Exploring Volume* lab.
7	Calculating Density	Students: (a) calculated density using a formula, • Reading selection – *Density* • *Calculating Density* - Worksheet • Quantitative understanding of density.

Table 15 (continued).

Lesson #	Lesson Title	Objective/Description
8	Density- Applying What You Have Learned	Students: (a) calculated the density of the objects that they have been using in these labs, (b) learned that the density of materials is fixed for a particular material and that materials that have different shapes or sizes that are made of the same materials will have the same density, (c) calculated the density of objects and then used that information to compare materials. • Density Assessment: • Quantitative understanding of density.

Comparison Lessons

There were eight lessons for the comparison groups that used a traditional teaching methodology. The lessons were based on current teaching practices in the school district where the study took place. The sequence of lessons was the same as the sequence in the inquiry group. However, students were introduced to the basic principles of density in a way that was more teacher-centered and traditional. There were reading excerpts, video clips, vocabulary exercises, notes, worksheets, and step-by-step activities. The content covered was comparable to that covered in the treatment group. The full comparison lessons with detailed teacher notes and keys are found in the appendix. Once the eight lessons on density were completed, students performed three traditional step-by-step procedural labs where they had to apply what they learned about density to solve a mystery. For all three labs, students were given the questions, the material list, the procedure, the labeled data table, they were told exactly what to graph and the type of graph that they should produce (bar versus line). In the analysis, they were given specific questions to answer. Table 16 outlines the lessons that the comparison group received.

Table 16
Traditional Lessons - Briefly Described

Lesson #	Lesson Title	Objective/Description
1	Properties of Matter	Students: (a) learned that everything that they touch, taste, and see is made of matter and that matter has characteristic properties. • Pre-test on properties of Matter • Video – Properties of Matter • *Properties of Matter Vocabulary* graphic organizer • *Video Quiz* worksheet • *Video Discussion Questions* Worksheet • Properties of Matter Wordsearch
2	Sinking and Floating	Students: (a) predicted and tested an object's ability to sink and float, and (b) developed rules for sinking and floating • Activity- *Sinking and Floating* • Make a visual representation of 3 objects that sink, float, and are neutral • Qualitative understanding of density
3	Mixing Materials	Students: (a) defined ratio, buoyant force, neutral buoyancy and applied those definitions to solving a few problems, (b) observed a neutrally buoyant object, (c) observes how Diet Coke and Classic Coke have different floating and sinking behaviors, (d) changed these objects by mixing materials so that they became neutrally buoyant, (e) explained how mixing the ratio of heavy for its size materials with lighter for its size materials changes how an object sinks or floats. • *Vocabulary and Problems on Buoyancy* worksheet • Teacher demonstration on neutral buoyancy • *Mixing Materials* Lab • Students use models to understand ratios and how mixing materials of different densities create objects with new densities. • Qualitative understanding of density
4	Changing the Liquid	Students: (a) changed the density of water by adding salt and see how this affected how an egg sinks or floats, (b) observed that objects put into different liquids will sink or float depending on the liquid (compare fresh water, salt water, and alcohol with a set of objects.) • Reading passage – *This Ice Sinks* • View video clip on *Buoyancy.* • Do activity – *Floating Eggs in Salt Water* • Do activity – *Floating Objects in Alcohol* • Create a model of a neutrally buoyant object and demonstrating how that objects looks different depending on the density of the liquid • Qualitative understanding of density

Table 16 (continued).

Lesson #	Lesson title	Objective/description
5	Measuring Matter	Students: (a) determined the mass of an object, and (b) discovered that the density of an object is not determined by mass alone. • Reading Selection – *Measuring Matter* • *Practice Reading the Balance* worksheets • Activity – *Which has more Mass?* • Differentiate between weight and density • Qualitative understanding of density
6	Exploring Volume	Students: (a) determined the volume of objects using 3 methods: i) water displacement in a graduated cylinder, ii) water displacement in an overflow can, and iii) using a ruler for three-dimensional rectangular solids and the volume formula. • Reading selection - *Volume* • *Exploring Volume* worksheet • Classroom discussion on volume and how it is measured • Building skills needed for determining the density of objects by completing *Calculating Volume* worksheet
7	Calculating Density	Students: (a) calculated density using a formula, • Reading selection – Density • Calculating Density - Worksheet • Quantitative understanding of density.
8	Density- Applying What You Have Learned	Students: (a) calculated the density of objects that they used in the preceding labs, (b) learned that the density of materials is fixed for a particular material and that materials that have different shapes or sizes that are made of the same materials will have the same density, (c) calculated the density of objects and then used that information to compare materials. • *Density Assessment* • *Density – Applying What you have Learned* - Lab • Quantitative understanding of density.

Pretest and Posttest Measures

Density Assessment

The lessons in both the treatment and comparison conditions aligned directly with this assessment. The pre- and post-tests were exactly the same. Reliability information is not available for this testing instrument. The primary purpose of the *Density Assessment* was to examine overall student knowledge gain on density. The 32-item multiple choice test (found in the appendix) was adapted from a 60-item assessment that Smith et al. (1987) used in a 12-week study that examined sixth and seventh grade students' conceptual change around density. Many of the questions that were used in this instrument were exactly the same as those published in the Smith et al. (1987) study to probe student conceptual understanding of density through modeling. In addition, I added more traditional problem sets using the density formulas that are typically given in middle school and content knowledge test items. The *Density Assessment* is intended to show how "students systematically apply their concept of density to a range of phenomenon" (Smith, 1987, p. 13).

By breaking down the 32 questions into several smaller categories, a more specific analysis can be conducted. The first question set, questions 1 through 7, used modeling to present information on two imaginary materials called Galt and Lidium. For these questions, students were asked to distinguish between weight and density. They were given weights and relative densities and asked to make relative density comparisons using this information. More specifically, students were asked to make paired comparisons for questions 3 through 7. The second question set, questions 8 through 10, also used modeling. Students were asked about the relative density of materials and if dividing an object changes its density. Questions 1 – 10 measured student conceptual and qualitative understanding of density.

In questions 11 through 16 and 20, students were asked to compute the density of objects using their understanding of the density formula and given volumes and weights. These questions evaluated student content knowledge and quantitative understanding of density. For questions 17 through 19 and 21 to 22, students were asked to make predictions about whether objects would sink or float. These questions measured conceptual and qualitative understanding of density. For questions 23 through 25, students were asked to make predictions about whether two objects with different densities could be made of the same material. These questions used a modeling approach and measured conceptual and qualitative understanding of density. Questions 26 through 29 returned to quantitative calculations of density, asking students to calculate the density of liquids and irregularly shaped objects. Questions 30 through 32 were content questions that students read about in the traditional lesson group. This information was not explicitly taught to the inquiry group, who would have to infer this knowledge from their experiences in the density unit.

Weight/Density Differentiation Task Assessment and Interview

The purpose of this assessment was to determine the gain in student conceptual understanding of density over the course of the study. The questions and tasks that students completed were based on activities developed by Smith et al. (1987). For this investigation, I conducted the pre/post weight/density differentiation task assessment and interviews (found in the appendix) with one to four students from each teacher participant. Students were selected from a pool of students selected from one of three groups: those with the lowest scores on the multiple choice pre-test, those with the highest pre-test scores on the same assessment, or those whose pre-test scores placed them in the middle of the scoring range. Teachers chose the students to be interviewed. A total of 17 student weight/density differentiation task assessments and interviews were conducted for this investigation, with students selected by each of the participating teachers. The same 17 students were assessed for the pre-task assessment and the post-task assessment.

An attempt was made to balance male (n = 9) and female (n = 8) students; students being taught using an inquiry (n = 9) versus traditional (n = 8) approach; and to ensure that students from SPED (n = 2), TAG (n = 4), and ELL (n = 2) groupings were interviewed. The range and mean for the OAKS Math performance scores for the task assessment group (n = 17, M = 230.59, range = 204 to 257) closely approximated that of the entire participant group (n = 479, M = 233.48, range = 204 to 266). The range and mean for the OAKS Reading performance scores for the task assessment group (n = 17, M = 230.76, range = 204 to 254) also closely approximated that of the participant group (n = 479, M = 231.84, range = 200 to 269). For the interview group (n = 17), 6 students had pre-test scores in the 5 to 11 range, six students had scores in the 12 to 13 range, and 5 students had scores in the 23 to 28 range. This pattern closely approximated the quartile separations for the entire sample (n = 479) with the bottom quartile pre-test scores ranging from 3 to 11 and the upper quartile pre-test scores ranging from 19 to 32. An Independent Samples t test showed no statistically significant differences between the student interviewees in the inquiry group for OAKS Math_{I} (M = 233.44, SD = 19.51) and the traditional group OAKS Math_{T} (M = 227.38), $t(15) = .877$, $p = .40$; for the inquiry group for OAKS $\text{Reading}_{\text{I}}$ (M = 233.89, SD = 15.34) and the traditional group for OAKS $\text{Reading}_{\text{T}}$ (M = 227.25, SD = 9.11), $t(15) = 1.07$, $p = .30$; and for the pre-test for the inquiry group $\text{Pretest}_{\text{I}}$ (M = 17.33, SD = 8.19) and for the traditional group $\text{Pretest}_{\text{T}}$ (M = 12.62, SD = 6.21), $t(15) = 1.34$, $p = .20$.

The scripted interview and task assessment took approximately 45 minutes per student. The interviews were conducted during students' science class or study hall in a science prep room that provided privacy. All density task assessments were audio recorded using a free Mac application called Audacity. The audio recordings were used to verify the accuracy of the written observations recorded during the interview. The researcher created the *Scoring Sheet for Task Analysis* for analyzing student performance on the assessment tasks (found in the appendix). Using this scoring sheet, each student's level of performance on weight/density differentiation was determined. At the end of the assessment, students were assigned an overall level of understanding of density.

There were four types of tasks for this assessment that focused on evaluating students' ability to distinguish between weight and density: (a) ordering tasks, (b) modeling tasks, (c) adding material tasks, and (d) sink/float tasks. The initial tasks did not require that students know the meaning of the word "density." The ordering tasks began by asking students to contrast which object was heavier than another and which object was made of a heavier kind of material. The word "density" was introduced to students in this fashion, "some materials are denser than others, which means that they are a "heavier kind of material."

Table 17

Information on Interview and Pre- Post-Task Assessment Participants

Student ID	School	Teacher	SPED	TAG	ELL	Gender	Inquiry	State math	State reading	Pre-test score
1	1	1	y	n	n	f	yes	225	232	11
2	2	2	n	y	n	f	no	229	224	26
3	2	2	n	n	n	m	no	232	236	5
4	2	2	n	n	y	f	no	215	211	7
5	2	2	n	n	n	m	no	229	234	13
6	2	3	n	n	n	m	yes	210	220	11
7	2	3	n	n	n	m	yes	226	228	24
8	2	3	n	n	y	f	yes	204	204	9
9	2	3	n	y	n	f	yes	256	246	28
10	3	4	n	n	n	m	no	222	222	13
11	3	4	n	n	n	m	no	224	222	13
12	3	4	n	n	n	f	no	232	238	12
13	3	4	n	n	n	f	no	236	231	12
14	4	5	n	y	n	m	yes	257	240	12
15	4	5	n	n	n	m	yes	242	243	23
16	4	5	n	y	n	m	yes	252	254	28
17	4	5	y	n	n	f	yes	229	233	10

Detailed Descriptions of Weight/Density Differentiation Tasks

Ordering Tasks

There were six types of ordering tasks: (a) sorting by materials, (b) paired comparison by weight, (c) paired comparison by density, (d) mystery materials, (e) seven-object ordering by weight, and (f) seven-object ordering by density. For each student, the individual score for each of these six task types was combined to give one overall score for "ordering." If a clear pattern of ordering was not evident in the evaluation of the student's performance, greater weight was given to tasks (d) and (f) which were considered to be critical tasks. For the set of ordering tasks, a student could show three levels of understanding: a clear distinction between weight and density, a beginning distinction between weight and density, or a weight-only distinction.

The objects that were used for the ordering tasks 1-3 were taken from a set of density cylinders (1 ½" diameter) made of black plastic, aluminum, or brass. These cylinders varied in length, density, color, and sheen. For the first ordering task- *Sorting by Materials*, there were three cylinders of varying sizes for each type of material. Students were told, "Some of these objects are made of different materials and some are made of the same material. Can you sort them into groups according to the kind of material they are made of?" Students then grouped the nine objects. Successful students formed three groups with three objects each. If a student was not able to complete this task successfully, he/she was helped and any mistakes he/she made were corrected.

For the *Paired Comparison by Weight Task* students were given six pairs of objects and asked to determine if one of the paired objects was heavier or if they weighed the same. If the student responded that one of the objects was heavier, they were asked to identify which object was heavier. Student responses were recorded. Students had a digital scale available that they could use to determine the weight of the objects. This scale was available during the entire assessment, and students who did not know how to use it were shown how to operate it. Periodic checks were made to inquire if the student needed help in operating the scale, so that any student could use it for the weight comparisons. After the paired-weight comparisons were made, students were asked, "How did you know which object was heavier?" For the *Paired Comparison by Density Task*, students were given eight different pairs of cylinders. They were asked to determine "Is one of these objects made of a heavier kind of material or not?" At the end of the comparisons, students were asked how they would tell which object was made of a heavier kind of material.

There were several paired combinations of objects that were similar in the paired-weight and paired-density tasks: (a) objects that were the same size, but different material; (b) objects that were the same material, but different size; (c) objects that were of equal weight, but different size and material; and (d) objects that varied by size, weight, and material. Comparisons (a) and (b) allowed students to make an inference about the relative densities of plastic, aluminum, and brass. Comparison (c) is critical to student understanding as items that are larger in size can be lower in density, and (d) is critical because the objects that are heavier can be lower in density than objects that weigh less. The most important concept being evaluated was whether students could ignore the weight of objects in order to make a judgment on the relative density of two objects.

The next ordering task was the *Mystery Material Task* where six new objects were introduced. These were one $inch^3$ density cubes that varied in material composition and density. Three cubes were made of the same materials that students had been using for the first three ordering tasks: plastic, aluminum, and brass. The other three objects were the mystery cubes, covered with blue masking tape and labeled either A, B, or C. Two of the mystery cubes were made of new materials – copper (A) and wood (C), and one was made of brass (B), a material with which students were familiar. To begin the task, students were given Mystery Cube A and asked, “Could this material be made of plastic, aluminum, or brass or must it be made of something else? How do you know?” The students’ strategy and explanation were recorded. This was repeated for Mystery Cubes B and C.

The last two ordering tasks were the *Seven-Object Ordering by Weight Task* and the *Seven-Object Ordering by Density Task.* The objects that were to be ordered for both the weight and density tasks were exactly the same. There was a wooden density cube (same as Mystery Cube C) and black plastic cylinder (from paired-comparison tasks). These two objects weighed the same. There was a one-inch^3 plastic cube, one-inch^3 aluminum cube, and a large plastic cylinder (same material/density as the one-inch^3 plastic cube) that was equal in weight to a small copper cylinder. Finally, there was a one-inch^3 copper cube that was the same density as the copper cylinder. These tasks were more demanding for students, as they were required to order a set of seven objects for weight (from lightest to heaviest) and density (from least dense to most dense) rather than just two objects and deal with materials that were the same and with different objects that had the same weight. The final ordering of the objects was different for the weight-ordering task than it was for the density-ordering task. For the pre-assessment, students were expected to get the weight-ordering task correct as they had the digital scale available to them, but students were expected to struggle with the ordering of objects by density.

Students were assigned to one of three levels of weight/density differentiation based on their performance on these ordering tasks: (a) *Absolute weight characterization* – students made little to no differentiation between weight and density. Objects were ordered by weight alone; (b) *Beginning weight/density characterization* – students were beginning to differentiate between weight and density but were not yet proficient. Some objects in a density ranking were ordered by weight and others were ordered by density; and (c) *Clear density characterization* – students clearly understood the difference between weight and density, that density is a characteristic property of matter that it is dependant on the material of which the object is made, and that an object that is smaller can be more dense than an object that is larger and weighs more. Please see the *Scoring Sheet for Task Analysis* in the appendix to see the exact scoring scale.

Modeling task. Students were asked to make visual representations of three of the objects that they had used in previous tasks: a long plastic cylinder, an aluminum cube, and a short brass cylinder. They were challenged to find a way to depict the size, weight, and density of the three objects. At issue was whether the students could represent weight and density as separate dimensions in their model and if they did, how they would distinguish them. This was potentially the most demanding of the tasks that students were asked to do, as students needed to reflect on concepts and then find a way to represent them in a drawing (Smith et al., 1987). As most students were able to represent the size dimension easily on the pre-assessment, this was not under consideration in the analysis. Student models were scored for whether they: (a) represented only weight or only density in their model (these students were scored for making no clear distinction between weight and density); (b) represented two distinct dimensions, but when the students represented the density of the objects, they in fact represented a mixture of density and weight; (these students were scored as beginning to distinguish the two dimensions in their model); or (c) accurately represented both dimensions of weight and density in their models.

The way that students depicted weight and density in their models was analyzed. Did they use “extensive codes for extensive dimensions like weight (e.g., number of dots), intensive codes for intensive dimensions like density (e.g., shading or color intensity, or number of dots/box) or neutral codes for these dimensions (e.g., ordering, a summary number)?” (Smith et al., 1987, p. 17). Models showed if the student concept of an object showed weight and density as a distinct physical characteristic of matter or if they believed that the two are interrelated.

Adding material task. Students were asked to determine if adding a small amount of clay to an object changed its weight and/or its density. Students were scored in the following ways: (a) made no distinction, both mass and density increased because more clay was added; (b) weight increased because more clay was added, but unsure if density increased; (c) made a clear distinction between weight and density, students understood that weight increases because they added more clay, but density did not increase because the same material was added.

Sinking/floating tasks. The sinking and floating tasks looked at student ability to use the concept of density in understanding sinking and floating. To begin, students conducted a mini sinking/floating experiment with a small set of objects that were different sizes and materials: two sizes of wood (float), gold ball (sink), ping pong ball (float), large and small pieces of clay (sink), large and small marbles (sink), and aluminum cylinder (sink). Students were asked, "What types of things sink and what types of things float? Can you make up a general rule which allows us to predict what will sink and what will float?" Once students made their prediction, they tested it by putting the objects in the water. This initial activity helped to establish the concept of density in relationship to sinking and floating. Students then had the density concept available to them to help explain their predictions and inferences about sinking and floating with a new set of novel objects.

Next students were given a prediction problem. They were shown four objects, a large and a small piece of wax and large and small aluminum cylinder (from paired comparison tasks). They were asked to order the objects by weight using a digital scale. Then they were shown a small piece of wax (which floats) and a large cylinder of aluminum (which sinks) and asked to predict if these objects would sink or float and then this prediction was tested. Finally, they were asked if a large piece of wax (heavier and bigger than the aluminum) would sink or float and if a small piece of aluminum (lighter and smaller than the wax) would sink or float. Students were asked to explain their predictions and then to test them. In order to complete this task correctly, students needed to determine if it is the relative density of the material that allowed an object to sink or float or if it was the weight that was important.

The next two sinking and floating tasks looked at the effect of changing the liquid on sinking and floating. The materials for the first task were a piece of acrylic plastic and a jar of fresh and salt water. Students were told, "Here is a piece of plastic. If I put it in here (fresh water), it floats. But if I put it in here (salt water), it sinks. How can that be?" Student responses were recorded. For the next task a jar of oil is brought out. The interviewer said, “This glass has oil in it. If I put the plastic in the oil, do you think that it will sink or float?” The student then made a prediction and tested it.

For the next sinking and floating task, students were given two same-sized pieces of clay that weighed the same (students could use the scale to weigh them). They were told, “Now I’ll put one of these pieces of clay in-between these two pieces of wax,” and then they were shown that the clay/wax piece clearly weighed more than the small clay piece alone. Next, the small clay piece was put into water where it sank. Students were then asked, “If we put this heavier object in water (Clay stuck between wax pieces), do you think that it will sink or float?” Once they made their prediction, the object was tested, and it floated. If they predicted that it would sink, they were asked for an explanation, “The clay ball sinks, but the heavier object made of clay and wax floats. How can that be?”

Students were then shown three objects: (a) a small piece of clay (lightest object), (b) a medium-sized object made of a mixture of wax and clay, (c) and a larger piece of wax (heaviest object). Students weighed the three objects, then they were asked to order the objects by weight and then by density. This exercise tested whether students would use information about sinking or floating behavior (rather than weight) to make inferences about density.

There were three possible patterns for the sinking and floating tasks: (a) weight patterns (all predictions and inferences were based solely on weight), (b) weight/density patterns (both density and weight patterns were used to make predictions and inferences), and (c) density patterns (all sinking and floating predictions and inferences were correctly based on the density of the object).

Scoring and interpreting results for all four tasks. Smith et al. (1987) found that there were four levels of understanding for these tasks. She described these as the student: (1) makes no distinction between weight and density, (2a) is beginning to make an uncertain distinction between weight and density, but the lack of differentiation is still strong, (2b) has some understanding of the difference between weight and density and is transitioning to full understanding, or (3) makes a clear distinction between weight and density. These levels are further described in Table 18. The pathways that Smith et al. (1987) used to help determine these levels can be seen in Figure 2.

Table 18

Description of Four Levels of Understanding of the Distinction Between Density and Weight (Smith et al., 1987)

Level	Description
1	The concept of density is absent (students only think in terms of weight). Students make no distinction among weight and density questions on all tasks. Very few students would be expected to be in this category.
2a	Students are beginning to differentiate between weight and density on the ordering task, but they do not do so consistently, especially on the modeling, adding, and sinking and floating tasks.
2b	Students are transitioning to a full understanding of the differentiation of weight and density, but are not quite there yet. They are able to mostly distinguish weight and density in the ordering task, show some awareness of the distinctness of weight and density in the modeling task, can mostly distinguish between weight and density in the adding task, and make some distinction between weight and density in the sinking/floating task.
3	These students can clearly distinguish between weight and density on all four types of tasks.

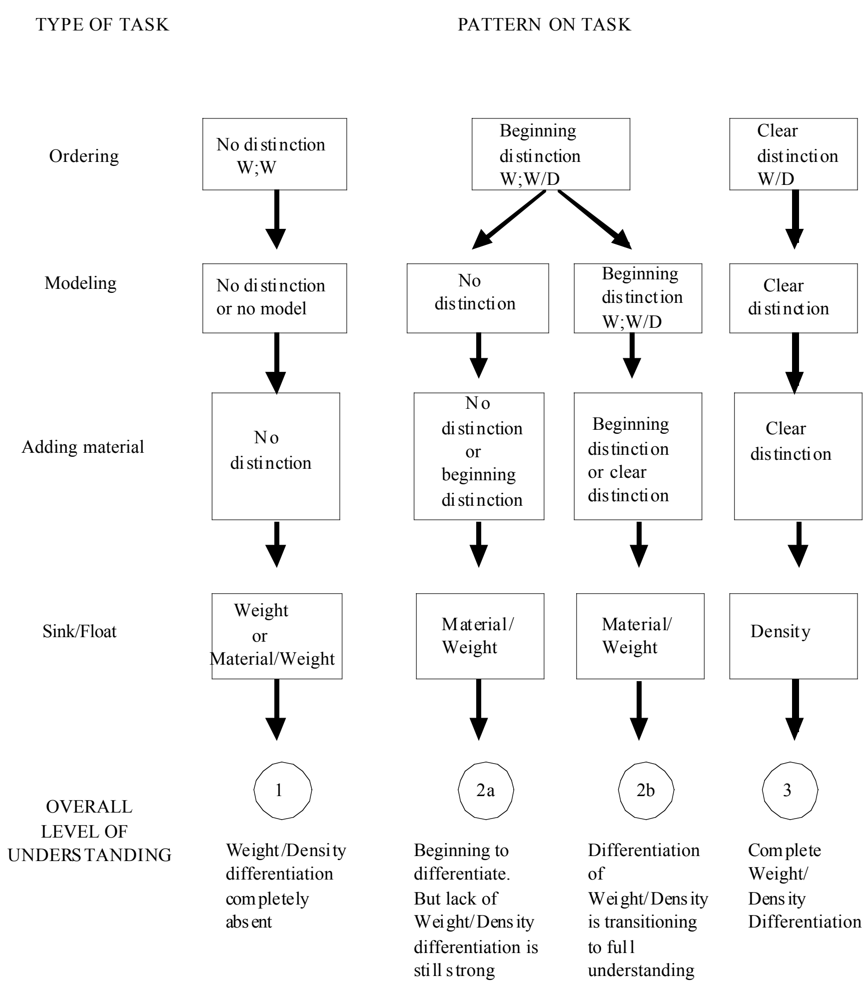


Figure 2. Four Levels of Understanding Density on the *Weight/Density Differentiation Task Assessment* (Smith et al., 1987)

I found that when I tried to place students in the four pathways in order to determine the overall level of understanding for density, the Smith et al. (1987) pathways did not work for the patterns that I was seeing in the students completing this assessment. I therefore had to modify the pathways to accommodate for these differences. Six levels of understanding resulted from these pathway revisions. The revised pathway can be seen in Figure 3. The six levels of understanding are described in Table 19.

Table 19

Description of Six Levels of Understanding of the Distinction Between Density and Weight

Level	Description
1	Weight/Density differentiation completely absent
2	Beginning to differentiation in some tasks but lack of weight/density differentiation is still strong. Still uses weight to explain most tasks. Has novel theories on why things float or sink
3	Beginning to differentiation in some tasks but lack of weight/density differentiation is still strong. Still uses weight to explain most tasks except sinking and floating. Knows the word "*density*" but not the concept.
4	Differentiation of weight/density is transitioning to full understanding, but still has novel theories on why things float or sink
5	Differentiation of weight/density is transitioning to full understanding, can explain why things sink or float in terms of density.
6	Complete weight/density differentiation.

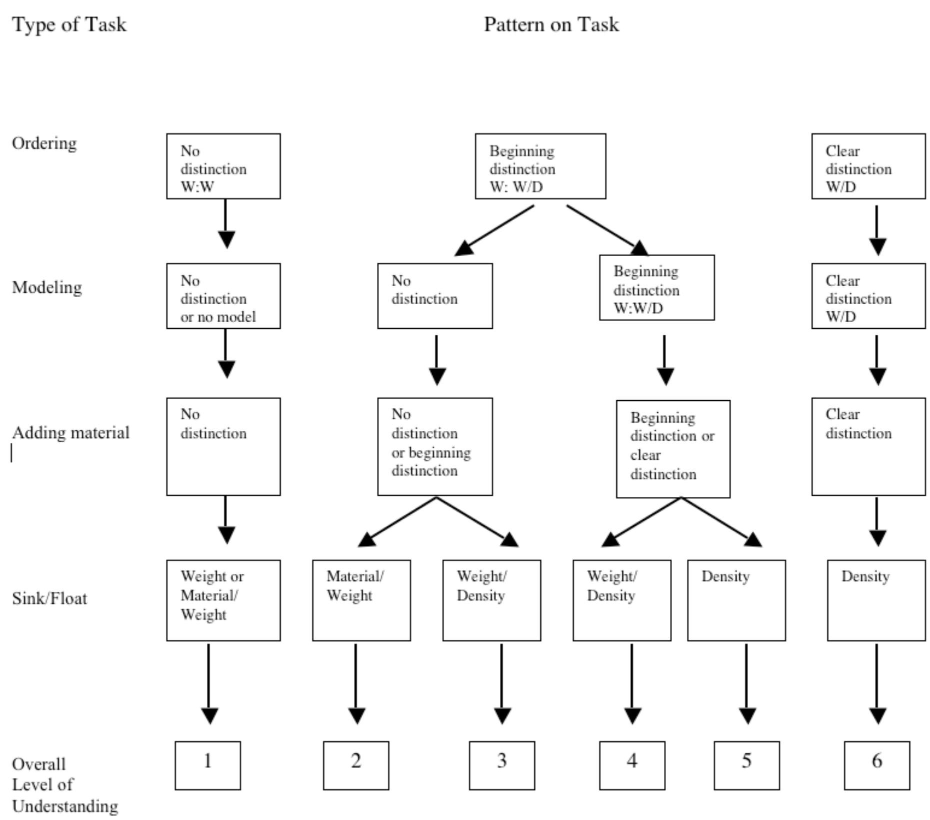


Figure 3. Six Levels of Understanding Density on the *Weight/Density Differentiation Task Assessment*

Density Task Assessment

To further understand the range of student understanding of density, an authentic task was given to all student participants on the same day that they were given the multiple choice Density Assessment. As most classrooms had both desks for students and lab benches for experimentation, students took the Density Assessment at their desks and completed the Density Task Assessment at one of 8 to 10 lab stations that had been set up by the teacher prior to class. Students were released by the teacher so they could go to the lab area to complete this task. When they were done, they returned to their desks to work on the multiple choice density test. Written instructions for the task assessment were at the lab station. Students were asked to determine if any of the three objects were made from the same material and were asked to communicate the process of how they arrived at their answers.

The scoring rubric for data collection was given to the students. This is the Oregon Department of Education Rubric for the Scientific Inquiry Data Collection Standard 7.3S.1. The rubric that was used to determine a student's ability to differentiate between weight and density was not given to the student. This rubric was created by the researcher and was used to evaluate if their understanding of density was qualitative or quantitative. Both rubrics are shown in Table 20. During this task, students were not allowed to confer with each other or with the teacher. At each station there was a digital scale, a ruler, and the three objects. The objects were especially chosen to challenge the students. There were 2 cubes of equal size but varying density and a rectangle that was the same density as one of the cubes. All cubes were painted green so that no clues about the nature of the material could be gleaned via visual inspection.

Table 20

Rubrics for Evaluating Student Performance on Density Task Assessment

Learning Target	Novice (1)	Working Toward (2)	Nearly Proficient (3)	Proficient (4)	Highly Proficient (5)
7.3S.1 Scientific Inquiry-Data Collection	Student collects data that is inconsistent with procedures. Student attempts to display data, but displays are significantly incorrect. Data tables lack titles.	Student collects relevant and reasonable data consistent with procedures, with inaccuracies. Student displays data in an unorganized char/table. Units are incomplete or incorrect. Data tables include irrelevant titles.	Student collects relevant, accurate and nearly sufficient data consistent with procedures. Student displays data in an organized chart/table, but units may be incomplete or incorrect. Data tables include incomplete titles.	Student collects relevant, accurate and sufficient data consistent with procedures. Student correctly and accurately displays data labeled with appropriate units in an organized chart/table. Data tables include relevant titles.	Student collects relevant accurate and clearly sufficient data consistent with procedures. Student correctly/ accurately displays data labeled with appropriate units in an organized chart/table that facilitates analysis. Data tables include titles addressing the variables.
Density	Student only provides weight of objects or does not attempt task.	Student shows the beginnings of understanding of the relationship between mass, volume, and density. Provides weight of objects and part of a volume measurement. All 3 aspects (L, H, W) of objects are not measured. Density may be calculated as D = M*V. Measure in inches.	Student shows understanding of the relationship between mass, volume, and density. However, they do not show how this physical characteristic can be used to determine whether one material is the same as another.	Student shows understanding of the relationship between mass, volume, and density, and how this physical characteristic can be used to determine whether one material is the same as another. States that cube and rectangle are same density	Student shows in-depth understanding of the relationship between mass, volume, and density, and how this physical characteristic can be used to determine whether one material is the same as another. Explicitly states that cube and rectangle are same density. Calculations/ measurements are exactly correct.
			Qualitative →		Quantitative
	Weight only →				Full Weight/ Density Differentiation

Qualitative Density Assessment

This assessment was developed to measure students' understanding of density in a qualitative way. The intent was to give this assessment at the end of the eight intervention lessons to probe student thinking about density and to capture if there were any differences between the two groups prior to the final crime solving labs. However, despite the assessment being embedded in the notebooks that teachers were given at this instructional point, there was variability in when this assessment was given by the teachers. Teacher 1 and Teacher 4 gave the Qualitative Density Assessment as a pretest and posttest to all of their students, Teacher 2 did not give it to any students, Teacher 3 and Teacher 5 gave it only as a pre-assessment. This variance can only be attributed to a miscommunication from the researcher, as no teacher gave it as an interim assessment and all other expectations for the timing of assessments within the study were met. In some respects it turned out to be beneficial to have two of the teachers give the assessment as a pre-post because it allowed the measurement of student growth for those classes. Because of the qualitative nature of the assessment, it was useful to the researcher in building a continuum of student conceptions of density.

The Qualitative Density Assessment consisted of seven questions presented in a flow chart format. Questions centered around a central theme of "*Why do objects float or sink?*" Students were asked to use words and pictures to explain their thinking. Six of the seven questions had an (a) or (b) response that students could chose as an answer. Then students were asked to explain their thinking. For example, the first question was: "*Does mass alone explain why objects float or sink when placed in water?*" Students could circle, "(a) *Mass alone explains floating and sinking*" or "(b) *Mass alone does not* *explain floating and sinking."* They were then asked to "*Explain your thinking*." Other questions included: (a) Does volume (or size) explain why objects float or sink when placed in water? (b) Does density explain why objects float or sink when placed in water? (c) What is density? (d) Is it possible to combine two materials that have different densities (one sinks and one floats in water) into a new object that has a density that is different from the original materials? (e) Can objects that float in water, sink in another type of liquid? (f) True or False. When an object sinks or floats it is dependent on the relationship between the density of the object and the density of the liquid. The only question that was not given the *a* or *b* choice was, "*What is density?"* as the researcher wanted to see how students would define this without any prompting. The series of seven questions in this assessment mimicked the order in which the lessons for the intervention were taught.

A scoring rubric called Scoring Rubric for Qualitative Density Assessment was developed to evaluate student responses for this assessment, and it can be found in the appendix. One point was given for each correct (a) or (b) answer for six of the questions. Student answers were also scored from 0-2 on the quality of their explanation: 2 = Explanation is accurate with supporting details and examples; 1 = Explanation is partially accurate. Supporting details and examples may be lacking. Some gaps in understanding may be evident, and 0 = Explanation is inaccurate or too brief to demonstrate understanding, for a total of 14 possible points for the seven questions. Student proficiency was determined by using a combined score of 20 possible points, where 19 to 20 points = highly proficient, 16 to 18 points = proficient, 12 to15 points = nearly proficient, 8 to 11 points = working towards proficiency, and 7 or fewer points = novice.

In addition, the answer type was noted. It was recorded if students answered in: (a) words and drawings, (b) words only, or (c) drawings only. The reason for this was that students were being exposed to modeling during the intervention lessons, and the researcher wanted to determine if students were using drawings as a way to communicate the complex notions of density through the sinking and floating of objects. Because students were asked to explain their thinking, students' theories about density were coded. Qualitative data were taken on this range and the movement of students from naïve theories about why objects sink or float to theories informed by the relationship between the density of the objects versus the density of the liquid into which the object is placed.

Data Collection

Procedure

A flow chart for the study is provided in Figure 3. All materials, lesson information, and keys for lessons were given to the teachers in February 2011. The intervention was taught to students between the end of February and the beginning of April. A University of Oregon Ken A. Erickson Memorial Award and a UO Graduate School Award provided money that paid for the purchase of the density materials for teachers. The materials were primarily durable supplies that teachers would continue to be able to use after the investigation was completed. All materials needed for each lesson were supplied. They were organized into tubs by lesson. Within each lesson tub there were 9 bags of materials, one for each lab station of 3-4 students. In this way, teachers did not have to provide or assemble any density materials for any of the lessons. This helped ensure the fidelity of implementation, as the researcher could be guaranteed that the variability of materials between teachers would be minimal. Teachers were trained how to use the instructional materials when they were delivered.

Two weeks before the unit on density began, the participating teachers sent home an informational letter to the parents of the participating students. The letter was translated into Spanish for students whose parents spoke this language at home (see appendix for both letters). Implied consent was used. If a student was withdrawn from the study by a parent, they still participated in the activities of the classroom and the study; however, their data were not collected and analyzed for the purpose of the investigation. Student ID numbers were used to maintain confidentiality and so that information could be compiled and compared for individual students. Students completed the *Student Assent Form* (found in appendix). On it there was a box that students could check giving permission to be recorded if they were chosen for the Weight/Density Task Assessment and Interview.

Teachers were assigned to either the treatment or the comparison condition based on their responses on the Teaching Methodology Preference Survey (found in appendix). All the students in all of the science classes that they taught had either the treatment or the comparison lessons based on teacher assignment. All student participants took the Density Task Assessment prior to the intervention. This was used to determine the prior experience students had in the skill of determining the density of actual objects. Students also took a multiple choice Density Assessment to determine what they already knew about density conceptually and content-wise before the study began. These pretests were scored quickly. From those scores, three groups were formed for each teacher: (a) a low group (LG) that contained the students with the seven lowest pretest scores in the class,

(b) a high group (HG) which contained the students who had the seven highest pretest scores in the class, and (c) a mid group (MG) with students whose scores fell into the middle range. Once these pools of students had been created, students were randomly selected from each group to participate in the Weight/Density Differentiation Task Assessment and Interview that was conducted by the researcher. Each student interview was recorded.

All students for a given teacher were taught either the traditional density lessons or the inquiry density lessons. These lessons were taught over the course of 15-16 days plus 3-4 days for the pre and post assessments. For each lesson, teachers used the Teacher Self-Reflection Rubric (found in appendix) to record if they: (a) were able to follow the lesson plan, (b) used the materials that were provided, (c) had to lengthen or shorten the time-frame, and to record (d) how difficult the lesson was for their students. This rubric is found in the appendix.

Once the eight lessons were taught and before the final three crime-solving labs were given, teachers were asked to give students the Qualitative Density Assessment. When students completed the three crime-solving labs, all students were given the Density Post-Assessment, and their tests were scored. The students who had the Weight/Density Differentiation Task Pre-Assessment and Interview before the intervention got an identical post-task assessment. The interviews were audio-recorded.

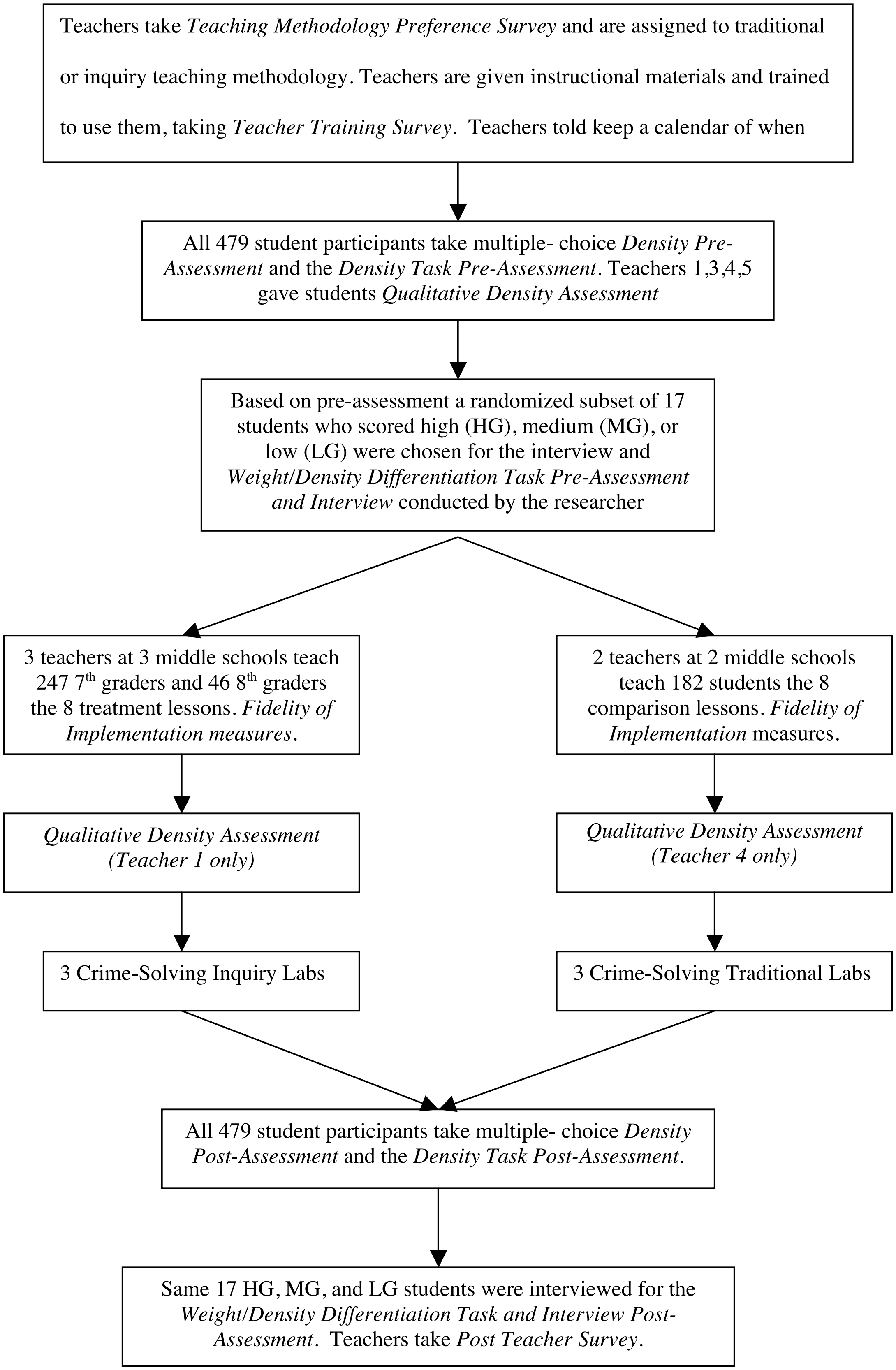


Figure 4. A flow chart of the major components of the procedure

Fidelity of Implementation

Treatment fidelity is very important in educational research. It enhances the accuracy of the study and ensures that each component is delivered as the researcher intended it to be given (Smith, Duanic, & Taylor, 2007). Assurances need to be made that all student participants received the same treatment and comparison lessons, by ensuring that all teachers deliver the lessons with accuracy and conformity. If treatment fidelity is not measured, it will not be clear whether differences between groups are due to the treatment or to other unmeasured factors. Treatment fidelity is needed in four key areas: (a) study design, (b) training, (c) treatment delivery, and (d) treatment receipt (Smith, Duanic, & Taylor, 2007). Following are descriptions of the actions taken in this study to ensure fidelity in each of these four areas.

Study Design

"Study design refers to the establishment of procedures that are consistent with relevant theory and practice and strategies that address and anticipate potential implementation setbacks" (Smith, Duanic, & Taylor, 2007, p. 125). This investigation is based on components that are found in a study by Smith et al. (1987) where they successfully measured middle school students' understanding of density. As my assessments and study design have similar components, it was anticipated that I would be able to measure student conception of density as well. My own practical experience of teaching density to middle school students for ten years helped me understand what effective teaching practices are on this topic and to anticipate problems and issues that would arise in teaching a unit on density in a middle school classroom.

In 2008, I conducted my first pilot study with three teacher participants and 390

7th grade student participants. It was similar in several aspects to this investigation. The order of the eight lesson topics was mostly similar, although most lessons were revised for the current investigation. The last three crime-solving labs were the same and much of the Density Assessment was similar. The major difference was that teacher participants taught both the treatment and the comparison groups. In order to reduce the potential for treatment diffusion, this current investigation had each teacher using only one set of lessons that used the teaching methodology with which they were most comfortable. From the pilot experience, I learned that the overall design for the study was reasonable and could be completed within a timeframe that was acceptable to teachers. I also learned that while all students made significant gains in their understanding of density that no significant difference was found between the inquiry and the traditional group. This led to a major revision of the inquiry lessons, as it was hypothesized that in the first pilot the two types of lessons were too similar for differences to occur or that the assessments were not sensitive enough to measure the difference.

I conducted a second pilot in 2009 with one teacher and 102 students to test the new set of inquiry lessons that were written for the dissertation study as well as the Qualitative Density Assessment and the Density Task Assessment. Some of the materials sets used for the forced density comparisons were also tried out. Under examination was student performance on the pre-post assessments, the length of time that the new lessons on inquiry took, and if the level of difficulty of the inquiry lessons was appropriate for 7th grade students. It was found that students made significant learning gains on density during this study, that the new assessments gave information that allowed the researcher to understand student misconceptions and conceptions of density in a variety of ways that were both quantitative and qualitative, and the pace of the lessons was reasonable. It was determined that providing teachers with materials helped their buy-in to the study. The teacher who participated in this 2009 pilot still uses these lessons and the materials to teach density.

As many teachers develop preferences for teaching methodologies, it was important to ensure that teachers would be comfortable teaching the methodology they were assigned so that the fidelity of implementation would be greater. The Survey to Determine Teacher Methodology Preferences (found in the appendix) was given to teachers to help with the assignment to the treatment or the comparison group. A 4-point Likert scale was used with 1 = *strongly agree* and 4 = *strongly disagree* for questions such as: (a) I am most comfortable in a student-centered classroom, (b) I use scientific inquiry frequently in my classroom (at least one time per unit), and (c) I would say that I primarily teach through traditional methods.

For the current dissertation study, the pace of the lessons was measured by asking teachers to calendar when they taught each lesson. When the calendars were compared, it was found that while there was some variability in how many days a teacher took on an individual lesson, each teacher took exactly 19 school days to teach the entire intervention and to give all the assessments to students (See Table 21). I believe that the implementation of the interventions occurred close enough together in the school year between the various teachers that the effect of the increasing maturity of the student population was reduced.

Table 21
Dates Intervention Taught

Teacher	Date Begun	Date Ended	Total Days Taught
1	2-28-11	4-7-11	19
2	1-31-11	2-24-11	19
3	2-18-11	3-30-11	19
4	3-18-11	4-23-11	19
5	3-14-11	4-19-11	19

Training

Prior to the training, all teachers completed a survey on teaching preferences in order to determine if they would be teaching using the inquiry teaching methodology or the traditional teaching methodology. Teachers were then assigned to one of these groups based on their responses. Once group assignment was determined, teachers were given a full notebook that contained lessons, detailed teacher notes, keys, and student worksheets for the methodology to which they were assigned. They were also given full material kits for those lessons. When these items were delivered to teachers, they were reviewed by the teacher and the researcher in an individualized training. For each teacher, this training occurred two to four weeks prior to his/her implementation of the study. Teachers had an opportunity to check out and use the materials that the students would use during the study. The various comparison groups of density objects were explained to the teachers so that they would understand the importance of promoting student exploration of these specific groups of objects. All teachers were familiar with the density content of the study, as they had all taught density before and were experienced teachers.

When the training was completed, teachers completed a 4-point Likert scale survey called the Teacher Training Survey (found in appendix*)*. Examples of questions include: (a) I understand what is expected of me as a teacher participant in this study, (b) I think that I will be able to teach most of the lessons as they are written, (c) The amount of work that is involved in teaching this unit looks reasonable, (d) If the lesson is not working and students are not engaged or there are behavior issues, I will modify the lesson to suit my classroom needs, (e) I am familiar with and can use the materials that were given to me for the labs. The information in the survey was gathered in hope it would be useful if student outcomes from a given teacher were poor or did not follow expected trends.

Treatment Delivery

To determine if there was fidelity of implementation or decay in the delivery of the density unit, teachers were asked to reflect on their own delivery of the lessons by completing a Teacher Self-Reflection Rubric for each lesson. The teacher reflection sheet was very simple and covered four areas: the lesson plan, materials, timing, and difficulty of the lesson. It was set up so that teachers could just check a box rating their fidelity to the lesson as it was written. If teachers had time, they were asked to comment on their answers. All teachers completed these rubrics for all lessons. An example of what teachers were asked to respond to is: ☐ I followed the lesson plan as it was written; ☐ I modified the lesson plan to meet the needs of my students, ☐ I added the following (please give the reason if you have time), ☐ I did not use the following (please give the reason if you have time). The complete Teacher Self-Reflection Rubric is found in the appendix.

Due to my own time constraints of working full-time during the implementation of this investigation, I was only able to observe teachers for two lessons, one at the beginning of the density unit and one near the end. I developed a Teacher Observation for Fidelity of Implementation Form to record those observations. There were three levels of fidelity that I scored for: *1 = with Fidelity*. The teacher evidenced careful implementation of the lesson, eliciting many appropriate student responses. The teacher was clear, and kept a sustained focus on the purposes of the lesson; *2 = Mostly with fidelity, minor changes to lesson.* The teacher evidenced some deviation in the implementation of the lesson, eliciting some appropriate student responses. The teacher was sometimes clear and focused on the purposes of lesson; *3 = Little to no fidelity, major changes to lesson.* The teacher evidenced little or no understanding of the implementation of the lesson, major changes were made that elicited minimal appropriate student responses. The teacher was unclear and unfocused regarding the purpose of lesson. I evaluated fidelity of implementation and teacher and student behaviors. Observed actions rated for fidelity included: (a) The lesson was implemented as written, (b) The materials that were designed to be used with the lesson were used, (c) The materials were used appropriately as written in the lesson. Observed teacher and student behaviors included: (a) The students were engaged in the lesson, (b) The teacher noticed if students were not engaged in the lesson and took action, (c) The teacher spoke clearly and could be understood. Information given to students was coherent. Instruction made logical sense, (d) Teacher seemed confident as he/she taught the lesson. Most teachers during my observations scored 1 for all the actions and behaviors for which I was observing, some scored 2's on some actions or behaviors, but no teacher scored a 3 for any actions or behaviors that I was evaluating.

Treatment Receipt

This aspect of fidelity ensures that student participants understand the information that is being provided to them during the treatment. The results that I obtained from the 2008 and 2009 pilot studies assured me that 7th grade students could understand the concepts that were being taught to them. Students in both the treatment and the comparison group made significant learning gains on their content knowledge of density. The number of items on the pre- and post assessment was reduced from the number in the Smith et al. (1987) study so that it would be more accessible to ELL and SPED students. The assessment also included many visuals that helped with student understanding of the questions. The Weight/Density Differentiation Task Assessment and Interview is not a written exam. Students were asked to do a series of tasks. Students who were classified as ELL or who had difficulty in reading and writing in English should not have experienced language barriers in this assessment, if they were chosen to be a part of this task assessment. I collected student samples of work on several written products that were produced from this study (Density of Mixed Materials lab and the final three crime-solving labs), and all their assessments. These were evaluated for conceptual and content understanding of density.

Data Analysis

Random assignment of teachers and students to the treatment and comparison groups was not feasible for this study. As a result, prior to the analysis of the effect of the treatment on student understanding of density, an independent samples *t*-test was performed using SPSS to see if there were significant differences between the treatment and the comparison teachers and classes prior to the start of the study. Scores for7th grade OAKS tests for math and reading, ELL, and SPED status were used for the *t*-test analysis. Teachers and classes that were statistically equivalent prior to the investigation were matched for the analysis of treatment effectiveness.

To ensure that the study population met the criteria for the independent samples *t*-test, I determined if data were being drawn from a normally distributed population by drawing a histogram of the population and by using simple descriptive statistics (mean, mode, and standard deviation). The sizes of the groups being compared were similar and were also independent of one another.

A one-tailed Pearson product-moment correlation coefficient was computed to show if there was a relationship between the two independent variables: Density Task Pre- Assessment score and Density Pre-Assessment score. This analysis allowed me to examine if students who had higher scores for the Density Pre-Assessment also did better on the Density Task Pre-Assessment. A scatter plot for the two independent variables was produced to illustrate variance in the data. A best-fit line was drawn to show the relationship between these two independent variables

Three different types of analysis were run for this investigation: (a) comparison between teachers teaching 7th grade in the same school, (b) comparison between teachers teaching 7th grade at different schools, and (c) comparison for the same teacher, teaching both 7th and 8th grade students. Data from the four pre- and post-assessments were analyzed using an independent samples *t*-test and SPSS: (a) Density Assessment, (b) Weight/Density Differentiation Task Assessment and Interview, (c) Density Task Assessment, and (d) Qualitative Density Assessment. For three of these assessments, sub-sections of the assessments were analyzed for treatment effect. See Table 22 for more detailed information of the assessment type, the variable being analyzed for the assessment as a whole and the subsections, the type of assessment, and the scoring type.

Table 22

Outcomes Being Analyzed in Full Assessment and Assessment Sub-Sections

Name of Assessment	Section of Assessment	Variable Being Analyzed	Type of Assessment	Type of Score
Density Assessment	Q 1 - 32	Overall gain in density knowledge – qualitative and quantitative; conceptual and content	Multiple choice	1 question = 1 point Score range 0 - 32
	Q 1-10; 17-19; 21-25	Conceptual understanding/ qualitative understanding of density	Multiple choice	1 question = 1 point Score range 0 - 18
	Q 11-16, 20; 26-29	Content knowledge/ quantitative understanding of density	Multiple choice	1 question = 1 point Score range 0 - 11
	Q 30 - 32	Content knowledge taught only to traditional group	Multiple choice	1 question = 1 point Score range 0 – 3
Density Task Assessment	Entire assessment	Qualitative/ quantitative understanding of density; weight/density differentiation	Open-ended	5-level rubric (Highly proficient to novice)

Table 22 (Continued)

Outcomes Being Analyzed in Full Assessment and Assessment Sub-Sections

Name of Assessment	Section of Assessment	Variable Being Analyzed	Type of Assessment	Type of Score
Weight/ Density Differentiation Task and Assessment Interview	Entire assessment	Conceptual understanding Weight/Density Differentiation	Open-ended/ structured response	6 levels of understanding (full weight/density differentiation to no weight density differentiation)
	Ordering Tasks	Conceptual understanding Weight/Density Differentiation	Structured response	Correct answer = 1 point); 3 levels of distinction (full to weight only)
	Modeling Tasks	Conceptual understanding Weight/Density Differentiation	Open-ended	3 levels of distinction (full to weight only)
	Adding Material Tasks	Conceptual understanding Weight/Density Differentiation	Structured response	3 levels of distinction (full to weight only)
	Sinking and Floating Tasks	Conceptual understanding Weight/Density Differentiation	Open-ended/ structured response	3 levels of distinction (Density patterns to weight patterns)
Qualitative Density Assessment	Entire assessment	Overall gain in density knowledge – qualitative and quantitative; conceptual and content	Multiple choice/ True-False/ Open-ended	5-level rubric (Highly proficient to novice); score range 0 - 20
	Questions	Content knowledge	Multiple choice/ True-False	1 question = 1 point; range 1-6
	Explanations	Conceptual knowledge, move from qualitative to quantitative explanation of density	Open-ended	Qualitative coding of answers

CHAPTER III

RESULTS

The data for this mixed methods investigation were obtained from: (a) three quantitative pre- post-assessments that were administered to 479 students, (b) a qualitative pre- post-assessment that was administered to 160 students, and (c) a pre-post-interview and task analysis that was administered to 17 students. The results are organized into quantitative and qualitative sections.

The quantitative analysis occurred at four levels: (a) overall student learning gains on density, (b) comparing the performance of students receiving the traditional versus the inquiry methodology across all students, (c) comparing the performance of students receiving the traditional versus the inquiry methodology between matched teachers, and (d) comparing the performance of students receiving the traditional versus the inquiry methodology between matched classes. Matching was based on the student scores on the OAKS Math Performance Assessment administered at the end of the year the study was implemented in. An independent samples *t*-test was used for these comparison analyses. A composite multilevel analysis was also used to examine relationships between student outcomes on a pre-post density assessment, teaching methodology and student scores on the OAKS Math Performance Assessment, taking into account the nested data structure.

In the qualitative results section, student conceptions about density were analyzed, by first categorizing the conceptions and then by examining changes in frequency of conceptions after the intervention. Results from an inquiry class were compared to results from a traditional class to investigate whether teaching methodology was related to student retention of misconceptions and student acquisition of accurate conceptions of density. Examples of student responses are given.

Quantitative Data

Student Learning Gains on Density

Three assessments were administered prior to and directly after the intervention was concluded: (a) the Density Assessment, which was a 32-question multiple choice test; (b) the Density Qualitative Assessment, which had 7 questions, each with both a multiple choice response and an open-ended explanation section, scored using a rubric; and (c) the Density Task Assessment. The Density Task Assessment was scored on a five-point proficiency scale for two components: (a) The Density Task which measured students' ability to determine the density of three objects and to analyze whether they were made of the same or different materials and (b) the Scientific Inquiry Task which measured students' ability to communicate the steps of their investigative process. The five-point rubric for this task, published by the Oregon Department of Education, was the same one that teachers use to score scientific inquiry work samples in the state where the study took place. The descriptive statistics for student performance on these assessments can be found in Table 23.

Density Assessment

Students made gains in their understanding of density regardless of teaching methodology. The mean learning gain for students on the Density Assessment was 10.87 points. A *t*-test comparing student pre-test scores ($M = 15.38$, $SD = 5.94$) and student post-test scores ($M = 26.25$, $SD = 5.55$); $t(479) = 42.83$, $p < .05$ shows a statistically significant increase in density scores. The Hedges' g effect size for the Density Unit as measured by the Density Assessment was very large, $g = +1.89$.

Table 23

Descriptive Statistics and Effect Sizes for Pre-test Post-test Measures

Instrument	*n*	Range	Median	*M*	Mode	*SD*	*g*
Density Assessment pre-test	479	3-32	15	15.38	15	5.94	+1.89
Density Assessment post-test	479	8-32	28	26.25	32	5.56	
Density Qualitative Assessment pre-test	362	0-18	6	6.36	6	4.15	+2.10
Density Qualitative Assessment post-test	171	4-20	16	15.12	20	4.07	
Density Task Assessment pre-test	449	1-4	1	1.49	1	.09	+1.47
Density Task Assessment post-test	438	1-5	4	3.20	4	1.36	
Scientific Inquiry Assessment pre-test	449	1-4	1	1.59	1	.82	+1.66
Scientific Inquiry Assessment post-test	438	1-4	3	3.31	4	1.21	

Figure 5 displays a histogram of the pre-test distribution, showing skewness of .56 (SE = .11) and a mode of 15. Figure 6 shows the post-test distribution, with a skewness of -1.03 (SE = .11) and mode of 32, which is the maximum score possible for this assessment.

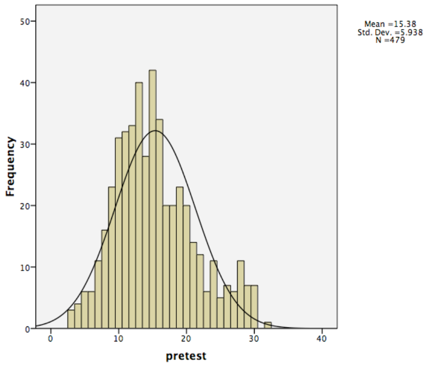


Figure 5. Histogram of *Density Assessment* Pre-test

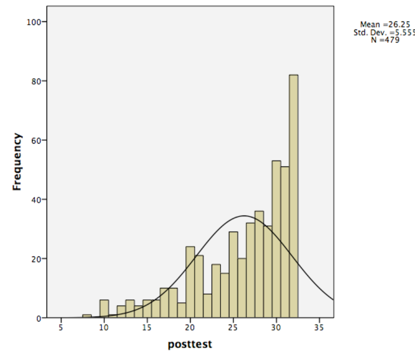
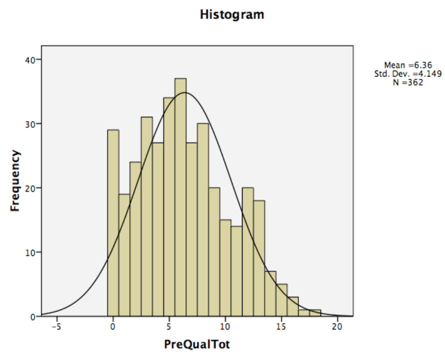


Figure 6. Histogram of *Density Assessment* Post-test

Density Qualitative Assessment

The results for the quantitative Density Assessment were mirrored in the Density Qualitative Assessment. The mean learning gain between the pre-post-assessment was 8.76 points. A *t*-test showed that students scored significantly lower on the pre-test (M = 6.36, SD = 4.15) than the post-test (M = 15.12, SD = 4.07); $t(171) = 28.15$, $p < .05$. The Hedges' g effect size on the Density Unit intervention as measured by the Density Qualitative Assessment is very large, $g = +2.10$.

For the pre-assessment, the distribution of scores was approximately normally distributed. On the post-assessment, the distribution of scores was somewhat negatively skewed. Figure 7 shows the pre-test distribution with a skewness of .36 (SE .13) and a mode of 6. Figure 8 shows the post-test distribution with a skewness of -.77 (SE .18) and a mode of 20. In addition, it should be noted that only four out of five teachers gave the qualitative density assessment as a pre-test (n=362) and only two out of five teachers gave it as a post-test (n = 171).



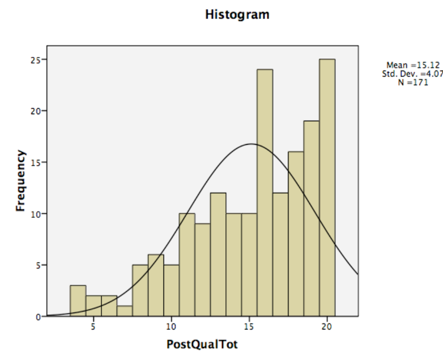


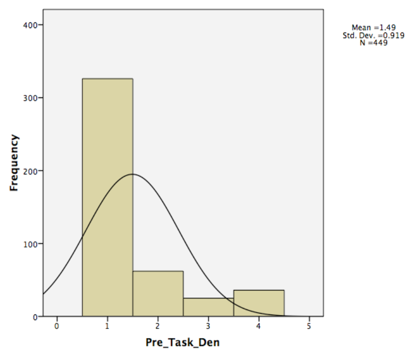
Figure 7. Histogram of *Density Qualitative Assessment* Pre-test

Figure 8. Histogram of *Density Qualitative Assessment* Post-test

Density Task

Students showed a mean learning gain of 1.71 points. A *t*-test comparing the pre-test scores (M = 1.49, SD = .92) and post-test (M = 3.20, SD = 1.36); $t(438) = 26.24$, p <.05 showed a statistically significant increase in density scores. The Hedges' *g* effect size for the Density Unit as measured by the Density Task is very large, $g = 1.47$.

For both the pre-test and the post-test, the score distribution was non-normal. Figure 9 shows the pre-test distribution with a skewness of 1.81 (SE .11) and a mode of 1. Figure 10 shows the normally distributed scores for the post-test showing a skewness of -.33 (SE .12) and a mode of 4.



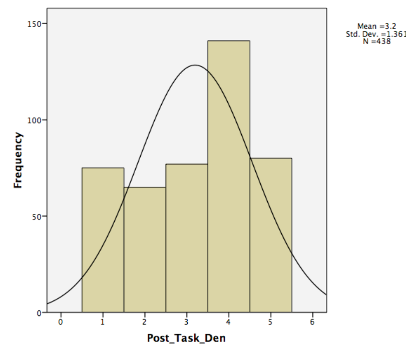


Figure 9. Histogram of *Density Task Assessment* Pre-test

Figure 10. Histogram of *Density Task Assessment* Post-test

Scientific Inquiry Task

On the Scientific Inquiry Task, students showed a mean learning gain of 1.72 points, comparable to the gains seen in the Density Task. A *t*-test showed that the pre-test scores (M = 1.59, SD = .819) and the post-test scores (M = 3.31, SD = 1.21); $t(438)$ = 29.79, $p < .05$ were statistically significantly different. The Hedges' *g* effect size for the Density Unit as measured by the Scientific Inquiry Task is very large, $g = +1.66$.

The pre-test scores were non-normally distributed. Figure 11 shows the pre-test distribution with skewness of 1.39 (SE .11) and a mode of 1. Figure 12 shows the post-test distribution with a skewness of -.29 (SE .12) and a mode of 4.

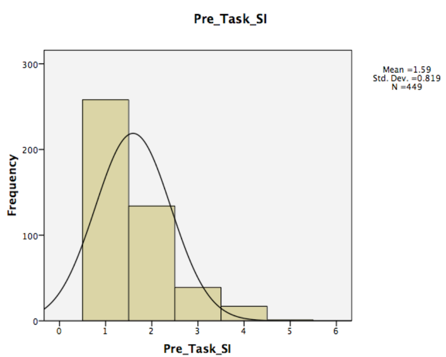


Figure 11. Histogram of *Scientific Inquiry Assessment* Pre-test

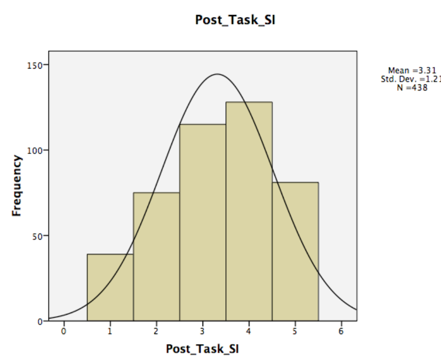


Figure 12. Histogram of *Scientific Inquiry Assessment* Post-test

In summary, when the effectiveness of the intervention is evaluated irrespective of the teaching methodology that is being used, it can be seen that student learning gains are large and statistically significant as measured by the independent samples *t*-tests. Further analysis showed that the effect sizes that were seen in all assessment outcomes are very large with the average post-assessment score from 1.47 to 2.10 standard deviations above the average pre-test score, lending strength to the inference that students learned about density as a result of the intervention.

General Trends of the Effect of Teaching Methodology on Understanding of Density

To examine the relationship between teaching method and student density outcomes, an independent samples *t*-test analysis using SPSS was conducted on student scores for the OAKS Math Performance Assessment and the three pre-post-assessments of the study that measured density knowledge: (a) quantitative Density Assessment, (b) Density Qualitative Assessment, and (c) Density Task Assessment. Although inferences drawn from this type of analysis may be weak because it was conducted without consideration of students' school or teacher, the purpose was to examine differences: (a) prior to the intervention (pre-test), (b) after the intervention (post-test), and (c) during the intervention period (pre-post score difference). Table 24 displays the results of this analysis.

The Hedges' *g* effect size was calculated in order to determine the effect of the teaching methodology. Mean post-test scores and standard deviations from the mean were used for the traditional and inquiry groups and for the pre-post test score differences. It can be seen in Table 24 that the effect size is moderate for the Scientific Inquiry Assessment and it is small for the all the rest of the assessments. Please note the difference in the effect size seen for the Density Assessment post-test (g = +. 42) and the pre-post difference (g = .+.01). This is most likely due to the non-equivalence of the traditional and the inquiry groups prior to experimentation, where the inquiry group performed statistically higher on the Density Assessment pre-test prior to the intervention. As a result, the effect size g = +.42 can not necessarily be attributed to the effect of the inquiry methodology. Proposed explanations for this will be discussed in later sections. Please note that the effect size was not calculated for pre-test scores of ODE math scores.

Table 24
Independent t-Test Analysis of Major Study Variables

Variable	*M*	*SD*	*t*	*p* *	*g*
OAKS Math Performance Assessment					
Inquiry	235.81	11.49	5.67	<.05	
Traditional	229.81	10.84			
Density Assessment pre-test					
Inquiry	16.24	6.14	4.02	<.05	
Traditional	14.03	5.34			
Density Assessment post-test					
Inquiry	27.17	5.05	4.65	<.05	+.42
Traditional	24.79	6.01			
Density Assessment pre-post score difference					
Inquiry	10.83	5.66	0.12	.91	+.01
Traditional	10.77	5.20			
Density Qualitative pre-test					
Inquiry	6.26	4.45	0.93	.35	
Traditional	6.77	2.70			
Density Qualitative post-test					
Inquiry	15.94	4.35	2.66	<.05	+.41
Traditional	14.31	3.59			
Density Qualitative pre-post score difference					
Inquiry	9.01	4.45	2.06	.042	+.33
Traditional	7.65	3.75			
Density Task pre-test					
Inquiry	1.49	0.98	0.16	.87	
Traditional	1.50	0.81			
Density Task post-test					
Inquiry	3.27	1.46	1.53	.127	+.15
Traditional	3.07	1.18			
Density Task pre-post score difference					
Inquiry	1.77	1.47	1.67	.095	+.17
Traditional	1.54	1.18			
Scientific Inquiry Task pre-test					
Inquiry	1.56	0.83	1.18	.240	
Traditional	1.65	0.80			
Scientific Inquiry Task post-test					
Inquiry	3.50	1.24	4.18	<.05	+.42
Traditional	3.01	1.10			
Scientific Inquiry Task Pre-Post score difference					
Inquiry	1.94	1.25	4.99	<.05	+.52
Traditional	1.33	1.09			

* = alpha adjusted for multiple testing (α =.10/8 = .0125) to maintain the probability of Type I error at .05.

OAKS Math Performance

The OAKS Math Performance Assessment was analyzed because the quantitative determination of density requires mathematical skills and reasoning. Students who are better at math may also be better at calculating density. To examine if the inquiry (M = 235.81, SD = 11.49) and traditional (M = 229.81, SD = 10.84) student groups were equivalent for this variable prior to the treatment, an independent samples t-test was performed $t(476) = 5.67$, $p < .05$.

The results of the t-test indicated that the groups were statistically significantly different in the area of math achievement prior to treatment, with the inquiry group scoring higher. The error bar plot in Figure 13 shows that the 95% confidence interval for the *OAKS Math* pre-score inquiry (M = 235.81) and traditional (M= 229.81) groups was small with no overlap. The box plot in Figure 14 demonstrates that there was a large overall range in both the inquiry and traditional score sets, reflecting large variability in the overall scores. Both plots were heavy-tailed in the lower scores and light-tailed in the upper scores. While the upper limit was the same for both the traditional and the inquiry group, the bottom limit was not. The traditional group had a much longer whisker in the lower score range. (Note: For the graphs, “0” represents the traditional group and “1” represents the inquiry group.)

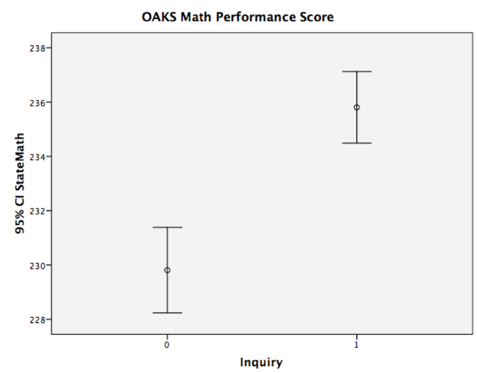


Figure 13. Error bar graph of *OAKS Math Performance Assessment* scores

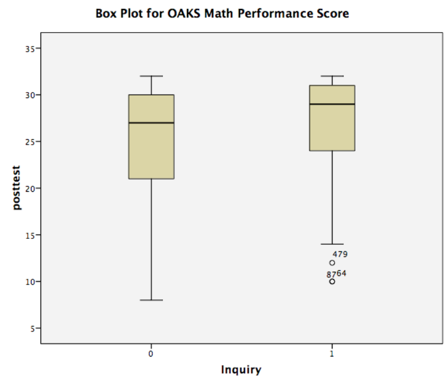


Figure 14. Box plot graph of *OAKS Math Performance Assessment* scores

Density Assessment

The Density Assessment was a multiple-choice assessment that measured both students' content and conceptual understanding of density. Prior to the initiation of the treatment, there were already statistically significant differences between the inquiry students (M = 16.24, SD = 6.14) and traditional students (M = 14.03, SD = 5.34); t(476), p < .05, following the trend associated with the OAKS math scores. The error bar graph presented in Figure 15 demonstrates the groups' differences. The 95% confidence interval for the means of the Density Assessment pre-score inquiry group (*M* = 16.24) and traditional group (*M* = 14.03) do not overlap, supporting the conclusion that the samples were statistically different. The box plot in Figure 16 shows that the lower limit for the pre-assessment scores was the same and with similar range. The upper limit was higher for the inquiry group than the traditional group, with outliers in the traditional group falling in the upper range of the inquiry group. The tails for both were heavier in the upper range.

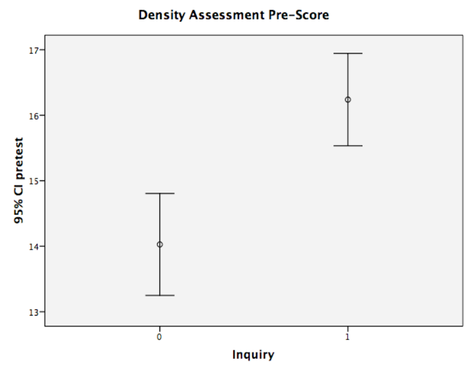


Figure 15. Error bar graph for *Density Assessment* pre-test

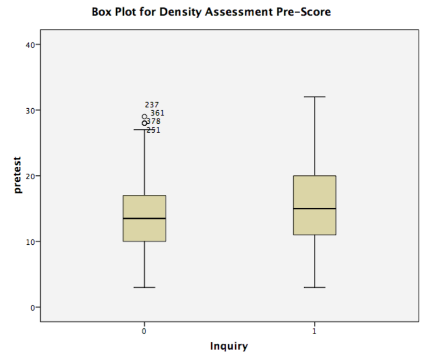


Figure 16. Box plot of error bar graph for *Density Assessment* pre-test

The Density Assessment post-assessment scores for the inquiry group (M = 27.17, SD = 5.05) and the traditional group (M = 24.79, SD = 6.01); $t(476) = 4.65$, $p < .05$ followed a similar trend, with inquiry students outperforming the traditional students. The error bar graph in Figure 17 demonstrates that the 95% confidence interval for the mean did not overlap, supporting a conclusion that the scores were statistically different. Because the scores were different before the treatment, definite conclusions regarding the "effects" of the treatment were not possible. The box plot graph in Figure 18 demonstrates that the distribution for scores was large, both heavy-tailed in the lower score range. It also shows that the upper scores were light-tailed and that the upper limit for the scores was similar.

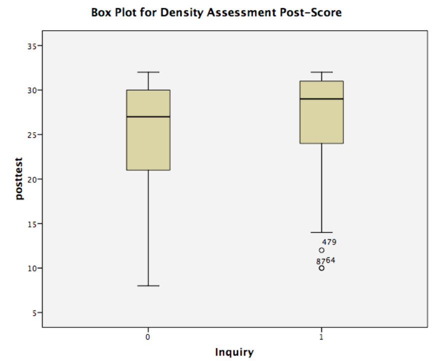


Figure 17. Error bar graph for *Density Assessment* post-test

Figure 18. Box plot of error bar graph for *Density Assessment* post-test

The inquiry group performed better on both the pre-test and on the post-test. However, the mean learning gain, represented by the pre-post score difference, for the inquiry group (*M* = 10.83, *SD* = 5.66) was not statistically different from the traditional group (*M* = 10.77, *SD* = 5.20); *t*(476), *p* = .91. Figure 19 illustrates the overlap of the 95% confidence interval of the mean for the pre-post difference for the inquiry group (*M* = 10.83) and traditional group (*M*= 10.77). The box plot in Figure 20 illustrates that the scores for the inquiry group were heavy-tailed in both the upper and lower ranges.

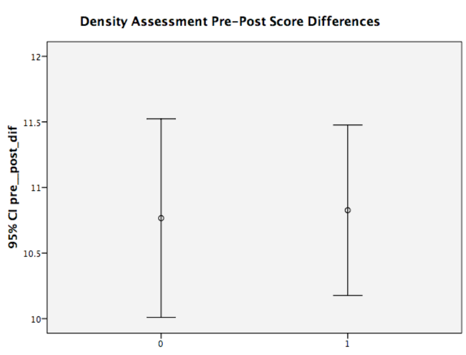


Figure 19. Error bar graph for *Density Assessment* pre-post score difference

Figure 20. Box plot graph for *Density Assessment* pre-post score difference

Density Qualitative Assessment

This density assessment was designed to examine students' conceptual understanding of density and their ability to provide explanations about sinking and floating phenomenon in terms of density. An independent samples *t*-test analysis indicated no statistically significant difference between the inquiry (M = 6.26, SD = 4.45) and the traditional groups (M = 6.77, SD = 2.70); $t(359) = .93$, $p = .35$, prior to the onset of the instructional treatment. The 95% confidence interval around the mean demonstrates some overlap (See Figure 21). The box plot in Figure 22 illustrates that the range of scores was higher for inquiry, with a heavy tail in the upper score range.

Figure 21. Error bar graph for *Density Qualitative Assessment* pre-test

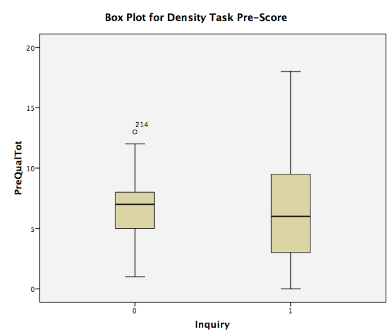


Figure 22. Box plot graph for *Density Qualitative Assessment* pre-test

For the post-assessment, the *t*-test analysis indicated statistically significant differences between the inquiry (M = 15.94, SD = 4.35) and traditional groups (M = 14.31, SD = 3.59); $t(168) = 2.66$, p <.05. As Figure 23 illustrates, the error bar plot showed some minimal overlap in the 95% confidence interval representing the two groups. The box plot in Figure 24 shows that the score range for both inquiry and traditional was nearly identical, but the distribution of scores was much heavier in the upper range for the inquiry group.

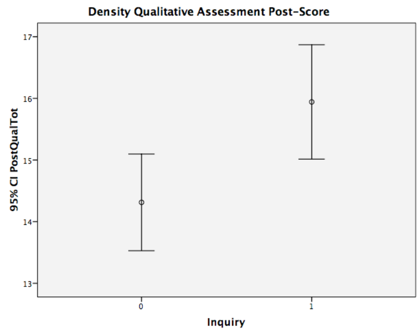


Figure 23. Error bar graph for *Density Qualitative Assessment* post-test

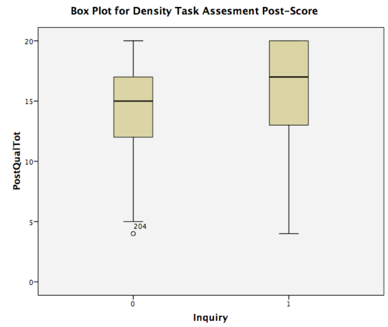


Figure 24. Box plot graph for *Density Qualitative Assessment* post-test

When looking at the mean learning gains through the pre-post score difference, students in the inquiry group (*M* = 9.01, *SD* = 4.45) outperformed students in the traditional group (*M* = 7.65, *SD* = 5.75); *t*(446) = 0.16, *p* =.042 . The error bar graph in Figure 25 shows a similar pattern to the post-score, but the box plot distribution appears more normally distributed, with inquiry having a greater range and higher upper limit (See Figure 26).

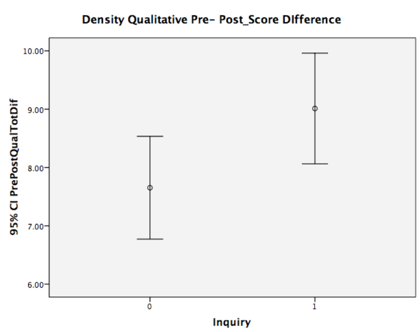


Figure 25. Error bar graph for *Density Qualitative Assessment* pre-post score difference

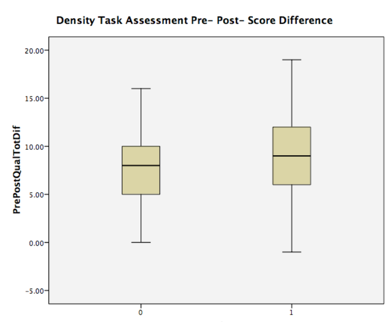


Figure 26. Box plot graph for *Density Qualitative Assessment* pre-post score difference

Density Task Assessment

For the Density Task pre-test, there were no statistically significant differences between the inquiry (*M* = 1.49, *SD* = 0.98) and traditional groups (*M* = 1.50, *SD* = 0.81);

$t(446) = 0.16$, $p = .87$. The error bar graph in Figure 27 shows that the 95% confidence intervals around the means to be very similar. However, the box plot in Figure 28 demonstrates that the distribution of scores was very different, with inquiry having no upper tail and many outliers in the upper range.

Figure 27. Error bar graph for *Density Task Assessment* pre-test

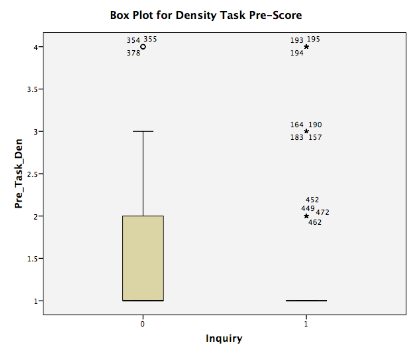
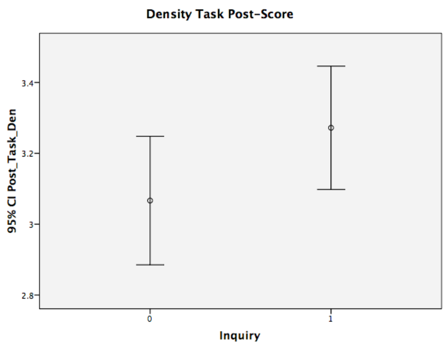


Figure 28. Box plot graph for *Density Task Assessment* pre-test

Neither the Density Task post-test scores $t(435) = 1.53$, $p = .13$ nor the Density Task pre-post score difference $t(411) = 1.67$, $p = .10$ reflected the presence of statistical differences between the traditional and inquiry groups for these variables. Both error bar graphs (Figures 29 and 31) were roughly similar, with overlapping 95% confidence intervals. The box plot in Figure 30 shows that the range for inquiry and traditional extended from the minimum and maximum scores possible, with the inquiry having no upper tail and the 75th percentile extending to the maximum score possible. The box plot in Figure 31 for the pre-post score difference has different characteristics. The 75th percentile was fairly similar for both groups. However, the traditional group had no upper tail and had a heavy lower range tail.



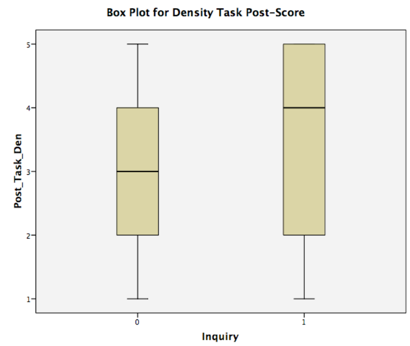
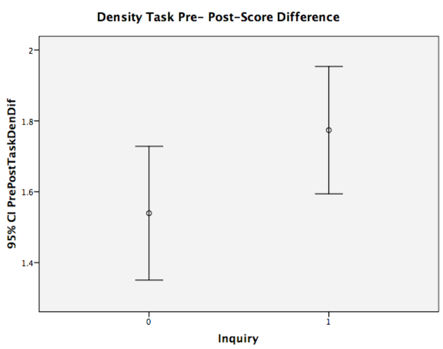


Figure 29. Error bar graph for *Density Task Assessment* post-test

Figure 30. Box plot graph for *Density Task Assessment* post-test



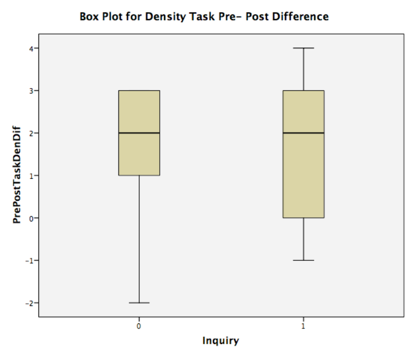
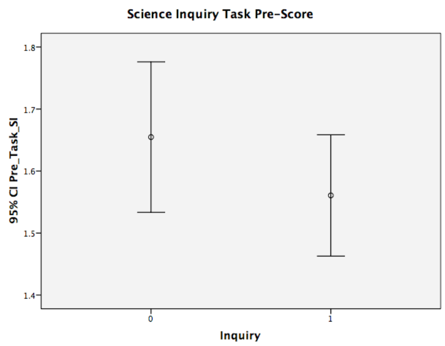


Figure 31. Error bar graph for *Density Task Assessment* pre-post score difference

Figure 32. Box plot graph for *Density Task Assessment* pre-post score difference

Scientific Inquiry Task

Prior to the intervention, there were no statistically significant differences between the inquiry (M = 1.56, SD = 0.83) and traditional groups (M = 1.65, SD = 0.80); $t(446) = 1.18$, p = .24. Figure 33 shows the error bar graph of the 95% confidence interval overlapped for the two groups. The box plot in Figure 34 for this variable shows the score distribution for the two groups to be nearly identical, with both showing outlying values.



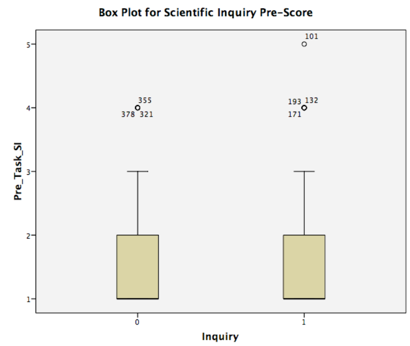
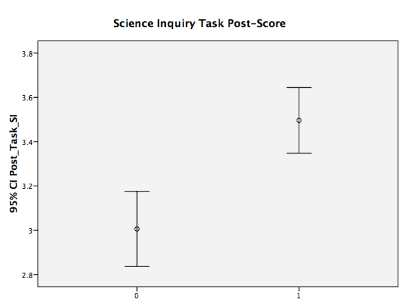


Figure 33. Error bar graph for *Scientific Inquiry Task Assessment* pre-test

Figure 34. Box plot graph for *Scientific Inquiry Task Assessment* pre-test

After the treatment, there was a statistically significant difference for the Science Inquiry Task post-score, with the inquiry group (M = 3.50, SD = 1.24) out-performing the traditional group (M = 3.01, SD = 1.10); $t(435)$, p <.05. There was also a statistically significant pre-post difference for the Science Inquiry Task between the inquiry group (M = 1.94, SD = 1.25) and the traditional group (M = 1.33, SD = 1.09); $t(411) = 4.99$, $p < .05$. The error bar graphs in Figures 35 and 36 for both variables show that the 95% confidence intervals for the inquiry and traditional groups did not overlap for the two means, with inquiry having a higher mean for both. The box plot graphs for the two variables shown in Figures 36 and 38 were not similar. In the traditional group the range of scores was not as large and the 50% bar was at the lower end of the range.



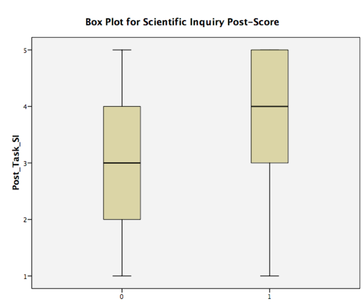
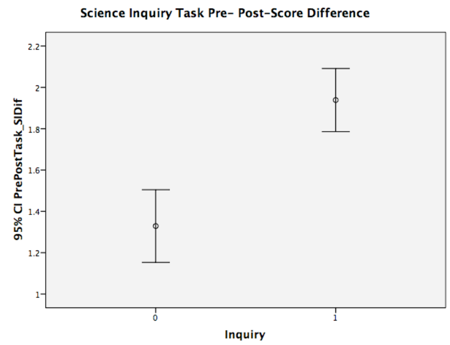


Figure 35. Error bar graph for *Scientific Inquiry Task Assessment* post-test

Figure 36. Box plot graph for *Scientific Inquiry Task Assessment* post-test



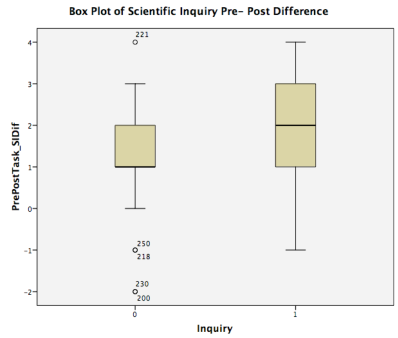


Figure 37. Error bar graph for *Scientific Inquiry Task Assessment* pre-post score difference

Figure 38. Box plot graph for Scientific Inquiry Task Assessment pre-post score difference

Correlation Between Math Skills and Density Knowledge

To explore the relationship between student math skills and density knowledge, correlations were run to assess the relation between the two variables OAKS Math Performance Assessment and Density Assessment. There was a moderately strong correlation between the Density pre-test and math score (r = .61, n = 479, p < .05) and a strong effect size of g = +1.54. This same pattern is seen as well when the Density post-test and math score are compared r = .57, n = 479, p < .05; g = +1.39. There was a statistically significant weak negative correlation between the and the Density pre-post test score and the math score r = -.091, n = 479, p <.05 and a small negative effect size of g = -.18.

In summary, by looking at the overall pattern of results, it can be concluded that the inquiry and the traditional groups were statistically different on the OAKS Math Performance Assessment and the Density Assessment prior to the intervention, with the inquiry group outperforming the traditional group. It was also shown that the OAKS Math scores and the pre- and post- Density Assessment scores were moderately correlated. Of particular note, these trends were not seen when pre-post score differences were analyzed, where a small negative correlation between the pre-post score differences and the OAKS math was seen, implying that as ODE math scores decreased, pre-post test score differences increased. Also, there were no statistically significant difference between the inquiry and the traditional group on the Density Assessment. To better isolate the relationship between treatment status and density outcome scores, teachers and classes matched on OAKS Math Performance Assessment scores were compared.

Comparing Matched Teachers

Determination of Equivalent Teachers

Three comparisons between an inquiry and a traditional teacher were proposed for this investigation. The first proposed comparison was between Teacher 2 and Teacher 3 who both taught science in the same middle school. Teacher 2 taught the traditional methodology and Teacher 3 taught the inquiry methodology. The second proposed comparison was between Teacher 4 (traditional) and Teacher 5 (inquiry). These teachers taught at two different schools with similar student ethnicity, SPED, ELL, and TAG composition. The third comparison was between the 7th and the 8th grade students of Teacher 1. All students for this teacher received the inquiry methodology.

A *t*-test was performed to analyze if these matched teachers' classes were equivalent for OAKS Math Performance Assessment scores and Density Assessment pre-test scores prior to the intervention. The results of that analysis are shown in Table 25 where it can be seen that student performance for Teachers 2 and 3 on the math and pre-test assessments were not statistically significantly different, indicating that these classes were comparable. Students from Teachers 4 and 5 could not be compared, as they were too different prior to the implementation of the intervention for such comparisons to be meaningful. Teacher 1's 7th and 8th grade classes were compared, with caution, as they were statistically different for the OAKS Math Performance Assessment but not for the Density Assessment pre-test scores.

Table 25

Determining Matched Student Performance on OAKS Math Performance and Density Assessment Pre-test Between Teachers

	OAKS Math Performance Assessment					Density Assessment Pre-test				
Variable	M	SD	*t*	df	*p*	M	SD	*t*	Df	*p*
Same school										
Teacher 2 -Traditional	232.41	12.28	1.51	194	.133	14.15	5.56	1.05	194	.296
Teacher 3 -Inquiry	229.86	11.38				14.96	5.20			
Different school										
Teacher 4 -Traditional	226.85	8.01	9.46	193	<.05	13.88	5.12	3.85	182	<.05
Teacher 5 -Inquiry	239.39	10.02				17.38	7.07			
Same teacher -Inquiry										
Teacher 1 -7th grade	233.57	8.58	3.84	86	<.05	15.14	4.80	1.69	86	.095
Teacher 1 -8th grade	241.80	11.19				17.15	6.19			

Additional class combinations were then considered. Table 26 presents the results of one other equivalent match that was located. For all other comparisons by teacher, only two matches were used: (a) Student outcomes for the two teachers who taught in the same school, Teacher 2 (traditional) was compared to Teacher 3 (inquiry) and (b) Student outcomes for teachers who taught at different schools, Teacher 4 (traditional) was compared to Teacher 3 (inquiry). Inquiry Teachers 1 and 5 had no matches with teachers teaching the traditional teaching methodology when looking at the OAKS Math Performance scores or the Density Assessment pre-test scores by class. Differences between 7th and 8th grade students for Teacher 1 were also examined.

Table 26

Additional Teacher Match for OAKS Math Performance and Density Assessment Pre-test

Variable	OAKS Math Performance Assessment					Density Assessment Pre-test				
	M	*SD*	*t*	*df*	*p*	*M*	*SD*	*t*	*Df*	*p*
Different school										
Teacher 4 - Traditional	226.85	8.01	2.05	182	.140	13.88	5.12	1.41	182	.160
Teacher 3 - Inquiry	229.86	11.38				14.96	5.20			

Analyzing Student Performance for Matched Teachers

An independent samples *t*-test using SPSS was used to determine if there were statistically significant differences in learning gains between the inquiry and traditional teaching methodologies for matched teachers for the Density Assessment. Both the post-test scores and the pre-post-score differences were analyzed. Results of the analysis are shown in Table 27, where it can be seen that for the analysis between Teachers 2 and 3 and for the analysis between Teachers 4 and 3, the student outcomes favored an inquiry teaching methodology for both assessments. The Hedges' *g* effect size was also calculated for each matched teacher comparison. It can be seen that for both the same school and the different school comparisons, the effect size for the inquiry methodology as measured by the Density Assessment post test and pre-post test difference is moderate.

Table 27

Comparing Matched Teachers on Pre-post for the Density Assessment

Variable	Density Assessment Post-Test					Density Assessment Pre-post Difference				
	M	*SD*	*t*	*p* *	*g*	*M*	*SD*	*t*	*p* *	*g*
Same School										
Teacher 2 -Traditional	24.85	6.49	4.10	<.05	+.58	10.69	5.19	3.48	<.05	+.50
Teacher 3 - Inquiry	28.13	4.57				13.17	4.78			
Different School										
Teacher 4 - Traditional	24.73	5.45	4.60	<.05	+.67	10.85	5.25	3.14	<.05	+.46
Teacher 3 - Inquiry	28.13	4.57				13.17	4.78			

* = alpha adjusted for multiple testing (α =.10/2 = .05) to maintain the probability of Type I error at .05.

Comparisons among the same set of matched teachers were conducted to investigate potential group differences in student performance for the two other pre-post assessments: Density Task Assessment and Scientific Inquiry Assessment. A matched teacher comparison could not be completed for the Density Qualitative Assessment, as some of the matched teachers did not complete both a pre- and post-test. Table 28 displays the results of this analysis.

For the Density Task, there was a statistically significant difference between the inquiry and traditional teaching methodologies. Same school Teachers 2 and 3 and different school Teachers 3 and 4 had better student performance in the inquiry groups. A moderate Hedges' *g* effect size was seen for the inquiry methodology for both matched teacher comparisons. For the Scientific Inquiry Task, students in classes where the inquiry teaching methodology was used had statistically better results than the students in the traditional classes. A large Hedges' *g* effect size for the inquiry methodology was seen for both matched teacher comparisons.

Table 28

Comparing Matched Teachers on Pre-Post Score Difference for the Density Task Assessment and Scientific Inquiry Task

Variable	Density Task Assessment					Scientific Inquiry Assessment				
	M	*SD*	*t*	*p* *	*g*	*M*	*SD*	*t*	*p* *	*g*
Same School										
Teacher 2 -Traditional	1.51	1.09	3.96	<.05	+.62	1.44	1.00	4.96	<.05	+.77
Teacher 3 - Inquiry	2.33	1.51				2.34	1.31			
Different School										
Teacher 4 - Traditional	1.57	1.27	3.44	<.05	+.54	1.22	1.19	5.71	<.05	+.89
Teacher 3 - Inquiry	2.33	1.51				2.34	1.31			

* = alpha adjusted for multiple testing (α =.10/2 = .05) to maintain the probability of Type I error at .05.

Previously, it was determined that within each teacher's set of classes there were class-to-class differences in pre-intervention math scores. The next series of analysis take these differences into consideration. Students in classes with high math performance were compared to other students in classes. Likewise, students in classes with low math performance were compared to other students in classes with low math performance.

Comparing Inquiry and Traditional Classes Matched for Math

Determination of Equivalent Classes

In this investigation there were 5 teachers who taught a total of 17 classes. Two teachers with 6 classes were assigned the traditional teaching methodology lessons on density and three teachers with 11 classes were assigned the inquiry teaching methodology lessons. Using the independent samples *t*-test presented previously, classes for each teacher were compared to other classes taught by the same teacher. Entire science classes were identified as having students who, on average, had either high or low math performance based on the OAKS Math Performance Assessment scores of students in that class. For example, for Teacher 1, Classes 1 and 2 were combined and classified as high performing math classes, as there were no significant differences in their OAKS Math scores, and the scores were significantly higher than other classes' OAKS Math scores.

A summary of the math level classification by class is given in Table 29. To reduce the number of comparisons that would need to be made at the class level, a new variable was created called Class Adjusted ($Class_A$) for analysis purposes. This variable combined classes that had a similar math level, by teacher. For example, for Teacher 2, Class 6 and Class 7 were combined to create one adjusted $Class_A$ 4 for high math. This new $Class_A$ 4 was then used in analysis to compare with other high performing math classes for other teachers. Class 5 was adjusted to $Class_A$ 3 low math. The high math level classes for the *Class Adjusted* variable were 1, 2, 4, 6, 8 and 9. The adjusted classes with the low math scores were 3, 5 and 7. The 8th grade adjusted $Class_A$ 2 was not used in comparisons with 7th grade classes.

Table 29

Identifying Science Classes by Student Math Level

School	Teacher	Original Class Assignment	Classes Adjusted (Class $_A$)	OAKS Math Performance Score *n*	*M*	*SD*	Math Level
1	1	1 + 2	1	42	233.6	8.58	High (7^{th})
1	1	3 + 4	2	46	241.8	11.2	High (8^{th})
2	2	5	3	32	227.1	9.16	Low (7^{th})
2	2	6 + 7	4	66	235.0	12.8	High (7^{th})
2	3	9	5	31	225.0	9.71	Low (7^{th})
2	3	8 + 10	6	67	232.1	11.5	High (7^{th})
3	4	11 + 12 + 13	7	86	226.9	8.01	Low (7^{th})
4	5	16	8	29	232.0	7.30	Low (7^{th})
4	5	14 + 15 + 16	9	80	242.1	9.54	High (7^{th})

An independent samples *t*-test analysis indicated that Math Level Low (M = 226.5, SD = 8.67) and Math Level High (M = 235.7, SD = 11.2) differed significantly $t(431) = 8.70$, $p < .05$. Next, an independent samples *t*-test was performed to match specific classes so that group comparisons could be made with math level taken into consideration. Only classes that were statistically similar for student OAKS math scores are shown in Table 30. These were the classes used to compare the inquiry versus the traditional teaching methodology for the two pre-post density assessments: (a) Density Assessment and (b) Density Task Assessment.

Class$_A$ 4 was used in three separate same school/different school comparisons. In order to account for the use of the same class in multiple *t*-test matched class comparisons, a Bonferroni correction was used for all matched class comparisons. The alpha value was adjusted for multiple testing (α =.10/3 = .033) to maintain the probability of Type I error at .05. A more liberal alpha (α = .10) was used for the Bonferroni correction for the matched class comparisons, so that the correction was not overly conservative.

Table 30

Determining Equivalent Classes Using ODE Math Performance

Comparison	Class Adjusted	Teaching Methodology	*M*	*SD*	*t*	*df*	*p* *
Same school	3	Traditional	227.09	9.16	.87	61	.39
	5	Inquiry	225.03	9.71			
Same school	4	Traditional	234.98	12.82	1.37	131	.17
	6	Inquiry	232.09	11.47			
Different school	7	Traditional	226.85	8.01	1.02	115	.31
	5	Inquiry	225.03	9.71			
Different school	4	Traditional	234.98	12.82	.63	106	.53
	1	Inquiry	233.57	8.58			
Different school	4	Traditional	234.98	12.82	1.18	93	.24
	8	Inquiry	231.97	7.30			

* = alpha adjusted for multiple testing (α =.10/5 = .02) to maintain the probability of Type I error at .05.

Matching for Reading Level

To explore the question, “If students are matched for math level, are they also matched for reading level?” an independent samples t-test was run. The results demonstrate that teachers who were matched for math were also matched for reading.

Matched classes that were high for math were also high for reading. So the classes were still equivalent and the comparison can be made. Results of the analysis are shown in Table 31.

Table 31

Independent Samples t-test Analysis Confirmation that Teachers and Classes that Are Matched for OAKS Math Performance Are also Matched to OAKS Reading Performance

Comparison	$Classes_A$	Teaching Methodology	*M*	*SD*	*t*	*df*	*p* *
Teacher							
Same school	2	Traditional	229.49	10.55	.15	194	.879
	3	Inquiry	229.27	10.10			
Different school	4	Traditional	227.34	7.78	1.43	182	.153
	3	Inquiry	229.27	10.10			
Classes							
Same school	3	Traditional	225.91	8.05	.111	61	.912
	5	Inquiry	225.68	8.24			
Same school	4	Traditional	231.23	11.21	.308	134	.758
	6	Inquiry	230.66	10.36			
Different school	7	Traditional	227.43	7.89	1.045	112	.298
	5	Inquiry	225.68	8.24			
Different school	4	Traditional	231.23	11.21	.860	106	.392
	1	Inquiry	233.23	10.66			
Different school	4	Traditional	231.23	11.21	.706	93	.482
	8	Inquiry	229.59	8.33			

* = alpha adjusted for multiple testing (α =.10/7 = .015) to maintain the probability of Type I error at .05

Comparing Matched Classes

An independent samples *t*-test was conducted to determine if there were statistically significant differences in learning gains between the inquiry and traditional teaching methodologies for matched classes for the Density Assessment and the Density Task Assessment. Calculated variables were used for the analysis: (a) Density Assessment pre-post score difference and (b) Density Task Assessment pre-post score difference (See Table 32).

Both of the matched low math inquiry classes showed statically significant results for the Density Assessment, with students receiving the inquiry methodology outperforming the traditional classes. One of the three high math classes showed the opposite result, with the classes receiving the traditional methodology doing better than the inquiry group. Two matches for the high math comparison showed no statistically significant results.

For the Density Task Assessment, two of the three high math classes had the traditional group significantly outperforming the inquiry group. For both of the low math group comparisons and one high math group comparison, there were no statistically significant differences in performance.

In the *Density Task Assessment*, students were also evaluated on the Scientific Inquiry Task on their proficiency collecting and presenting data. Using an independent samples *t*-test to compare inquiry and traditional classes matched by math level, the two low math classes which had the inquiry teaching methodology had statistically higher mean scores than the two low math traditional classes: (a) ClassA 7 (M= 1.28, SD = 1.14) and ClassA 5 (M = 2.36, SD = 1.47); $t(97) = 3.89$, p <.05 and (b) ClassA 3 (M =

1.42, *SD* = .97) and ClassA 5 (*M* = 2.36, *SD* = 1.47); $t(50) = 2.67$, $p < .05$. However, the results were different for the high math classes, where ClassA 6 (*M* = 2.21, *SD* = 1.37) and ClassA 4 (*M* = 1.44, *SD* = 1.02); $t(119) = 3.41$, $p < .05$ showed statistically significantly better results for the students in the traditional class. For the other two high math classes there were no statistically significant differences in performance.

Table 32

Comparing Matched Classes on Pre-post Score Differences for the Density Assessment and the Density Task Assessment

Variable		Density Assessment					Density Task Assessment				
	Math Level	*M*	*SD*	*t*	*p* *	*g*	*M*	*SD*	*t*	*p* *	*g*
Same School											
$Class_A$ 3 -Traditional	Low	10.06	5.79	2.66	<.05	+.67	1.62	1.09	1.31	.20	+.37
$Class_A$ 5- Inquiry		13.52	4.41				2.14	1.65			
Same School											
$Class_A$ 6 -Traditional	High	12.86	4.93	2.20	<.05	-.38	2.30	1.52	3.40	<.05	-.63
$Class_A$ 4- Inquiry		11.00	4.89				1.46	1.09			
Different School											
$Class_A$ 7 - Traditional	Low	10.85	5.25	2.52	<.05	+.55	1.63	1.25	1.67	.10	+.35
$Class_A$ 5 - Inquiry		13.52	4.41				2.14	1.65			
Different school											
$Class_A$ 4 - Traditional	High	11.00	4.89	.34	.74	-.07	1.46	1.09	1.30	.20	+.27
$Class_A$ 1 - Inquiry		10.67	5.15				1.79	1.35			
Different School											
$Class_A$ 4 - Traditional	High	11.00	4.89	1.81	.07	-.40	1.46	1.09	2.31	<.05	-.56
$Class_A$ 8 - Inquiry		9.03	4.87				.76	1.37			

* = alpha adjusted for multiple testing ($\alpha = .10/7 = .0125$) to maintain the probability of Type I error at .05.

The Hedges' *g* effect size for the matched classes comparisons for the Density Assessment were positive for the low math classes where inquiry classes had a moderate effect for both the same school and the different school comparisons. For the high math classes the effect size was negatively small for the same school and for one of the different school comparisons, with students in the traditional methodology making greater learning gains than students in the inquiry methodology. A very small negative effect size was seen for the second high math different school comparison.

The Hedges' *g* effect size for the matched classes comparisons for the Density Task Assessment was positive and small for the low math classes for the inquiry methodology in both the same school and different school comparisons. The effect size in the high math classes was negative and moderate for the same school comparison and for one of the different school comparisons. The effect size was small and negative for the second different school comparison.

Qualitative versus Quantitative Understanding

Comparing Subsets of Questions on the Density Assessment

The Density Assessment was designed to have three different types of questions: (a) conceptual/ qualitative questions, (b) quantitative/ content questions, and (c) questions that referred to information that was only explicitly taught in the traditional classes. Analyzing student performance by question type demonstrates whether there was a relationship between teaching methodology and students' ability to answer a specific question type. There were a total of 18 questions tested for students' qualitative or conceptual understanding, 11 questions measured students' quantitative or content understanding by asking students to calculate density using a formula, and 3 questions were based on readings or lecture notes from the traditional teaching methodology.

For the Density Assessment pre-test and post-test, the questions were distributed as follows: (a) qualitative/conceptual questions were Questions # 1-10, 17-19, 21, 23-25; (b) quantitative/content questions were Questions #11-16, 20, 26- 29; and (c) traditional questions were Questions # 30 – 32. Comparisons were made at three levels (a) overall results comparing all students who had the inquiry teaching methodology with all students in the traditional teaching methodology, (b) comparing inquiry and traditional teaching methodologies between teachers matched for students with similar math abilities, and (c) comparing inquiry and traditional teaching methodologies between classes matched for students with similar math abilities. Independent samples *t*-tests were used to conduct the comparisons.

At the broadest level of comparison, across all students who received either inquiry or a traditional teaching methodology, there were no statistically significant differences for: (a) qualitative/conceptual understanding - inquiry ($M = 5.79$, $SD = 3.56$) and traditional ($M = 5.60$, $SD = 3.26$); $t(476) = .60$, $p = .55$; (b) quantitative/content understanding – inquiry ($M = 4.49$, $SD = 2.95$) and traditional ($M = 4.57$, $SD = 2.89$); $t(476) = .28$, $p = .78$; and (c) the traditional questions – inquiry ($M = .71$, $SD = 1.26$) and traditional ($M = .66$, $SD = 1.19$); $t(476) = .43$, $p = .67$.

Comparing Matched Teachers

Teachers whose students were matched for OAKS math performance and overall performance on the Density Assessment pre-test were compared to investigate if students in inquiry classes performed differently than students in traditional classes for the three different question types on the assessment. The results are shown in Table 33. Statistically different results were seen for both the conceptual/qualitative and quantitative questions for Teachers 2 and 3 (at the same school), where the inquiry group outperformed the traditional group. Teachers 4 and 3 (at different schools) showed a statistically significant result for the quantitative/content questions only, with students in the inquiry group performing better than students in the traditional group. No statistically significant differences were observed for any teacher comparison for the traditional content questions that were based on information that was only given in classes using the traditional methodology.

Table 33

Comparing Matched Teachers on Pre-post Score Difference for Conceptual and Quantitative Questions on the Density Assessment

Variable	Qualitative/Conceptual Questions					Quantitative/Content Questions				
	M	*SD*	*t*	*p* *	*g*	*M*	*SD*	*t*	*p* *	*g*
Same School										
Teacher 2 -Traditional	5.47	3.11	2.608	<.05	+.37	4.40	3.04	3.384	<.05	+.48
Teacher 3 - Inquiry	6.63	3.13				5.75	2.50			
Different School										
Teacher 4 - Traditional	5.74	3.44	1.833	.07	+.27	4.76	2.59	2.602	<.05	+.37
Teacher 3 - Inquiry	6.63	3.13				5.70	2.50			

* = alpha adjusted for multiple testing (α = .10/2 = .05) to maintain the probability of Type I error at .05

The Hedges' *g* effect size for the matched teacher comparisons for the Density Task Assessment was small for the qualitative/conceptual questions and for the quantitative/content questions for both the same school and different school comparisons. The methodology effect was on average weaker for the qualitative questions than it was for the quantitative questions.

Comparing Matched Classes

Classes whose students were matched for OAKS math performance were compared to investigate if students in high or low math classes who were given the inquiry methodology would perform differently than students in traditional classes for the three different question types on the assessment. The results are shown in Table 34. The results of this analysis demonstrated that only one high math class comparison (ClassA 6 and ClassA 4) showed statistically significant differences for the qualitative/conceptual understanding question type, with students in the traditional group outperforming students in the inquiry group.

For the quantitative/content questions, four comparison groups showed statistically significant differences. Within the same school, low math group inquiry students (ClassA 5) statistically outperformed traditional students (ClassA 3). For the same school high math group, the traditional students (ClassA 6) statistically outperformed the inquiry students (ClassA 4). A similar result was seen in the high math class at different schools, where students in the traditional teaching methodology (ClassA 4) outperformed students in the inquiry methodology (ClassA 8) and students in a low math class receiving inquiry methodology (ClassA 5) outperformed students in the traditional class (ClassA 7). The third high math comparison group (ClassA 4 and ClassA 1) did not have statistically significant differences in performance.

Table 34

Comparing Matched Classes on Pre-post Score Difference for Conceptual and Quantitative Questions on the Density Assessment

Variable		Qualitative/Conceptual Questions					Quantitative/Content Questions				
	Math Level	*M*	*SD*	*t*	*p* *	*g*	*M*	*SD*	*t*	*p* *	*g*
Same School											
$Class_A$ 3 -Traditional	Low	5.25	3.50	1.71	.09	+.42	4.00	3.14	2.66	<.05	+.67
$Class_A$ 5- Inquiry		6.64	2.98				5.94	2.59			
Same School											
$Class_A$ 6 -Traditional	High	6.64	3.18	2.04	.04	-.35	5.63	2.43	2.22	<.05	-.38
$Class_A$ 4- Inquiry		5.57	2.92				4.59	3.00			
Different School											
$Class_A$ 7 - Traditional	Low	5.70	3.49	1.34	.18	+.29	4.76	2.62	2.13	<.05	+.45
$Class_A$ 5 - Inquiry		6.64	2.93				5.93	2.59			
Different school											
$Class_A$ 4 - Traditional	High	5.58	2.92	.39	.70	-.08	4.59	3.00	.40	.69	-.08
$Class_A$ 1 - Inquiry		5.33	3.50				4.36	2.96			
Different School											
$Class_A$ 4 - Traditional	High	5.58	2.92	.33	.75	-.07	4.59	3.00	2.10	.04	-.47
$Class_A$ 8 - Inquiry		5.34	3.71				3.24	2.63			

* = alpha adjusted for multiple testing ($\alpha = .10/7 = .0125$) to maintain the probability of Type I error at .05

An interesting pattern emerges from the qualitative/quantitative question data for matched classes when the Hedges' *g* effect size is considered. On average the effect of the teaching methodology is greater for the quantitative questions. The effect of the inquiry methodology is greater on average for the both the quantitative and qualitative questions for students in low math classes. It can be seen that for the different school high math comparisons for the high math classes there is essentially no effect of methodology seen in the analysis. For high math classes at the same school there is only a small effect when looking specifically at learning gains for both the qualitative and quantitative questions types.

A limitation of using specific matched comparisons is that not all student data that were collected could be used in the analysis. A different analysis that allowed an examination of patterns across all students who received the inquiry versus the traditional teaching methodology follows.

Multilevel Model

As a means of conducting a composite analysis that explicitly recognized the nested structure of the data, a series of multilevel regression models were estimated. Three-level gain score models were estimated using the Hierarchical Linear Modeling (HLM) program, version 7. An unconditional three-level model was first estimated to partition density gain score variance into student, classroom, and teacher components. A conditional three-level model was then used to investigate relationships between the prior math performance of students, treatment condition (i.e., inquiry vs. traditional) and density gain scores. In the conditional model, the slopes relating the initial mathematics performance to density gain scores were specified to randomly vary across classes and teachers. The prior math achievement/density gain score slopes were freed to vary in order to examine whether treatment condition served to moderate the relationship between the pretreatment level of mathematics performance and density score gains. The full conditional model is specified below:

Level-1 Model

$$Y_{ijk} = \pi_{0jk} + \pi_{1jk}*(STATEMATH_{ijk}) + e_{ijk}$$

Level-2 Model

$$\pi_{0jk} = \beta_{00k} + r_{0jk}$$

$$\pi_{1jk} = \beta_{10k} + r_{1jk}$$

Level-3 Model

$$\beta_{00k} = \gamma_{000} + \gamma_{001}(INQUIRY_k) + u_{00k}$$

$$\beta_{10k} = \gamma_{100} + \gamma_{101}(INQUIRY_k) + u_{10k}$$

Results of the unconditional model indicated that students gained an average of 10.85 density score units over the intervention period. The partitioning of variance across students, classes, and teachers revealed that the majority of the outcome variance (91%) was between students within classes (level-1), whereas approximately 2% of the variance was between classes within teachers (level-2), and 7% of the variance was between teachers (level-3).

Conditional model results revealed a statistically significant positive relationship between prior math performance and density score gains. For every one unit increase in prior math score, students gained an additional .16 density score units over the intervention period. However, the relationship between prior math level and density score gains was observed to vary across teachers, suggesting that the relationship was stronger among the classes of some teachers on average while for others, the relationship was null or negative. Examination of the variability in the prior math/density score slopes revealed a cross-level interaction with treatment condition. In inquiry classes, students with the lowest prior math scores outperformed their initially higher-scoring peers. The converse was true in classes taught in a traditional manner whereby students with the higher prior math achievement had larger gains than students with initially lower math achievement. The descriptive and inferential relationship between prior math performance and density score gains as a function of treatment status at the class and teacher level can be clearly seen in Figures 39 and 40. Tables 35-37 present coefficients associated with the conditional model.

Table 35

Final Estimation of Fixed Effects

Fixed Effect	Coefficient	Standard error	*t*-ratio	Approx *d.f.*	*p*-value
For INTRCPT1, π_0					
For INTRCPT2, β_{00}					
INTRCPT3, γ_{000}	10.758288	1.124075	9.571	3	0.002
INQUIRY, γ_{001}	0.149054	1.444836	0.103	3	0.924
For STATEMAT slope, π_1					
For INTRCPT2, β_{10}					
INTRCPT3, γ_{100}	0.162148	0.040555	3.998	3	0.028
INQUIRY, γ_{101}	-0.287438	0.051967	-5.531	3	0.012

Table 36

Final estimation of Level-1 and Level-2 Variance Components

Random Effect	Standard Deviation	Variance Component	*d.f.*	χ^2	*p*-value
INTRCPT1, r_0	0.83403	0.69561	12	22.49013	0.032
STATEMAT slope, r_1	0.01739	0.00030	12	15.74041	0.203
level-1, e	5.02185	25.21898			

Table 37

Final Estimation of Level-3 Variance Components

Random Effect	Standard Deviation	Variance Component	*d.f.*	χ^2	*p*-value
INTRCPT1/INTRCPT2, u_{00}	1.42115	2.01968	3	26.96341	<0.001
STATEMAT/INTRCPT2, u_{10}	0.02035	0.00041	3	1.77123	>.500

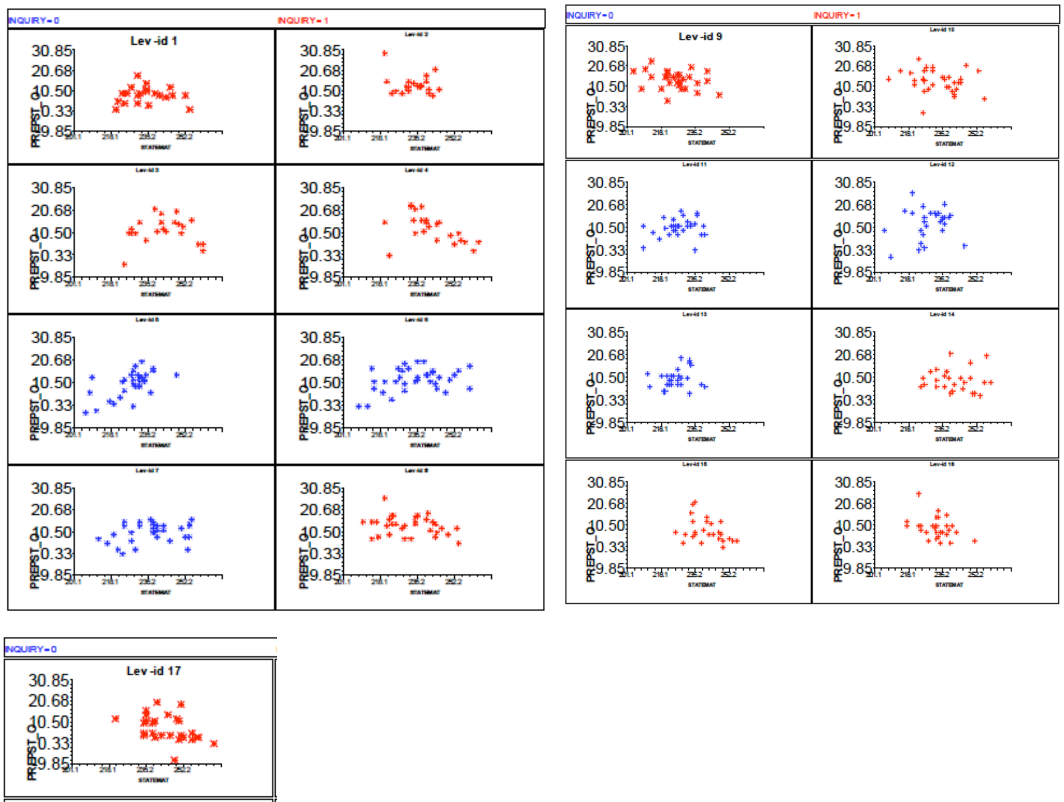


Figure 39. Relationship between prior math achievement and density score gain as a function of treatment condition, traditional (0) and inquiry (1) at the class level.

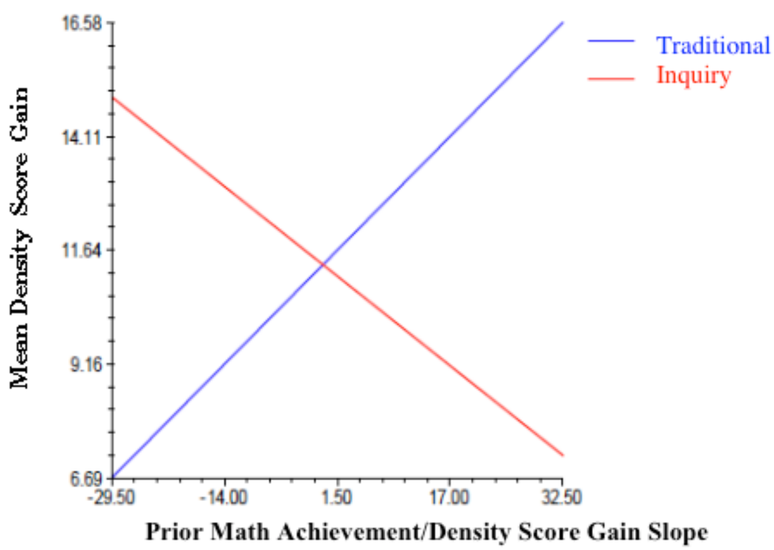


Figure 40. Relationship between prior math achievement and density score gain as a function of treatment condition.

In summary, the Hedges' *g* effect sizes calculated for the Density Unit intervention without regard to teaching methodology shows that students made very large learning gains as a result of being taught density with this unit. Effect sizes ranged from *g* =+1.47 for the Density Task, to *g* = + 1.89 for the Density Assessment, to *g* = +2.10 for the Density Qualitative Assessment. Students also made very large gains with their scientific inquiry skills as measured by the presenting and collecting data ODE rubric *g* = +1.66.

When teachers were matched for students' mean pre-test scores and ODE math scores, the inquiry methodology showed statistically significant results for all assessments. For the matched teachers effect sizes were moderate for the Density Assessment for the same school (*g* = +.50) and the different school match (*g* = +.46). They were also moderate for the Density Task same school match (*g* = +.62) and the different school match (*g* = .54). For the Scientific Inquiry assessment, the effect size was large for the same school match (*g* = +.77) and the different school (*g* = + .89).

The quantitative data obtained from the Density Assessment and the Density Task Assessment suggests that the inquiry methodology was significantly better for students who were in matched low math classes. For the Density Assessment, effect sizes for low math classes were positive and they were negative for high math classes. For the low math matches, the effect size was moderate for both the same school comparison (*g* = +67) and for the different school comparison (*g* = + 55). For high math the effect size was small for the same school comparison (*g* = -.38), very small for one for the two different school comparisons (g = -.07) and moderate for the other different school comparisons (g = -.40). For the Density Task Assessment, the effect size for the low math was small for the same school (*g* = +.37) and small for the different school (*g*

=+35). For the high math classes the effect was moderate and negative for the same school match (*g* = -.63) and positive and small of one different school comparison (*g* = +.27) and moderate and negative for the other different school comparison (*g* = -.56). It is interesting to note that even though the t-test results did not show statistically significant results for several of the class high and low math matches, a small effect size was seen for some of the matches.

When qualitative and quantitative questions were analyzed at the teacher level, the inquiry methodology supported larger statistically significant learning gains. The effect sizes were small, on average being smaller for the qualitative questions (*g* = +.37 and *g* = +.27) than for the quantitative questions (*g* = +.48 and *g* = +.37). When the effect of math level and teaching methodology was analyzed. It was seen that even thought there were no statiscial differences for most matches for qualitative questions, a small effect size was noted that was postive for low math classes and negative for high math classes. The effect was larger on average for the inquiry/low math classes (g = +.42 and g = +.29) than it was for the high math/traditional classes (*g* = -.35; *g* = - .08; *g* = -.07). For quantitative questions, the effect is more pronounced. For low math classes the effect was on average higher in the moderate range (*g* = +.67 ; *g* = +.45) and for high it was smaller in the very small to moderate range (*g* = -.38; g = -.08; *g* = -.47).

When the nested structure of the data was accounted for in a three-level regression model, the students with the lowest math scores had greatest learning gains. In the traditional methodology, students in matched high math classes had statistically significantly better results when a *t*-test analysis was performed. When the multilevel analysis was performed on data from students in the traditional classroom, the density score gain for students was greatest for students with the highest math scores. These results were mirrored in the Density Assessment and the Scientific Inquiry Assessment: Students with low math ability did better in the inquiry classroom, and students with higher math ability did better in the traditional classroom. In order to more specifically explore the effect of teaching methodology on the change in student density conceptions, qualitative data were coded and analyzed. The results of that analysis are found in the following section.

Qualitative Data

Density Qualitative Assessment

The Density Qualitative Assessment was scored using a rubric divided into three sections. The first section tallied the correct answers to five multiple-choice and one true/false question for a total of 6 points. The second section rated the explanation students gave using a three-point scale. For the seven questions, a total of 14 points was possible. The third section characterized if a student answered the question with words only, drawings only, or a combination of words and drawings, but no points were assigned to this section. Thus, a total score was computed based on adding two scores together, with a maximum score of 20 for both sections.

Only two teachers gave this assessment as a pre-post assessment. An independent samples t-test on the learning gains exhibited by the students for these two teachers revealed that students in the inquiry methodology class ($M = 9.01$, $SD = 4.45$) outperformed students in the traditional methodology class ($M = 7.65$, $SD = 3.75$); $t(157) = 2.06$, $p < .05$. However, these results really only tell a partial story. In the next section, the student responses to each of the seven questions on the assessment are categorized.

This categorization provides a detailed insight into the conceptual understanding that students held about density. Overall trends and differences between the students in the traditional versus the inquiry classroom are discussed.

This section is organized by question. The range of student responses for each question is explored. Specific examples of student responses in each category are given. Student answers could fall into three levels: (a) Level 2 = Explanation is accurate with supporting details and examples. Answer is quantitative; (b) Level 1 = Explanation is accurate. Supporting details and examples may be lacking. Some gap in explanation may be evident. Answer is qualitative; and (c) Level 0 = Explanation is inaccurate or too brief to demonstrate understanding or the explanation does not answer questions. All misconceptions of density will fall into this category.

Question 1 – Does mass alone explain why objects float or sink when placed in water?

Before the implementation of the study, students in both the comparison and the treatment group held many misconceptions about mass and its relationship to sinking and floating. For the inquiry group, approximately 66% of answers were at the Level 0, compared to 69.5% in the traditional group. Student misconceptions on this question could be arranged into seven categories. Students said that objects sink and float because of: (a) an object's mass alone, (b) an object's shape, (c) an object's texture, (d) an object's hollowness, (d) the amount of air an object has, (e) gravity, and (f) the size of an object. Table 38 shows the frequency of answers for each level and category for this question. The most frequent misconception in both groups was that mass alone was responsible for sinking and floating. Some students also left the explanation blank or wrote "don't know." Several students said that mass alone could not explain sinking and floating, but gave no explanation as to why it did not explain it. Table 39 contains typical student responses to this question prior to the intervention.

After the intervention, the number of categories of misconceptions diminished for both the inquiry and traditional groups. For inquiry, there were six categories of misconceptions prior to the intervention and one after the intervention, compared to seven before and one after for the traditional group (note: mass alone and no answer were not counted as misconceptions). The only misconception that remained for both groups was that mass alone was responsible for sinking and floating. These students still had not yet made the distinction between weight and density, even after the unit had been taught. Overall, 17% of students in the inquiry group answered at Level 1 compared to 18% in the traditional group, an indication that both methodologies were relatively successful in dispelling misconceptions on this question. Examples of student responses from the post-assessment can be found in Table 40.

Table 38

Frequencies of Students Responding in Each Category for Question 1

Student response level	Pre-assessment		Post-assessment	
	Inquiry	Traditional	Inquiry	Traditional
Level 2				
Used density formula	0.01	0.01	0.22	0.13
Formula + liquid was important	0.00	0.00	0.04	0.00
Total for level 2	0.01	0.01	0.26	0.13
Level 1				
Wrote word "Density"	0.13	0.12	0.24	0.30
Need both "volume and mass"	0.10	0.10	0.10	0.33
Gave an example	0.07	0.02	0.20	0.05
Material of object	0.01	0.02	0.04	0.01
Buoyancy	0.00	0.01	0.00	0.00
Liquid	0.01	0.01	0.00	0.00
Total for level 1	0.33	0.29	0.57	0.70
Level 0				
Don't know/blank	0.12	0.12	0.01	0.00
Mass alone	0.35	0.32	0.09	0.11
Mass does not explain	0.00	0.13	0.07	0.06
Gravity	0.10	0.05	0.00	0.00
Shape/thickness	0.02	0.02	0.00	0.00
Air in Object	0.05	0.01	0.00	0.00
Texture	0.01	0.01	0.00	0.00
Hollowness	0.01	0.01	0.00	0.00
Size of object	0.00	0.01	0.00	0.00
Total for level 0	0.66	0.70	0.17	0.18

Table 39

Sample Student Responses to Question # 1- "Does mass alone explain why objects float or sink when placed in water?" (pre-assessment)

Student Responses for Level 1	Student Responses for Level 0
• Mass does not have to do with it alone. Volume matters. The material of an object is important and helps determine if it will sink or float.	• The mass of an object is the majority of it, but you also need to know the texture.
• Wood always floats on water. Wood could weigh a lot and it would still float.	• No because it has to so with gravity.
• To explain floating and sinking you need weight and space	• Floating depends on mass
• Mass alone does not explain floating and sinking because the icebergs are heavy and they float but diving rings are light and they sink	• If you have a rock and you drop it in water it will sink, but if you have that rock and you make it paper thin, but it keeps its original mass it will float
• Wood floats and can weigh over 500 pounds, mass alone does not explain floating and sinking	• No because it also has to do with hollowness
• An object can be really small but can be really dense and weigh a lot so it will sink.	• You need air to float so objects have holes to float.
• A bowling ball doesn't float and a giant ship does and it weighs a million times more than a bowling ball	• If an object has a lighter mass than another object it will most likely float.
• Volume and mass explain if something floats or sinks.	• If an object is too heavy it will sink, if it is too light it will bounce in the air
• When I think of sinking and floating, I begin with the largest objects that can float. Boats, like the Titantic have huge masses, and yet float. Like a cork in the water. Mass alone does not explain floating and sinking.	• An object's shape is a factor (shows picture of a rectangle sideways on water floating and longways in water sinking.)

Students responding with a Level 1 answer were starting to distinguish between weight and density, but had not yet quantified it. Prior to the intervention, 33% of students in the inquiry group answered at this level compared to 29% of students in the traditional group. The most common response that students gave in this category for both groups was that density was responsible for an object's sinking and floating. Other response categories were: (a) volume was important, (b) examples of heavy objects that floated or light ones that sank, (c) the material out of which the object was made was important, (d) buoyancy played a role, and (e) that the liquid the object was placed in was important. Prior to the intervention, the examples that students gave were primarily from things they might have observed such as a heavy boat or a heavy log that floated while a person or a small rock sank.

Table 40

Sample Student Responses to Question #1 - "Does mass alone explain why objects float or sink when placed in water?" (post-assessment)

Student Responses for Level 2	Student Responses for Level 1	Student Responses for Level 0
• The formula for density is D = M/V. If you don't have the volume you can't find the density. If density is less than 1 it will float.	• Mass alone does not explain floating and sinking because it has to be divided by volume in order to know what the density is	• If an object has a lighter mass than another object it will most likely float.
• You need to know mass and volume then do the formula D = M/V if the answer is higher than 1.0 it sinks, lower it floats	• Density explains sinking and floating. Mass is a part of density, but it does not explain sinking and floating.	• Mass makes things float and also sink
• You need volume and mass to get the density which tells you whether the object will sink or float when you compare to density of water (I g/mL)	• Because when we did a lab using big or little objects like the soap, the little one sank and the big one floated.	• I think mass does float and sink. Sometimes it can explain sinking and floating
• M/V = D If you only had mass you would need volume too. Then you would have to compare it to the density of water to see if it would sink or float.	• Size and mass make density and density affects if things float or sink. So mass alone does not explain it.	• Mass is basically weight and if an object weighs more it will sink

After the intervention, the total number of responses for both Level 1 and Level 2 were equivalent for both groups (83% of responses). However, the distribution of the answers varied, with 57.3% of responses given by students in the inquiry group at Level 1 compared to 69.6% of the traditional group. Both groups had many students who wrote that density was important. Many more students in the traditional group gave the answer that volume was important, without mentioning the word density. More students in the inquiry group gave examples of heavy objects floating and light ones sinking. Their examples were primarily taken from laboratory experiences that they had in the treatment.

On the pre-assessment, one student in each methodology group gave a Level 2 answer. An example from the inquiry class of this type of answer was, "Mass has a part in it, but volume is the other half. An object will float or sink based on its density m/v=d." After the intervention, there was a difference between the groups, with the inquiry group being twice as likely to use a Level 2 quantitative answer (25.6% compared to 12.6% in the traditional group). Also, three students in the inquiry group mentioned the density formula and the fact that the density of the liquid was also important, while no students in the traditional group did this.

Question 2 – Does volume alone explain why objects float or sink when placed in water?

Similar to question one, most student responses were at Level 0 and 1 on the pre-assessment. The distribution of answers was different for the inquiry and traditional groups, with the traditional group answering 63% at Level 0 and 35% at Level 1 compared to the inquiry group with 45% at Level 0 and 53% at Level 1. See Table 41 for the frequencies of student responses for this question.

Table 41

Frequencies of Students Responding in Each Category for Question 2

	Pre-assessment		Post-assessment	
Student response level	Inquiry	Traditional	Inquiry	Traditional
Level 2				
Used density formula	0.04	0.01	0.14	0.07
Formula + liquid was important	0.00	0.00	0.02	0.00
Total for level 2	0.04	0.01	0.16	0.07
Level 1				
Wrote word "Density"	0.09	0.10	0.28	0.32
Need both "volume and mass"	0.18	0.17	0.06	0.33
Gave an example	0.25	0.09	0.23	0.06
Material of object	0.01	0.00	0.07	0.01
Liquid	0.00	0.00	0.02	0.04
Total for level 1	0.53	0.35	0.68	0.76
Level 0				
Don't know/blank	0.05	0.05	0.00	0.00
Volume alone	0.04	0.07	0.02	0.01
Volume does not explain	0.16	0.24	0.12	0.12
Mass only	0.08	0.11	0.00	0.00
Gravity	0.05	0.00	0.00	0.00
Shape/thickness	0.01	0.05	0.01	0.00
Texture	0.00	0.01	0.00	0.00
Hollowness	0.03	0.05	0.00	0.00
Size of object	0.04	0.05	0.00	0.01
Atoms	0.00	0.00	0.00	0.02
Total for level 0	0.45	0.63	0.16	0.17

The high percentages of students answering at Level 1 indicate that both groups of students had previous experience with this concept and understood it to some degree. The misconception categories were similar to those found in Question 1 on mass. However, many fewer students indicated that volume alone caused objects to sink or float than believed that mass alone was responsible. Examples of student responses to this question prior to the intervention are given in Table 42. The most common answer for both groups for Level 0 was that volume alone did not explain why objects sank or floated, with no further explanation given.

Table 42

Sample Student Responses to Question #2 - "Does volume alone explain why objects float or sink when placed in water?" (pre -assessment)

Student Responses for Level 1	Student Responses for Level 0
• You need to know space and weight too	• Volume is how much an item can hold
• Volume is only how much space it takes up. You need to know mass too.	• Volume is height, length, and weight, that's all the things that are needed.
• Volume does not explain floating and sinking alone, for example, a large ship floats and so does a small piece of drift wood.	• Because it matters how big it is, if it is almost as big as the cup then it will sink
• No, because an object with a large volume or a large size can still float.	• If it is heavy or big it sinks, but if it is light and small it floats. It's only the size and volume.
• Volume is how much space an object takes up and an object can be very big, but weigh barely anything.	• If the object is too skinny then it will fall like there is no tomorrow and it if it is too thick it will also sink
• No because it can be huge and still float and it can be tiny and still float.	• Yes because if something is tiny it will float and if something is really big it will sink.
• Something can be absolutely huge but made of Styrofoam and it would probably float in the ocean.	• An object could be huge but have a small density and it will sink
• A big ship has more volume than a bowl and it floats.	• Volume explains how much something can hold. The more it can hold, the more likely it will sink

After the intervention, 17% of students in the traditional group answered at Level 1 and 16% of inquiry students. The percentage of students with misconceptions was even smaller, with 4.9% of students in the traditional group holding them and 3.7% in the inquiry group. Both methodologies seemed to be able to address student misconceptions on this topic. For Level 1, many students in the inquiry group gave examples of a large object that floated and a small object that sank as their explanation. This was one of the noticeable differences between the two groups. However, this difference was likely not due to the intervention, as the percentage for both groups remained about the same before and after the lessons were delivered.

The type of explanation changed in a similar way as it did for Question 1, changing from students giving examples of things they had personally observed or seen on television (like a large boat floating) to explanations that related to laboratory experiences (a small piece of soap sinking). The level of detail in the explanations also increased from pre- to post-assessment. The other difference at Level 1 was that in the traditional group 33% of students answered that you needed both mass and volume to explain why objects sink or float, without mentioning the word "density" as compared to only 6% in the inquiry group who did this. The number of students mentioning the word "density" in the explanation was fairly similar between the groups for the post-assessment. Examples of student responses for the post assessment are found in Table 43.

Table 43

Sample Student Responses to Question #2 - "Does volume alone explain why objects float or sink when placed in water?" - (post-assessment)

Student Responses for Level 2	Student Responses for Level 1	Student Responses for Level 0
• Volume isn't the only indicator of density. The formula D = m/v states that volume must be divided from mass to find the density	• I think it is because it depends on the mass, volume, and density.	• Because you need volume to float something or sink something
• Volume alone does not explain whether an object will float or sink. You need to know the mass of the object (m/v) and know what type of liquid you are using.	• You need to know mass too.	• Volume does not explain sinking and floating
• You need mass and volume to find the density of the object to see if it floats. D = M/V	• No because you need volume and mass to find density	• The size of the object is the most important thing.
• The formula for density is D = M/V. If you don't have the volume you can't find the density	• You need density or volume and mass	• It is about mass, heavy things sink.

On the post-assessment, a larger number of students in the inquiry group (16%) gave a Level 2 quantitative answer than in the traditional group (7%), where students related the concept of density through the formula, explaining that it was a ratio of mass to volume. Very few students in either group at Level 1 or 2 mentioned the importance of the density of the liquid in determining if an object would sink or float.

Question 3 – Does density explain why objects float or sink when placed in water?

For both the traditional and inquiry methodologies, many students did not know how to explain density when they took this as a pre-assessment and left the explanation blank. For those who did try to explain their answer, most were at Level 0 where the primary response used the words "density" and "weight" or "mass" interchangeably. The same misconceptions that were seen in the first two questions were also seen here, with the conception of "high density floats and low density sinks," which had not been seen before. Some students had the idea that density was a property that could be changed as opposed to being a characteristic property of matter. These were students who confused mass and density. See Table 44 for the frequency of answers for each category for this question.

On the post-assessment, student misconceptions were reduced in both groups. Excluding Level 0 answers that: (a) were left blank and (b) agreed with the statement that density could explain singing and floating, but the student did not provide any supporting statement as to how or why, there was a 25% reduction in conceptual misunderstanding in the inquiry groups compared to a 28% reduction in the traditional group. At the conclusion of the study, only 7% of students in the traditional group had misunderstandings about density, while 14% of students in the traditional group had them.

Table 44

Frequencies of Students Responding in Each Category for Question 3

Student response level	Pre-assessment		Post-assessment	
	Inquiry	Traditional	Inquiry	Traditional
Level 2				
Used density formula	0.00	0.00	0.06	0.04
Formula + liquid was important	0.04	0.00	0.28	0.22
Total for level 2	0.04	0.00	0.34	0.26
Level 1				
Used density correctly in explanation	0.06	0.09	0.24	0.06
Density of liquid	0.18	0.09	0.24	0.28
Gave an example	0.00	0.01	0.02	0.01
Material of object	0.02	0.01	0.00	0.00

Table 44 (Continued)

Frequencies of Students Responding in Each Category for Question 3

Student response level	Pre-assessment		Post-assessment	
	Inquiry	Traditional	Inquiry	Traditional
Denser objects sink, less dense objects float	0.04	0.00	0.00	0.09
Buoyancy	0.01	0.01	0.00	0.00
Total for level 1	0.31	0.30	0.50	0.54
Level 0				
Don't know/blank	0.15	0.17	0.01	0.01
Confused mass and density	0.20	0.21	0.07	0.06
Density explains	0.11	0.16	0.01	0.10
Density does not explain	0.01	0.01	0.04	0.02
Air in object	0.01	0.01	0.01	0.00
Gravity	0.00	0.01	0.00	0.00
Thickness	0.05	0.02	0.00	0.00
Texture	0.00	0.01	0.00	0.00
Hollowness	0.04	0.04	0.00	0.00
Size/shape of object	0.01	0.02	0.00	0.01
Atoms/molecules	0.02	0.01	0.02	0.00
High density floats, low density sinks	0.05	0.01	0.00	0.00
Total for level 0	0.65	0.70	0.16	0.20

On the pre-assessment, the number of students who were able to answer at Level 1 was very similar between the two groups; however, the distribution of answers varied. Twice as many students in the inquiry groups referred to the density of the liquid as being an important factor in determining if an object would sink or float. After the density lessons, the number of students who included the density of liquids slightly increased in the inquiry group (from 18% to 23%), but it increased by a large amount in the traditional group (from 9% to 28%). Understanding the relationship between the density of the object versus the density of the liquid in which it is placed is important in understanding floating and sinking. It is one of the first steps in building a complex understanding of this phenomenon. At Level 1, the relationship between the object and the liquid was not quantified. For example, the density of water (1 g/mL) was not given. Answers were given in general terms. Examples of student answers for this concept can be found in Table 45.

Table 45

Sample Student Responses to Question #3 -" Does density explain why objects float or sink when placed in water?" (pre-assessment)

Student Responses for Level 1	Student Responses for Level 0
• When an object is denser than water it will sink. When an object is less dense than water, it will float	• Because something can be more dense than something else and sink. It is weight.
• Density does, because the weight of the object can be very heavy but not sink.	• An object may not be hollow, it may be fully filled with matter.
• Density explains it. If you know something's density is greater than water it will sink if it is less it will float.	• There is more bubbles
• If an object is less dense than water it will float.	• Yes, because it explains how many grams it is, that explains how much it weighs, and that explains if its heavy (sinking) or light (floating)
• If your object is very dense and very small it will sink. And if the object is huge and the density is high it will most likely float. Thus stating you need volume and mass too.	• If you know the density of something, then you know that you have to make the object's density smaller for it to float.

For Level 2 there was a significant increase in both the traditional and the inquiry groups in the frequency of answers that were given. The inquiry group increased from

4% of students answering at Level 2 in the pre-assessment to 34% in the post assessment, and the traditional group increased from 0% to 26%. The type of student responses that were given on the pre-assessment differed from those on the post-assessment. Students responding at Level 2 had a quantitative explanation of sinking and floating in terms of density. They gave the density of water specifically and described how an object with density greater or less than that density would behave. Some students gave the density of the object as well. Table 46 contains examples of student responses for this question. This is a significant change from pre-assessment Question 1 and 2 where the density of the liquid in which the object is being placed was only mentioned by a few students (4% of inquiry for question 1 and 2% of inquiry students for Question 2).

Table 46

Sample Student Responses to Question #3 -" Does density explain why objects float or sink when placed in water?" - (post-assessment)

Student Responses for Level 2	Student Responses for Level 1	Student Responses for Level 0
• It does because if you know the density of an object and the density of the liquid you would know right away if it would sink or float. If water is 1 g/mL and if the object is 1.5, then it would sink because it has a higher density.	• Because if it has high density it will sink. If it has low density it will float	• If your object is very dense and very small it will sink. And if the object is huge and the density is high it will most likely float. Thus stating you need volume and mass too.
• Water's density is 1.0 g/ml. An object that floats is less dense than water. An object that sinks is more dense. Ice is .92 g/cm3 so it floats, glass is 2.3 g/cm3 so it sinks	• Yes, if the object is less dense than the liquid it will float	• Yes because it's the mass divided by volume and the mass explains sinking and floating.
• Water is 1.0 g/ml. Divide the mass by volume (always its mass/volume) and if the object is over 1.0 it will sink and if it's under 1.0 it will float.	• Density is mass and volume together, so you can tell from density if it will sink or float.	• Density is how much an object weighs underwater and if the object will sink or not.
• The density of water is 1.0 g/mL. If the object's density is more than that it would sink and if it is less, it would float.	• Density explains if you know if something's density is greater than water it will sink if it is less it will float.	• Density is how much mass is in an object, so yes it does

Question 4 – What is density?

On the pre-assessment, 72% of students in the inquiry group and 76% of students in the traditional group answered this question at a Level 0. The two most frequent answers were either: (a) I don't know/answer left blank (22% of inquiry students and 26% of traditional students), or (b) students equated mass and density in their answer (28% of inquiry students and 32% of traditional students). Twenty-two percent of students in the inquiry group answered with alternate Level 0 explanations compared to 18% of the students in the traditional group. There were student misconceptions that had been identified before in assessment questions 1-3 such as: density has to do with: (a) the thickness of an object, (b) an object's hollowness, (c) an object's volume, and (d) how much air or space is inside an object. New explanations appeared in response to this question that had not been in student explanations for the first 3 questions. These are that density is related to (a) the fullness of an object, (b) deepness, (c) solidness/hardness, (d) the displacement of an object in a liquid. Four percent of students in both the inquiry and traditional group gave an incorrect formula for density (D = V/M or M + V). See Table 47 for the frequencies of student answers in each of the categories and Table 48 for examples of student responses on the pre-assessment.

Table 47

Frequencies of Students Responding in Each Category for Question 4

	Pre-assessment		Post-assessment	
Student response level	Inquiry	Traditional	Inquiry	Traditional
Level 2				
Used density formula	0.00	0.00	0.32	0.22
Total for level 2	0.00	0.00	0.32	0.22
Level 1				
Mass per unit volume	0.14	0.13	0.22	0.38
Used to determine sinking and floating	0.00	0.00	0.04	0.04
Gave an example	0.01	0.02	0.01	0.00
Material of object	0.02	0.02	0.02	0.00
Atoms/molecules packed together	0.11	0.06	0.15	0.04
Total for level 1	0.28	0.24	0.44	0.46
Level 0				
Don't know/blank	0.20	0.23	0.04	0.01
Density = mass	0.26	0.29	0.12	0.22
Thickness	0.09	0.02	0.01	0.01
Hollowness	0.01	0.01	0.01	0.00
Air/space in object	0.01	0.01	0.01	0.01
Displacement of liquid/volume	0.01	0.02	0.02	0.05
Nonsense	0.06	0.06	0.00	0.00
Used incorrect formula	0.04	0.04	0.00	0.01
Deepness	0.02	0.00	0.01	0.00
Fullness	0.01	0.01	0.00	0.00
Solidness/hardness	0.00	0.05	0.01	0.00
Total for level 0	0.72	0.76	0.24	0.32

Table 48

Sample Student Responses to Question #4 - "What is density?"- (pre-assessment)

Student Responses for Level 1	Student Responses for Level 0
• The measurement used to determine if something will sink or float	• It is kind of like when you dig a hole and see how deep it is so then that is density
• Density describes how much mass and volume are put into an object	• Density is how much something takes up. If a cube is placed in water, it will be less dense and therefore float.
• Mass over volume	• Density is how heavy the object is.
• Mass over volume. The amount of mass in a certain space. A ratio of mass to volume	• Density is the thickness of an object.
• Measurement of mass in a cubic unit	• Density is mass over height.
• Density is a measure of how much something weighs (mass) per cm^3	• Density is when you weigh an object to see if it will float or sink
• Density is how closely packed the molecules are in an object	• Density is how much something weighs or how big it is
• Density is how much a material is packed together	• Density is whether something is hollow or not
• Having atoms crowed together in a certain area	• A number that explains it's height, length, and weight.
• I think density explains floating and sinking	• Density is how tough or full something is
• The mass of a substance per unit volume	• How much air is in an object.
• Density is when something in one cube is heavy and the material in another cube is not smaller size but still weigh the same as the large cube.	• Weight multiplied by size of object

On the post-assessment, the number of students who answered at Level 1 remained fairly high. Twenty-four percent of students in the inquiry group compared to 32% of students in the traditional group still answered at this level even after they had been taught the density unit. The most common Level 0 category of answers was equating mass or weight with density. The percentage of students for this response type in the traditional group (22%) was nearly double that of students in the inquiry group (12%). Examples of student responses on the post assessment are presented in Table 49.

Table 49

Sample Student Responses to Question #4 - "What is density?"- (post-assessment)

Student Responses for Level 2	Student Responses for Level 1	Student Responses for Level 0
• The amount of mass in an object divided by the volume , d = m/v	• The amount per cubic centimeter or milliliter	• The amount of space an object takes up
• Density is the amount of matter per unit volume (D = m/v)	• How compact something is in a given space	• Density is the object weighing more or less than water and see it if floats or sinks.
• The density is the weight of an object per square inch or cm. D = M/V. It's why the Titantic floated and heavy rocks sink.	• The weight and the space of an object (combined)	• The ability to measure mass
• Density is a measurement of how an object/substance floats/sinks in liquids/gases. The more dense an object is the closer the molecules are to each other, making it heavier despite size/mass, making it sink. The less dense an object is, the more spread apart the molecules are despite size/mass making it float or be neutrally buoyant. Density can be calculated by a formula, D = M/V.	• The amount of mass in a certain amount of space.	• Density is a way of finding how much it weighs

On the pre-assessment for Level 1, the overall frequency of responses for the two groups was fairly similar—28% for the inquiry group versus 24% for the traditional group. On the post assessment, the response rate for Level 1 was 44% for the inquiry group and 46% for the traditional group. However, the distribution and type of answers varied. The first notable difference was that 11% of students in the inquiry group gave an explanation of density that had to do with atoms or molecules being more tightly packed together in denser materials on the pre-assessment compared to 6% in the traditional group. On the post assessment this trend continued, with 15% of students in the inquiry group using this explanation of density and only 4% in the traditional group using it.

The other notable observation was that on the post-assessment nearly all students in the traditional group gave exactly the same answer word for word for "What is density?" They answered, "mass per unit volume." This was the definition that was given to them in the lessons. Nearly all of the 38% of students in the traditional group who responded with a Level 1 answer gave this exact answer. However, in the inquiry group, the 22% of students who answered in the category for Level 1 did not use these exact words and had alternate wording. Examples include: (a) "Density is the ratio of how much mass there is in a cubed centimeter or milliliter of matter," (b) "Mass divided by volume equals density," (c) "Density is the amount of mass per cm^3 of a material. To find the density you divide mass by volume," and (d) Density tells the amount of mass in an object per cubed unit of volume. From density you can know if an object sinks or floats."

Prior to the density unit being taught, no students in either group gave a Level 2 quantitative answer to this question. More students in the inquiry group gave a quantitative explanation of density: 32% compared to 22% of students in the traditional group.

Question 5 – Is it possible to combine two materials that have different densities (one sinks and one floats in water) into a new object that has a density that is different from the original materials?

This question refers to a slightly complex topic that is not always taught in middle school, the idea of density of mixed objects. On the pre-assessment, the combined percentage of students who left the answer blank, did not think it was possible or thought it was possible to combine two different materials to get a new one, but gave no explanation of how it could be done, was high for both groups (inquiry = 33% and traditional = 51%). For the post-assessment, this percentage reduced for inquiry to 12% but was still very high for the traditional group of students, at 31%. See Table 50 for the frequency of student answers for this question.

Several misconceptions were held by students at Level 0 that had not surfaced in prior questions: (a) Density is additive. If two objects are combined to form a new object, then the density of the new object will be the sum of the densities of the original objects; (b) If an object that sinks is combined with an object that floats, then the new object will half float and half sink. No mention is made of average density or that the amount of each type of material might influence the new object's sinking or floating behavior; (c) Combining two materials together does not change an object's properties, the density will remain the same; (d) When combining two materials together the new object will always sink; and (e) If you put a sinking object inside a floating object, it will float. See Table 47 for student responses to this question.

Table 50

Frequencies of Students Responding in Each Category for Question 5

	Pre-assessment		Post-assessment	
Student response level	Inquiry	Traditional	Inquiry	Traditional
Level 2	0.01	0.02	0.11	0.02
Used ratio-float/sink/neutrally buoyant	0.01	0.02	0.11	0.02
Gave quantitative answer	0.00	0.00	0.04	0.00
Total for level 2	0.01	0.02	0.15	0.02
Level 1				
Adding objects together changes floating	0.11	0.02	0.35	0.31
Changing mass &volume, changes density	0.02	0.01	0.05	0.00
Creating new materials changes density	0.05	0.01	0.09	0.11
Chemical reaction change density	0.04	0.00	0.01	0.00
Average density, "in-between"	0.07	0.06	0.09	0.09
Total for level 1	0.30	0.11	0.59	0.51
Level 0				
Don't know/blank	0.25	0.28	0.01	0.02
Not possible	0.10	0.18	0.07	0.10
Possible – no explanation	0.06	0.16	0.06	0.26
1/2 sinks and 1/2 floats	0.07	0.06	0.02	0.01
Add densities	0.12	0.13	0.09	0.06
Shape/size/thickness	0.02	0.01	0.00	0.01
Always sink	0.01	0.01	0.00	0.00
Put inside	0.02	0.01	0.01	0.00
No change	0.02	0.01	0.00	0.00
Total for level 0	0.69	0.87	0.27	0.47

Some of the misconceptions that had been seen before were still seen for this question, that density is affected by shape, size, and thickness. For the pre-assessment, 23% of inquiry students held these misconceptions and 20% of students in the traditional group did. For the post-assessment, the frequency of students holding misconceptions dropped for both groups to 10% for the inquiry group and 7% for the traditional group.

Table 51

Sample Student Responses to Question #5 - "Is it possible to combine two materials that have different densities (one sinks and one floats in water) into a new object that has a density that is different from the original materials?"- (pre-assessment)

Student Responses for Level 1	Student Responses for Level 0
• If you mix dirt with water, you get mud. Mud has completely different density than water and dirt, so it is possible.	• It is not possible, because then half of it will sink and the other half will just float.
• If you modify two different type of materials into a newer better material, it could definitely have a different density.	• It is possible, because they can add together and get heavier.
• Because it would combine their densities and materials	• Even if you had a sponge and added a single M&M, it would change the mass, which would change the density.
• Two materials can combine to form a new material like bronze. When combined the ratio of less dense to more dense determines what its new density is.	• I think if they will have a different density, they can both sink and float.
• It is possible if you mix up the liquids hard enough you could create a new one.	• It will probably be a little underwater, but not completely sink
• Different objects can get together to make new things like a chemical reaction	• If one is thin and flat it will float and if one is thick and flat, it won't float.
• This is possible because the combination of these densities will form the new object to have an in between density.	• If you combine materials it raises the density.
• If you put one heavy and one light density together, you would get a new density in between	• You can take a certain amount of each material so that each material has an equal density and then you would combine them.
• Flour, sugar, and butter all have a different density, but when you put them together, they have a different density.	• When a different bigger density is added to a smaller density, it grows in density because the bigger overpowers the smaller and vice versa.

The Level 1 responses for the pre-assessment were varied and fell into five categories:

1. Students who explained that adding two objects or materials together would change whether the new object sank or floated. Many mentioned neutral buoyancy and gave as an example in the post-assessment the experience that they had in lesson 5.

2. Students who thought that changing mass and volume changes density. Students were able to articulate that when two materials or objects are put together, that both the volume and mass change and as density is a ratio of mass to volume, then density also must change.

3. Students who thought that creating new materials changes density. Student answers were somewhat vague as to how this was done, but the generalization is correct, different materials have different densities, as density is a property of matter.

4. Chemical reactions change densities. A few students gave this explanation. The densities of products and reactants do vary, so this was a correct explanation. For example, for the standard baking soda and vinegar reaction, the density of the carbon dioxide gas produced is different than either the baking soda or the vinegar reactants.

5. If an object that has a high density is added to an object with a low density, the combined object's density will be an average or somewhere in between these two densities.

In terms of students who provided Level 1 responses, there were fairly large differences in the pre-assessment for the two groups (inquiry 30% and traditional 11%). For the post assessment in this area, the two groups were fairly close, with 59% of inquiry students answering the question at Level 1 compared to 51% of the traditional group. One of the reasons for this large gain may be that students did an entire lesson on this topic that involved making neutrally buoyant objects in both the traditional and inquiry classes. Many answers were similar, with students citing their lab experiences in the explanations.

At Level 2, students needed to either give a quantitative answer, which few did in either the pre- or post-assessment, or give an explanation that talked about the ratio of the amount of materials that were being combined as being important. On the post-assessment, 15% of students in the inquiry group answered at this level, compared to only 2% in the traditional group. Examples of student responses are found in Table 52.

Table 52

Sample Student Responses to Question #5 - "Is it possible to combine two materials that have different densities (one sinks and one floats in water) into a new object that has a density that is different from the original materials?" - (post-assessment)

Student Responses for Level 2	Student Responses for Level 1	Student Responses for Level 0
• By mixing the two materials, you create a new one. If there is a new object with new properties, then it will change the density. This is because you are changing the ratio of mass to volume.	• It is possible. It is like putting something that will sink onto something that will float to get something that will be neutrally buoyant.	• If it's two liquids then it would be possible. Also, the result would sink because it has both densities put together.
• If you have cork (floats) and clay (sinks) putting clay with the cork will change the density. It will sink or float depending on the ratio of cork to clay.	• Then density changes because there's a different mass and volume	• You just need to add the densities and combine the objects and find the new densities.
• If they are metals you can melt them down and mix them together and you would have a different density. Like a metal with a density of 10 g/cm^3 put with a metal of a density of 8 g/cm^3 could give you a new metal with a density of 9 g/cm^3. You can combine liquids to get a liquid with a new density. That is easier.	• It is possible to combine materials to form a new materials that has different density cause its mass and volume would change, changing the density.	• I think that it is not possible, because if you do, the object will float and then sink.
• For example, cork and clay have a different densities. Cork floats and clay sinks. But if you have a certain proportion of clay and cork, they can sink, float, or drift in the middle.	• Yes, because combining two different objects that sink and float so they would balance each other out.	• If you put items together, it will have a bigger density.
• Because there are two different materials they will have different densities, like a 3 g/cm^3 object added to a 8 g/ g/cm^3 object. The new combined object would have a density less than 8 but greater than 3, depending in the amount of each that you combined. When you combine them they make a new density that is somewhere in between the original densities.	• Yes. It is probably like a positive/negative relationship. If you add a positive (a non-floating object) with a negative (A floating object) you will have an intermediate object. That will give it a new density different from the "parent" object.	• If you have a cork that floats and a clay that sinks if you put them together the mass increases.

Question 6: Can objects that float in water, sink in another type of liquid?

Many students in both the inquiry (63%) and the traditional group (67%) answered this question at a Level 0 on the pre-assessment. For inquiry, 16% percent of students responding at Level 0 either left the explanation blank or said it was possible but gave no explanation. The most common misconception that students held was that all liquids have the same density and if an object floats in water, it will float in any liquid (19% for inquiry and 20% for traditional). Novel conceptions that were not seen before on Questions 1-5 include: (a) Chemicals or other substances in a liquid cause objects to sink or float, (b) Not all things can float, (c) Liquids have different masses, (d) Objects change density when placed in different liquids, (e) Water is the least dense liquid, and (f) Water is different than other liquids. The "thickness" and "thinness" of liquids are still important in explanations given by some students (11% for inquiry and 9% for traditional). Students appear to be confusing viscosity with density. The example that students generally give is oil, which is viewed by many students as a "thick" liquid. This thickness makes it "heavier" or "stronger" than water. However, cooking oil's density is 0.84 g/mL, which is less than water's 1 g/mL density. So objects that float in water may actually sink in oil. Many student examples are exactly the opposite, that somehow, the "thickness" of the oil will support the object that is placed into it, causing objects that would sink in water to float in oil. See Table 53 for the frequencies of student responses to Question 6. Table 54 has examples of student responses.

After the unit on density was taught, the explanations on the post-assessment improved. Level 0 answers were less frequent, dropping to 16% for the inquiry group and

12% for the traditional group. The number and frequency of misconceptions was noticeably diminished in both groups.

Table 53

Frequencies of Students Responding in Each Category for Question 6

Student response level	Pre-assessment		Post-assessment	
	Inquiry	Traditional	Inquiry	Traditional
Level 2				
Gave quantitative answer	0.00	0.00	0.18	0.05
Total for level 2	0.00	0.00	0.18	0.05
Level 1				
Sinking and floating depend on the relationship between object and liquid	0.14	0.12	0.16	0.40
Liquids have different densities	0.23	0.21	0.50	0.43
Total for level 1	0.37	0.33	0.66	0.83
Level 0				
Don't know/blank	0.12	0.17	0.00	0.00
Not possible	0.04	0.06	0.02	0.00
All liquids are the same	0.19	0.20	0.06	0.09
Thicker/thinner, stronger/weaker, heavier/lighter	0.11	0.09	0.05	0.01
Chemicals/substances in water	0.04	0.07	0.01	0.00
Not all things can float	0.00	0.00	0.00	0.00
Liquids have different masses	0.02	0.00	0.00	0.00
Objects change density in different liquids	0.01	0.01	0.01	0.02
If liquid more dense than water object sinks	0.02	0.02	0.00	0.00
Water is least dense liquid	0.04	0.02	0.00	0.00
Water is different than other liquids	0.04	0.02	0.00	0.00
Total for level 0	0.63	0.67	0.16	0.12

Table 54

Sample Student Responses to Question #6 - "Can objects that float in water, sink in another type of liquid?"- (pre-assessment)

Student Responses for Level 1	Student Responses for Level 0
• I have heard that objects act differently in mercury	• They can not sink because water is the least dense of all the liquids
• There are liquids with less density than water (I think)	• If it floats in one liquid it will float in another.
• Because objects might sink in water and float in mercury (some objects)	• Water is thinnest liquid, if it floats in water it will float in anything else.
• Some liquids are more dense than others	• Objects float in all liquids.
• Yes, because different liquids have different densities.	• All liquids should have the same density.
• If an object is put into something with more density, it object could still float, but if it is put into a liquid with less density it could either sink OR float.	• This is because most types of liquids have the same density as water, causing the object to float in other types of liquids.
• It is possible, because the density relationship between the object and liquid might be different with another liquid. If we have a less dense liquid and a denser object, the object will sink. If you have a denser liquid, that object will probably float.	• Water is the liquid that has the lowest density. Some liquids can be more dense because they have something else and not 100% water. Well, water is water. Some objects may float in some type of liquid and sink in water, but if they float in water, they float in all liquids
• An object can sink in one liquid and float in another liquid if the second liquid is denser than the object.	• Yes it will float because the liquid might be heavy and strong so then it sinks.

At Level 1, there were two categories of answers. Students either explained that liquids have different densities in fairly generic terms or they were able to be more specific and state that sinking and floating depended on the relationship between the object's density and the density of the liquid. In response to this question, there was a growth of 29% from pre- to post-assessment for the inquiry group and a growth of 50% for the traditional group. This represents a significant gain in understanding this complex concept of density. See Table 55 for examples of students' post-assessment explanations for this question.

Table 55

Sample Student Responses to Question #6 - "Can objects that float in water, sink in another type of liquid?"- (post-assessment)

Student Responses for Level 2	Student Responses for Level 1	Student Responses for Level 0
• Alcohol (.8 g/ml^3) has a lower density than water (1 g/ml^3) so things that float in water may sink in alcohol	• Water is not the least dense liquid so if a cork sunk in alcohol, it's still possible for it to float in water.	• Thicker liquids often sink materials that float in water
• If an object had a density of 0.9 g/cm3 it would float in water. But if you put it in alcohol it would sink because the liquids have different densities.	• Different liquids have different densities	• The liquid could be very thick
• A liquid like water has a density of 1.00 Other liquids like gasoline/oil float on top of water meaning they have a density of less than water. If oil is .96 then an object of .98 will sink in oil but float in water.	• Yes because there could be liquids that have a density that is lower than water	• In water, the item's density is lower allowing it to float
• If the density of water is 1.00 and the density of alcohol is .88, then an object that is .99 will float in water and sink in alcohol.	• Because they are liquids like seawater and mercury that are denser than water	• There are other liquids that are not as dense as water, making the object more dense.
• Alcohol has a lower density than water. If an object that is .99 g/cm^3 floats in water, it will sink in alcohol because it is more dense than alcohol.	• It depends on the density of the object and the density of the liquid	• It depends on what type of chemicals are in the product.
• It is possible. If you have an object with a density of .97 g/cm^3, it will float in water. But if you put that object into alcohol, it will sink because alcohols' density is 0.8 g/cm^3	• Yes, because all liquids have a different density, which allows objects to sink or float.	• Well, if it sinks in water then it is possible that the object can float in other liquids, if the liquid is very strong and has a strong smell, then it will totally start sinking

At Level 2, on the pre-assessment no students in either group gave a qualitative answer. However, for the post-assessment 18% of the inquiry students and 5% of the traditional students did.

On the post-assessment, for Level 1 and 2 explanations, most students cited alcohol as an example of a liquid having a different density than water. Alcohol is a liquid that is less dense than water. This is in contrast to the pre-assessment, where most cited examples were mercury, a liquid denser than water, or oil, a liquid students thought was more dense than water, but was actually not. This is a trend that was seen in the other questions; as students had experiences that contradicted their misconceptions, they began using their laboratory experiences to create explanations that were more accurate and consistent with accepted scientific concepts of density.

Question 7: True or False: When an object sinks or floats, it is dependent on the relationship between the density of the object and the density of the liquid.

On the pre-assessments, 67% of students in the inquiry group and 72% of students in the traditional group answered at Level 0. Of this, 33% of students in the inquiry group and 41% of students in the traditional group did not provide an explanation for this statement. Thirty-four percent of students in the inquiry group and 31% of students in the traditional group held misconceptions. New misconceptions that surfaced on this question that had not been seen before were: (a) liquid density only is responsible for floating, (b) solid density only is responsible for floating, (c) the density of a liquid and the object need to be balanced for an object to float, and (d) the density of the liquid does not matter, a lower density than water. See Table 56 for the frequencies of student responses to Question 6. Examples of student responses for the pre-assessment can be found in Table 57.

Table 56

Frequencies of Students Responding in Each Category for Question 7

	Pre-assessment		Post-assessment	
Student response level	Inquiry	Traditional	Inquiry	Traditional
Level 2				
Gave quantitative answer	0.00	0.02	0.18	0.10
Total for level 2	0.00	0.02	0.18	0.10
Level 1				
Sinking and floating depend on the relationship between object and liquid	0.33	0.26	0.49	0.52
Total for level 1	0.33	0.26	0.49	0.52
Level 0				
Don't know/blank	0.16	0.17	0.04	0.04
True (no explanation)	0.16	0.15	0.06	0.10
False	0.01	0.09	0.04	0.02
If mass is heavier it will sink	0.01	0.11	0.05	0.01
Objects float in thick liquids	0.06	0.00	0.02	0.00
Air bubbles	0.01	0.00	0.00	0.00
Object density is reason for floating	0.02	0.02	0.01	0.02
Liquid density is reason for floating	0.06	0.00	0.04	0.02
Depends on density	0.14	0.13	0.06	0.16
Density of liquid and object need to balance for floating	0.01	0.02	0.01	0.00
Surface tension/flatness	0.01	0.00	0.00	0.00
Density of liquid does not matter	0.00	0.02	0.00	0.00
Total for level 0	0.67	0.72	0.33	0.38

Table 57

Sample Student Responses to Question #7 - "True or False: When an object sinks or floats, it is dependent on the relationship between the density of the object and the density of the liquid" - pre-assessment

Student Responses for Level 1	Student Responses for Level 0
• True, if the density of the object is less than the liquid, it will float.	• True, because the object is the main reason an object sinks or floats.
• It the object is less dense than the liquid, it will float and vice versa.	• If an object is more dense than a liquid, it slips through to the bottom.
• The liquid has to have more density than the object in order for the object to float.	• The density of the object is all that matters
• True, because if a liquid is very dense and the object is not, it will float. On the other hand, if the object is dense and the liquid is not, the object will sink.	• False. It does not matter what the density is or the liquid
• True, because if the density of the object is a lot and the density of the liquid was low, then the object would sink.	• True, density can be heavy and light and something light (like a feather) can float in a light liquid, but if the liquid is thick (like tar), it would sink.
• True, because if a liquid is very dense and the object is not, it will float. ON the other hand, if the object is dense and the liquid is not, the object will sink.	• Yes, but I am not sure how to explain, but I will try True, because a paper clip weighs I think 2 grams and if it floats in water then it is because of the air bubbles.
• Smaller density for liquid than object = object sinks. Larger density for liquid than object = object floats.	• True, because if the object is light in density and if the liquid is thicker in density then the object will float.

On the post-assessment for students who responded at Level 0, the number of answers that did not contain explanations reduced to 14% for the inquiry and 16% for the traditional group and the number of misconceptions reduced for both groups, to 17% for inquiry and 22% for the traditional group.

The frequency of Level 1 answers increased between the pre- and post-assessment for both groups. For the inquiry group, the frequency of Level 1 answers increased 16% compared to an increase of 26% for the traditional group. After the density unit was taught, the most common answer was a Level 1 answer that stated that, "If the object's density is less that the liquid, it would float. If the object's density is greater it would sink." For Level 2 answers, students were able to qualitatively explain that the relationship between the object's density and the liquid density was important. Very few students were able to do this on the pre-assessment, 18% of inquiry students were able to give a quantitative answer on the post-assessment compared to 10% of traditional students. See Table 58 for examples of student responses on the post-assessment.

After the density unit was taught, the most common answer was a Level 1 answer that stated that, "If the object's density is less than the liquid, it would float. If the object's density is greater it would sink." A very few students stated the answer quantitatively as a Level 2 answer, giving specific densities for objects and liquids. Some still held novel conceptions at Level 0 that did not make sense scientifically. A few still could provide no answer even after they had been taught the unit.

Table 58

Sample Student Responses to Question #7 - ""True or False: When an object sinks or floats, it is dependent on the relationship between the density of the object and the density of the liquid"- post-assessment

Student Responses for Level 2	Student Responses for Level 1	Student Responses for Level 0
• True, if the liquid is water (density 1.0 g/mL) and the object is 1.2 g/mL it will sink. If the object is the same as water it will be neutrally buoyant or if the object is 0.9 g/mL it will float	• If the object's density is less that the liquid, it would float. If the object's density is greater it would sink.	• True because objects have different effects on different liquids
• If the liquid's density is more than an object the object will float, if the liquid's density is less it will sink. A .9 g/cm3 object would float in water, but it would sink in alcohol. A .7 g/cm3 object would float in both liquids. A 1.2 g/cm3 object would sink in both liquids.	• Densities are the determining factor. They depend on each other. If the object's density is less than the liquids, then it floats and if it is more, then it sinks.	• This statement is totally false because size does not matter. There is still a 50% chance that is will start sinking and a 50% chance that it will start floating.
• If you object is .73, it would float because the density of water is 1.0 and its more than your object. If your object is 9.33 compared to 1.0, it would sink all the way to the bottom.	• They work together to determine is the object will sink or float. Heavier liquid + lighter object = float. lighter liquid + heavier object = sink	• Yes because the densities have to be certain.
• True. Water has a density of 1 g/mL. If an object has a density greater than the water, then it will sink. If it is less than the water , it will float.	• True because the density of the object must be lower than the density of the liquid to float and more to sink.	• True to make it float you need to balance the density of the object and the liquid.

Frequency Change for the Three Levels of the Qualitative Assessment

To distill the qualitative data that has been analyzed in this section from the 162 students, the frequency change for each of the questions for both the inquiry and the traditional groups was calculated using this formula:

$$\text{Frequency change}_{\text{Level x}} = |\,\text{pre-assessment frequency}_{\text{Level x}} - \text{post-assessment frequency}_{\text{Level x}}\,|$$

Overview of Results

All values for each level of explanation were averaged and a graph was created to show the overall response trends for each level of question (See Figure 41). An independent samples *t*-test was used to compare the responses for each level without distinguishing between inquiry and traditional groups. The results showed that statistically significant changes occurred at each level of explanation: (a) Level 0 (M = -.45, SD = .07) and Level 1 (M = .28, SD = .11); $t(26) = -20.62$, $p <.05$; (b) Level 1 (M = .28, SD = .11) and Level 2 (M = .09, SD = .32); $t(26) = -.21$, $p <.05$; and (c) Level 0 (M = -.45, SD = .07) and Level 2 (M = -.09, SD = .32); $t(26) = 6.16$; $p <. 05$. A noticeable change occurred for students at each level. There was an overall reduction in student explanations at Level 0 and an increase in Level 1 and 2 explanations, which shows growth in their understanding of density.

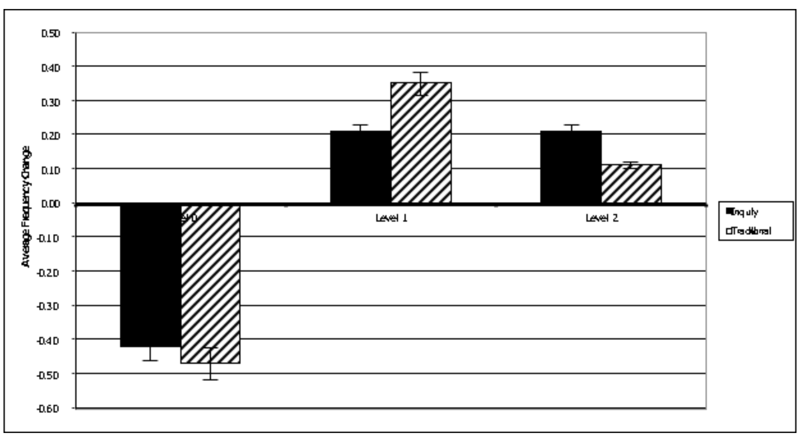


Figure 41. Average of frequency changes between the pre- and post assessment for the *Qualitative Assessment* for each level of student explanations

These frequency change values were then graphed for each Level$_{(0-2)}$ of explanation for both the traditional and inquiry groups. Figure 42 shows the results for Level 0. In general, the greatest change in frequency was seen for students in the traditional group, who also began with a higher frequency of Level 0 answers. An independent samples *t*-test showed no statistically significant difference between the inquiry group (*M* = .42, *SD* = .08) and the traditional group (*M* = .47, *SD* = .06); *t*(12) = 1.29, *p* = .22 for the Level 0 explanations.

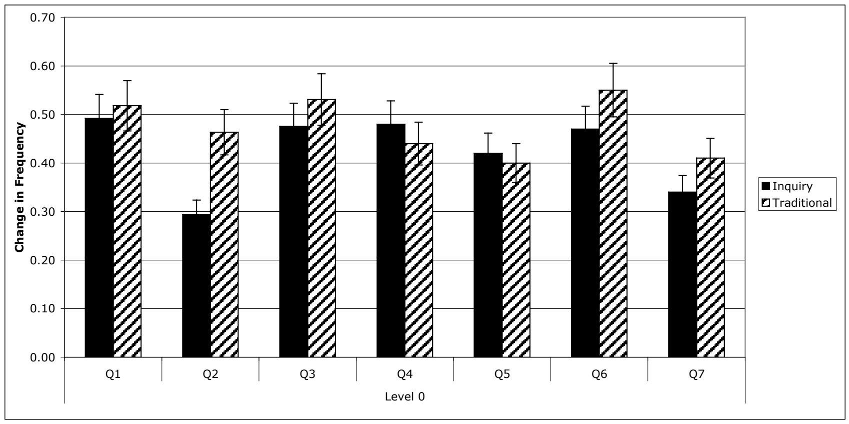


Figure 42. Net Change in Frequency of Level 0 Explanations for Questions 1-7 between the Pre-*Qualitative Assessment* and the Post-*Qualitative Assessment*

One of goals of this investigation was to explore the differences in conceptual understanding between the two groups. To do this more accurately, Level 0 data were modified to exclude the students' responses that did not have to do with misconceptions. These would be the explanations where students wrote down nothing that could be categorized. When blank explanations were excluded from the Level 0 analysis, the results were still not significantly different between the inquiry group (*M* = .18, *SD* = .04) and the traditional group (*M* = .20, *SD* = .06); *t*(12) = .74, *p* = .47 across all seven questions. However, there does appear to be a difference on Question 2, where the traditional group made large gains, and on Question 4, where the inquiry group made large gains (see Figure 43).

Finally, Figure 44 shows the final frequency of student misconceptions for each question at the end of the unit. It can be seen for most questions the level of misconception was fairly equal between the groups, except for Question 4 where the traditional group still had 31% of students holding misconceptions on density, compared to 21% in the inquiry group.

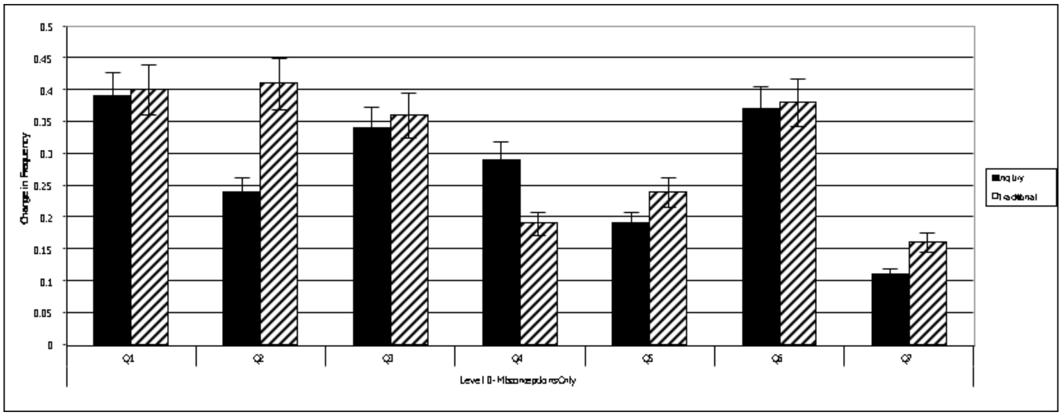


Figure 43. Change in frequency of Level 0 Student Explanations for Density Misconceptions for Questions 1-7 between the Pre-*Qualitative Assessment* and the Post-*Qualitative Assessment*

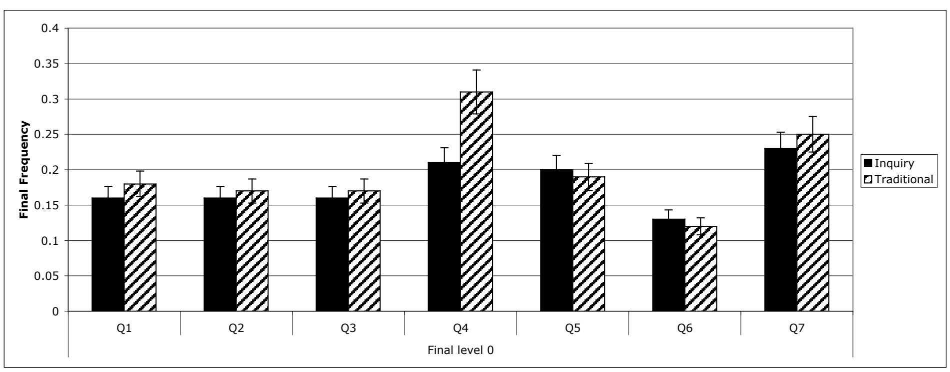


Figure 44. Final frequency of Level 0 Student Explanations for Density Misconceptions for Questions 1-7 for the Post-*Qualitative Assessment*

Level 1 explanations showed a different pattern (See Figure 45). The traditional group showed much higher growth between the pre- and post assessment when compared to the inquiry group. The change in frequency was statistically significantly higher for the traditional group (*M* = .35, *SD* = .10) than for the inquiry group (*M* = .21, *SD* = .06); $t(12) = .32$, $p <.05$. The Hedges'*g* effect size is $g = -\ 1.64$, which is very large.

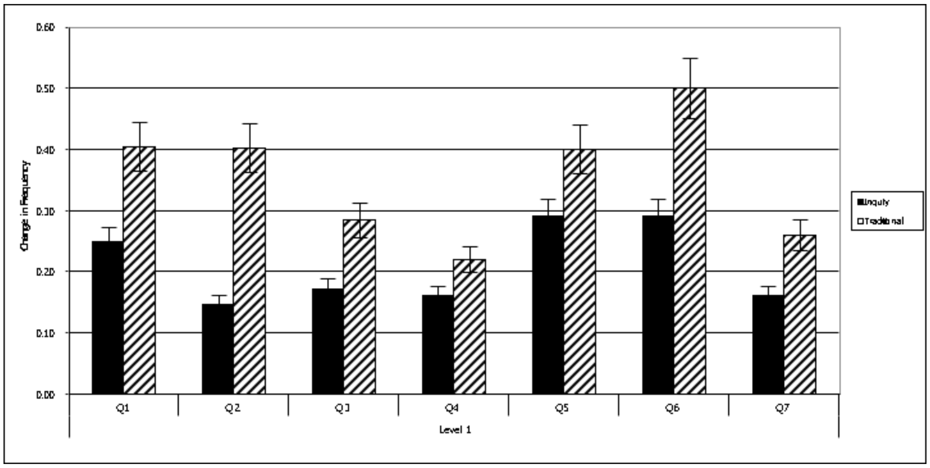


Figure 45. Change in Frequency of Level 1 Explanations for Questions 1-7 between the Pre-*Qualitative Assessment* and the Post-*Qualitative Assessment*

In Level 2 explanations, the inquiry group (*M* = .21, *SD* = .08) significantly outperformed the traditional group (*M* = .11, *SD* = .09); $t(12) = 2.22$, $p < .05$. Figure 46 shows the graph of the frequency change between the two groups for all seven questions. The inquiry group was more likely to give a quantitative answer to any of the seven questions than the traditional group. The Hedges' *g* effect size is $g = +1.14$, which is very large.

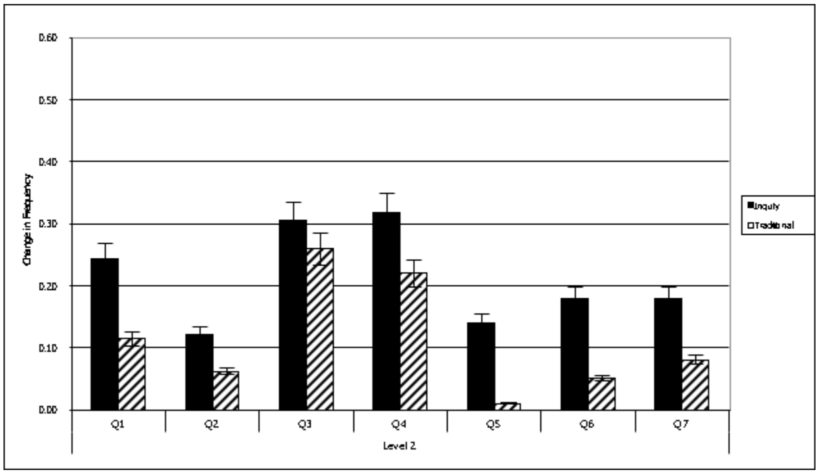


Figure 46. Change in Frequency of Level 2 Explanations for Questions 1-7 between the Pre-*Qualitative Assessment* and the Post-*Qualitative Assessment*

A Continuum of Understanding of Density

As the student work for the Density Task Assessment was further analyzed, it was seen that the range of student work was not being captured by the rubric that had been developed for this study. For the Density Task rubric, there were five levels of proficiency. Students were given a score from 0-5 based on this. The rubric that was used is shown in Table 59. Although this five-level rubric was quick to use to assess student understanding on a broad scale, it did not actually capture the full range of student abilities. It was particularly deficient in distinguishing the variation of student abilities on the lower end of the scale.

Table 59

Student Proficiency Levels for The Density Task Assessment

Proficiency Level	Novice	Working Toward	Nearly Proficient	Proficient	Highly Proficient
Description of Skill	Student only provides weight of objects or does not attempt task.	Student shows the beginnings of understanding of the relationship between mass, volume, and density. Provides weight of objects and part of a volume measurement. All 3 aspects (L, H, W) of objects are not measured. Density may be calculated as D = M*V. Measure in inches.	Student shows understanding of the relationship between mass, volume, and density. However, they do not show how this physical characteristic can be used to determine whether one material is the same as another.	Student shows understanding of the relationship between mass, volume, and density, and how this physical characteristic can be used to determine whether one material is the same as another. States that cube and rectangle are same density	Student shows in-depth understanding of the relationship between mass, volume, and density, and how this physical characteristic can be used to determine whether one material is the same as another. Explicitly states that cube and rectangle are same density. Calculations/ measurements are exactly correct.

It would be informative to know more specifically where a student lies on a continuum of skills in their understanding of density. To create this continuum, the five proficiency levels were divided into skills. In order to define these skills, student data were categorized into 11 subsections. To accurately define exactly what each student had accomplished on the assessment, the skills were further broken down into 18 performances. The data from 430 students who were administered both the pre-and post-assessment were categorized into one of the performance levels for the *Density Task*. Data from students in the inquiry and traditional groups are separately reported and recorded in Table 60.

Next, the change in frequency was calculated for each proficiency level for both the inquiry and the traditional group. Figure 47 shows the results of that calculation.

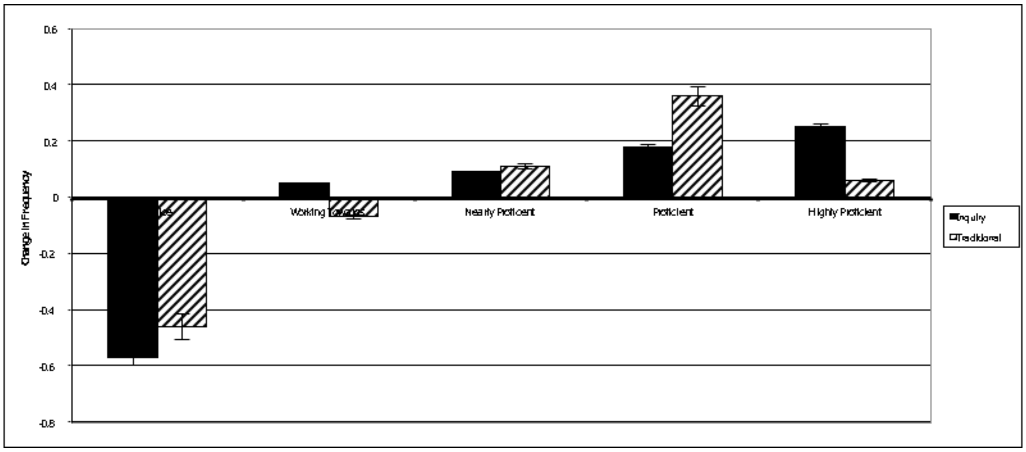


Figure 47. Change in frequency for the *Density Task Assessment*, comparing students in the traditional and the inquiry groups

As Figure 47 illustrates, there was a greater frequency change for students in the inquiry group at the *novice* proficiency level. For the pre-assessment 78% of inquiry students were at the novice level compared to 66% of the traditional students. After the intervention, 21% of inquiry students completed the Density Task at the novice level on the post-assessment, compared to 20% for the traditional group.

Table 60

Student Frequencies for the Inquiry and Traditional (Trad) Groups - Aligned with a Continuum of Skills on Student's Ability to Calculate the Density of Three Objects During the Pre- & Post- Density Task Assessment

Proficiency Level	Skill	Description of student performance level	Inquiry Pre-	Trad Pre-	Inquiry Post-	Trad Post-
Novice	No attempt	• Blank	.06	.04	.00	.02
	Draw picture only	• No words, drawing only	.00	.01	.01	.00
	Drew picture and had some measurements	• Inaccurate or nonsense	.02	.03	.01	.00
		• Accurate	.01	.03	.00	.00
	Partial measurement - weigh or measure some or parts of given objects	• Inaccurate or nonsense or so disorganized meaning can not be understood	.10	,07	.03	.02
		• Accurate	.04	.02	.00	.00
	Weigh only	• Weight inaccurate or weight may be accurate but student also weighed ruler; added 2 or more objects weight together	.14	.01	.01	.04
		• Weight accurate. Student may have included inaccurate volume or density calculations that are guesses	.29	.15	.10	.06
	Measure dimensions (H,L,W) objects only	• Inaccurate, partial, or not in cm	.01	.00	.00	.01
		• Accurate	.00	.00	.00	.00
Working Towards	Weigh and measure dimensions	• Student includes both weight and partial volume measurements. Mass measurements are accurate. Not all dimensions are measured (H, L, W), not all objects measured, some measurements may be inaccurate	.10	.31	.05	.06
		• Weight and size measurements are accurate (may be in inches or cm), all object's weight and 3 dimensions provided. May give a density - but it is wrong and how it was arrived at is not clear	.05	.15	.02	.04
	Weigh, measure, and calculate volume	• Weight and size measurements are accurate. All object's weight and 3 dimensions provided, however, volume is not calculated accurately. Students may have used inches or only multiplied 2-D (i.e. cm2)	.02	.09	.10	.13

Table 60 (Continued)

Student Frequencies for the Inquiry and Traditional (Trad) Groups - Aligned with a Continuum of Skills on Student's Ability to Calculate the Density of Three Objects During the Pre- & Post- Density Task Assessment

Proficiency Level	Skill	Description of student performance level	Inquiry Pre-	Trad Pre-	Inquiry Post-	Trad Post-
Nearly Proficient	Calculate density incorrect	• Accurate volume calculation in cm3 & mass given	.03	.02	.01	.01
		• Mass accurate. Volume calculation (HxLxW) used, but some inaccuracy in measurement causes density calculation to be significantly off. May use correct formula (given) but wrong answer. Volume calculation accurate but wrong density formula used (D = M*V or D= M+V or D = V/M).	.03	.04	.14	.15
Proficient	Calculate density correctly	• For most objects, students calculated density correctly-one answer maybe wrong due to a minor measurement error	.05	.02	.13	.19
		• Calculated density correctly and all answers are correct	.05	.03	.15	.22
Highly Proficient	Calculate density correctly & draw conclusions	• All measurements are correct, densities are correct, conclusions are drawn	.00	.00	.25	.06

The traditional group made its greatest frequency change at the *proficient* level for the Density Task. For the pre-assessment, 10% of inquiry students completed the task at the *proficient* level compared to 5% of traditional students. After the intervention, 25% of inquiry students completed the task at this level on the post-assessment, compared to 41% of the traditional students.   The inquiry group made its greatest frequency change at the *highly proficient* level. For both groups for the pre-assessment, 0% of students performed at the *highly proficient* level. After the intervention, 25% of the inquiry students were highly proficient compared to only 6% of the traditional students.

A *t*-test demonstrated that there was significantly greater improvement for students in the inquiry group (M = -.57) than for the traditional group (M = -.46) at the novice proficiency level $t(242) = 1.32$, $p < .05$. The trend that the traditional group (M = .36) had a greater gain than the inquiry group (M = .18) at the proficient level $t(72) = 1.3$, $p < .05$ and the inquiry group (M = .25) has a greater gain than the traditional group (M = .06) in the highly proficient or quantitative level $t(75) = 8.20$, $p <.05$ continues to be seen in this assessment analysis. There were not significant differences at the working towards or nearly proficient level.

In summary, student conceptions of density significantly changed from naïve conceptions to more accurate conceptions over the course of the study. Both the inquiry and the traditional methodologies were effective in moving students away from novice explanations of density phenomenon. Students in inquiry were able to give on average a greater number of explanations at the quantitative level than students who were in traditional classes. This level represents the highest level of explanation of density and sinking and floating phenomenon in this study. Students in the traditional classes had the greatest improvement in their ability to accurately explain density qualitatively, which is a precursor to a quantitative understanding.

Student Interview Data for the Task Assessment

Seventeen students (nine in the inquiry group and eight in the traditional group) were interviewed as part of this study. Both a pre- and post-interview was conducted for each student. During the interview, students were asked to do a series of 16 tasks that focused on distinguishing between weight and density. These tasks were grouped into five categories for evaluation: (a) ordering, (b) modeling, (c) sinking and floating, and (d) adding materials. Using the flowchart "Pattern on Task" an overall level of understanding was calculated, ranging from a low of 0 (weight/density differentiation completely absent) to a high of 6 (complete weight/density differentiation). Descriptive statistics for the interview scores can be found in Table 61.

Table 61

Descriptive Statistics for the Student Interview and Task Assessment

	n	Range	Median	*M*	Mode	*SD*	Skewness
Pre-interview							
Inquiry	9	1-4	2	2.44	2	.88	.21
Traditional	8	1-3	3	2.25	3	1.03	-.64
Post-Interview							
Inquiry	9	4-6	6	5.44	6	.88	-1.19
Traditional	8	3-6	5.5	5.25	6	1.03	-1.67
Pre-post Interview Difference							
Inquiry	9	2-4	3	3	3	.71	.717
Traditional	8	0-4	3	3	3	1.31	.752

Learning gains occurred over the course of the intervention, for students who were interviewed regardless of teaching methodology. Pre-interview scores (M = 2.24, SD = .97) were statistically significantly lower than post assessment scores (M = 5.35, SD = .93); $t(16) = 13.78$, $p < .05$. The Hedges' g effect size for the intervention is very large g = +3.20. Students made significant learning gains as a result of the intervention. Figure

53 illustrates the nearly normal distribution of the pre-interview scores for the inquiry group of students and Figure 54 shows the distribution for the traditional group. While the means were similar between the groups, the distribution of the scores for the level of understanding of weight/density differentiation was slightly different, with the traditional group only having students respond at Level 1and 3. Figures 50 and 51 illustrate the post-interview scores for the inquiry and traditional groups, respectively. It can be seen that the distribution of scores varies between the two groups, both having a negative skew and a mode of 6

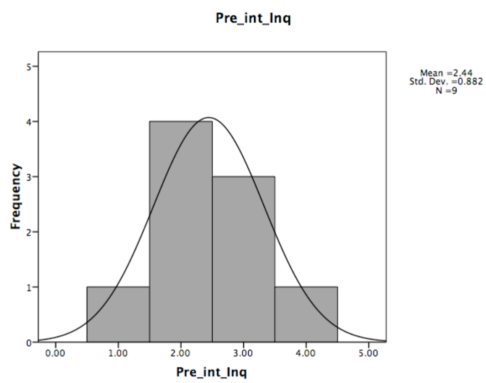


Figure 48. Histogram of Inquiry group pre-interview scores

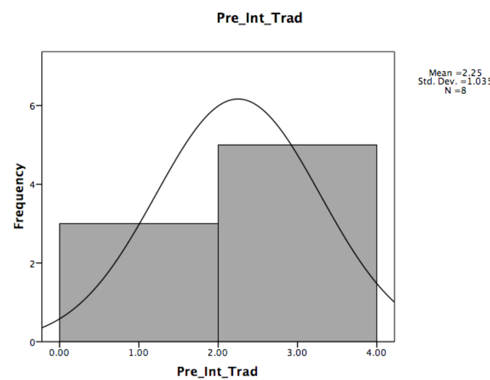


Figure 49. Histogram of Traditional group pre-interview score

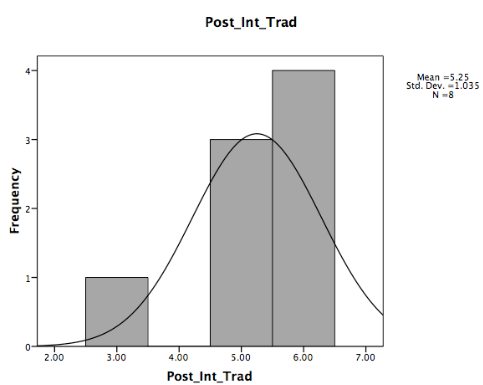


Figure 50. Histogram of Inquiry group post-interview scores

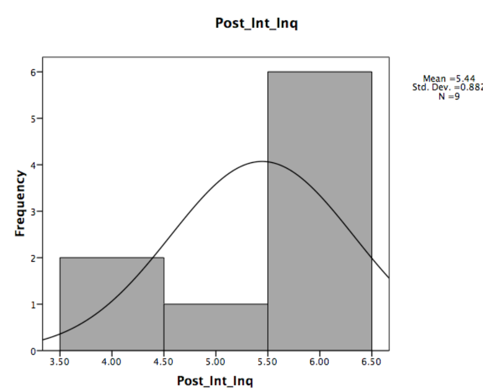


Figure 51. Histogram of Traditional group post-interview scores

Figures 52 and 53 show the histogram of the pre-post score difference for the inquiry and the traditional group, respectively. The histogram for the inquiry group shows a normal distribution with a mode of 3, and the histogram for the traditional group also has a mode of 3, but it shows a distribution with larger range, but with a gap, due to one student who made no gains between the pre- and post interview.

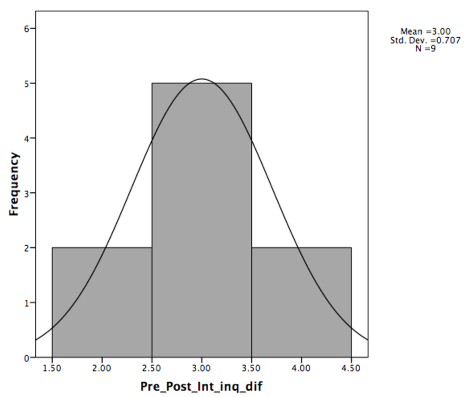


Figure 52. Histogram of Inquiry Group pre-post Score Difference on Interview Scores

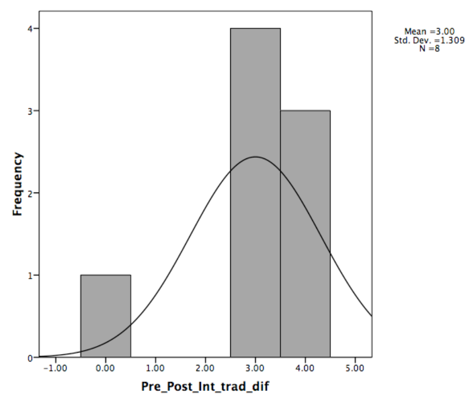


Figure 53. Histogram of Traditional Group pre-post Score Difference on Interview Scores

When data from the student interviews were analyzed using SPSS and an independent samples t-test, there was no statistically significant difference between the students in the inquiry group (M = 3.22, SD = .67) and the students in the traditional group (M = 3.00, SD = 1.31); t(15) = .45, p = .66. The Hedges' *g* effect size for the inquiry treatment was small *g* = +.20. As the error bar plot in Figure 54 further confirmed, the two groups did not differ in their level of responses after the intervention had occurred, as there was a large overlap between the scores of the two groups. The box plot in Figure 55 shows that the distribution of scores differed between the two groups, with the inquiry group having two outlying scores in the low range. While the box plot in the traditional group was heavy tailed in the lower range, it did not show outlying scores for the assessment.

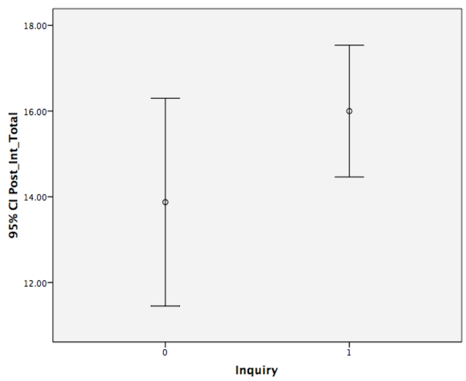


Figure 54. Error Bar Plot of Interview scores for the Inquiry group (1) versus the Traditional Group (0)

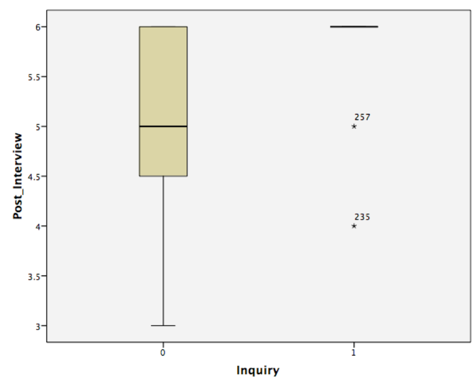


Figure 55. Box Plot of Interview Post-scores for the Inquiry Group (1) versus the Traditional Group (0)

Some interesting observations that were recorded during the interview are discussed in the next section, with the analysis organized by interview task.

Comparing Materials

Two ordering tasks provided interesting insights into students' conceptions of density. The first was the *Paired Comparisons of Density of Material Task*. For this task, students compared 8 pairs of cylinders made of different materials. Forced pairs were: (a) same size, different material, (b) different size, different material, (c) equal weight, different material, and (d) same material, different size. In both the pre- and post-interview, many students chose not to use the digital scale that was provided and decided to "weigh" the objects in their hand, trying to determine if the object was made of a "heavier kind of material." More students did the hand-weighing in the pre-interview, but there were still students who did it in the post-interview.

Comments that students made during the pre-interview include: (a) "When you pick it up, you can feel in your hand if it is heavier; " (b) "I lifted it up, it felt heavier;"

(c) It was heavier, you could tell, it gave more resistance;" and (d) "You can just tell which one was lighter or heavier." Some students used their hand as an initial heaviness test for the comparison and then resorted to the scale, "In my hands it feels heavier, and on scale it weighed more." During the pre-interview, some students also paid attention to shape and material. "Sometimes the color helps you decide, like the gold. The texture you can feel. Weight you can feel it." A few students were very methodical about this task and were able to articulate their thoughts about the difference between weight and density, "If they are the same size and one weighs more and the materials are different, then they have different densities," and "If an object is smaller, but heavier, it has to be more dense."

During the post-interview, students had greater familiarity with the objects, as many of them had been used in both the traditional and the inquiry lessons. They tended to be more specific in their answers and usually referred to the material of the object and used the word density. Comments include: (a) "I can tell by the material – brass is usually heavier for its size than most materials;" (b) "I can tell because it felt heavier that it was denser. Also by the color;" (c) "I can tell if one is smaller in size, but heavier—instead of bigger and lighter. The smaller one is a heavier kind of material;" (d) "Brass is heavier than other objects and more dense. Same thing for copper, a small piece, but heavier kind of material;" and (e) "If it is smaller but heavier, it has to be more dense." Fourteen students completed this task correctly, two students in the inquiry group and one in the traditional group missed 2 out of the 8 comparisons, one each: (a) equal weight – different material and (b) same material – different size. However, all three of these students did complete another paired task for of each of these categories of comparisons correctly.

Mystery Materials

Students were given three cubes that they could see the material of (white plastic, aluminum, and brass) and three cubes of materials that were covered in tape – the mystery objects (copper, wood, and brass). Students were asked for each of the three mystery objects, "Are they made of plastic, aluminum or brass or must they be made of a different kind of material?" Very few students completed this task correctly during the pre-interview. They tried to make a one-to-one match between the mystery cubes and the cubes whose materials they could see, even though the mystery cube was exactly the same size and weighed more or less. Most students opted to not use the digital scale even though it was suggested that they use it.

For the post-assessment, students still matched the cubes in many cases, but after this went one step further and then weighed the objects to see if they had a different weight. For example, when the copper mystery cube was weighed against the brass cube, students saw that it weighed significantly more and said, "this object is different, it is too heavy to be brass." Likewise, when the mystery wood cube was weighed against the plastic cube, students could see that the wood weighed significantly less.

The comparison that confused some students was the mystery brass and the known brass. If they weighed these two objects, the brass cube covered in tape weighed about 2 grams more than the known brass cube, due to the weight of the tape. This confused some students until they accounted for the weight of the tape. Students from the treatment and comparison group performed similarly on this task. Seven inquiry and six traditional students got it 100% correct. Two inquiry students and two traditional students missed one of the mystery cube questions, one inquiry student missed 2 of the 3 cube questions, and one traditional student missed all three of the questions.

Ordering Tasks

After the *Ordering by Weight* task, which most students did correctly during both the pre-and post interview, students were given the same set of 7 objects and asked to order them by density. While many were able to order by weight by using the digital scale, ordering by density was a much harder task, as the students needed to determine relative density through inference. Some objects were the same material, but different sizes/weights; some weighed the same, but were different materials; and some objects were different in material, size, and weight. Most students did not complete this task correctly during the pre-interview. Several did not know what density was, so just repeated the weight ordering. When students were asked, "how did you know where to place them?" students' responses usually referred to the weight of the objects: (a) "I saw what was the lightest and heaviest'" (b) "I felt what was lighter (and had holes in it like wood). Mostly I knew by weight and materials;" (c) "Heavier is more dense." One student grouped objects by shape.

While a few students tried to make size/weight comparisons to approximate relative density, only one student was able to order all objects correctly during the pre-interview. She had a good strategy that was matched by many more students in the post-interview. She used the three cubes (wood, plastic, and copper) to establish parameters of the ordering line. Because they were the same size, weighing them gave her the relative densities. The least dense cube (wood) was put at one end of the continuum, the plastic cube had an in-between density and was put into the middle, and the heaviest cube, which was the most dense (copper) was put at the opposite end of the continuum. As these cubes were all the same size, this was a great strategy. Then she put the rest of the objects in between these cubes. She knew to match the small copper cylinder with the copper cube, and match the large white plastic cylinder with the white plastic cube. These objects had the same density, as they are the same material. This only left two objects to place in order. A black plastic cylinder that was the same weight, but smaller in size than the white plastic cylinder (making it more dense) and a smaller aluminum cylinder that weighed the same as both plastic cylinders, making it more dense than both plastics, but less dense than the copper.

For the post-interview, several students asked for a graduated cylinder so they could determine the volume of the objects and calculate the density. This is the technique that they had used in the density lessons. However, this was not allowed during the interview. When asked, “How did you know where to place them?” one student responded, “By experience and reasoning.” Students in the inquiry and traditional groups performed similarly. Five students in each group correctly completed this task. Two students in the inquiry group and one in the traditional group got 5 of the 7 correct; one student in the traditional and one in the inquiry got 4 of the 7 correct; and one student in the inquiry group and one in the traditional group got 2 of the 7 correct (these students both ordered by weight).

Sinking and Floating Tasks

Students completed several sinking and floating tasks that were designed to uncover misconceptions about density. For the pre-interview, student misconceptions about weight/density identified through this task were the same as those found and categorized on the *Density Qualitative Assessment.* Items that sink: (a) are heavy in weight and (b) have no place for air. Items that float: (a) are hollow on the inside - filled with air (like a ping-pong ball), (b) have unseen pores or pockets of air (like wood), so air molecules help objects to float, (c) have a round shape, (d) are light and have texture, and (e) are long and thin. The most common answer given was “things that float have air hidden inside of them that you can not see” (unless it is hollow) this conception persisted in several student explanations into the post–interview.

During the pre-interview, two students referred to the objects’ density as being important in the determination of sinking and floating behavior. One student said that the density of the object needed to be less than the water’s density of 1 g/mL in order to float and heavier in order to sink. Thirteen students referred to comparison of the object’s density to the density of water during the post-interview. Four students did not, and referenced the weight of the object and air as being the determining factors in sinking and floating; two students were from the inquiry group and two were from the traditional group.

During the post-interview, a few students still said that you could determine floating and sinking by the weight of the object; however, most students said that you need to, “Compare the density to water. It will float if less and sink if more.”

Effects of Transformation on Objects and Materials

For this task, students were given a ball of clay about the diameter of a quarter. Then they were given a small piece of the same clay to add to the ball they were holding. Next, students were asked three questions: (a) “Did I change the amount of clay in the ball (more or less)? (b) Did I change the weight of the ball (heavier or lighter?), and (c) Did I change the density of the ball (denser, less dense)? For the pre-interview, 11 out of 17 answered question (c) "more dense," showing that they had not made the distinction between weight and density. Six of these students were from the traditional group and 5 were from the inquiry group. Only two students during the post-interview answered this question (c) "more dense" and both were from the traditional group.

In summary, while students in both the inquiry and the traditional groups made significant improvement over the course of the intervention in their ability to explain density phenomenon, the interview and task assessment did not uncover a significant difference between the change in the level of understanding between the traditional and the inquiry groups. The interviews afforded an opportunity to document student conceptions of density in detail and to observe student problem solving behavior as they completed a series of tasks. Overall, students were more accurate and faster in completing tasks the post interview. The students familiarity with the objects and materials was greater and may have contributed to their improved performance. Many of the misconceptions that were captured during the interview, were also seen in the qualitative assessment, showing that these misconceptions were pervasive and not just being captured by one assessment.

Comparing the Performance of Seventh versus Eighth Grade Students

One teacher in the study taught two classes of 7th and two classes of 8th grade students, allowing an evaluation of whether there were any statistically significant differences between these classes on their ability to learn density. All this teacher's students received the same inquiry lessons. Previously it had been determined that the classes were not equivalent in terms of their math ability, as the 8th grade students (*M* = 241.80, *SD* = 11.19) outperformed the 7th grade group (*M* = 233.57, *SD* = 8.58); $t(86) = 3.84$, $p < .05$ on the OAKS Math Performance Assessment. When the pre-post assessment was compared using an independent samples *t*-test, the only statistically significant difference between the groups was found on the Scientific Inquiry Assessment, where 8th grade students (*M* = 2.20, *SD* = 1.31) statistically out performed 7th grade students (*M* = 1.57, *SD* = 1.27); $t(86) = 2.26$, $p < .05$. The Hedges' effect size for grade on the performance of students on the inquiry task was found to be moderate $g = .49$. On none of the other three pre-post assessments (Density Task, Density Assessment, and Density Qualitative Assessment) did the 8th grade students statistically out perform the 7th grade students. Results for these *t*-tests can be found in Table 62.

The Hedges' *g* effect size for grade level effect each of these tests is small to very small. This indicates that for these assessments for the Density Unit that 7th and 8th grade students were performing similarly.

Table 62

Comparing Seventh and Eight Grade Classes on Three Density Assessments

	M	*SD*	*t*	*df*	*P**	*g*
Density Assessment						
Seventh Grade	10.67	5.15	.98	86	.33	+.21
Eighth Grade	11.85	6.08				
Density Task Assessment						
Seventh Grade	1.79	1.35	.30	86	.77	-.06
Eighth Grade	1.70	1.47				
Density Qualitative Assessment						

Seventh Grade	8.59	4.74	.79	86	.43	+.17
Eighth Grade	9.35	4.15				

• = alpha adjusted for multiple testing (α = .10/3 = .033) to maintain the probability of Type I error at .05

Fidelity of Implementation

As reported previously, all teachers took exactly 19 school days to teach the Density Unit. This timeframe included the administration of the lessons as well as the pre- and post- assessments. Teachers 1, 2, and 3 taught the Density Unit before Spring Break and Teachers 4 and 5 taught it right after Spring Break in 2011.

Each teacher was asked to complete a self-reflection rubric on the day that they taught their lesson. There were four sections for teachers to comment on: (a) Lesson Plan, (b) Materials, (c) Timing, and (d) Difficulty. Teachers rated the *Lessons Plan* and *Materials* sections using a two-point scale: (a) 1 = completed as written, (b) 2 = made minor modifications. If teachers responded with a 2, they were asked to explain what they added or removed. The *Timing* section had three levels of response: (a) the length of time fit my class, (b) lesson was too short, or (c) lesson was too long. The *Difficulty* section also had three levels of response: (a) the difficulty was appropriate, (b) the lesson was too difficult, or (c) the lesson was too easy. All teachers completed all self-reflections for the lessons that they taught. The averaged results for each teacher for these four sections are shown in Table 63. In general, there was not much difference in the average scores between the inquiry and the traditional group on evaluation of the their implementation of lessons. The largest difference was seen in the lesson plan category, where the inquiry group reported an average score of 1.16 and the traditional group reported an average score of 1.45.

Table 63

Average Scores for Teachers' Self-Reflections on Lesson Fidelity of Implementation

Teacher	Inquiry	Lesson	Materials	Timing	Difficulty
1	Yes	1.00	1.00	1.65	1.00
2	No	1.14	1.00	1.00	1.00
3	Yes	1.00	1.00	1.25	1.25
4	No	1.75	1.00	1.63	1.25
5	Yes	1.50	1.12	1.50	1.00
Inquiry (average for all teachers)	Yes	1.16	1.04	1.47	1.08
Traditional (average for all teachers)	No	1.45	1.00	1.32	1.12

Teacher 4, a traditional teacher, reported modifying 6 out of 8 lessons. The comments on the self-reflection were: (a) Lesson 1- For periods 2 & 6, I poured some honey in a beaker to use as "an unknown substance" for the opener. We did not write down the answers on the board. We just discussed them. We also discussed what is not matter. It took a class and a half to complete; (b) Lesson 2 - Part D was pretty confusing for kids, so I had to help them to arrive at the correct answer; (c) Lesson 3 - I was unable to use the video, so I used a clip of YouTube: Eureka Episode 26: Buoyancy; (d) Lesson 4 - Question #4 was confusing for my kids. We had to spend time reviewing in order to get solid understanding; (e) Lesson 5 - We had worked with TBBs before so I projected the worksheets for quick answers as opposed to making copies; (f) Lesson 6- I wrote questions on the overhead for students to answer as they read. I did the reading and parts A-D in class. E & F were homework. The HW page was assigned the following night.

Teacher 2, a traditional teacher, reported modifying one lesson. The comment on the self-reflection was: (a) Lesson 5- did not do the triple beam balance activities. I liked the reading activities though I think they should have had to write answers to the questions after they read and keep those in their folders for future reference.

Teacher 5, an inquiry teacher, reported modifying four out of eight lessons. The comments on the self-reflection were: (a) Lesson 1- It took the kids longer to make and complete the table. The difficulty was just right for most students. Good lesson to introduce chemistry; (b) Lesson 4 - I couldn't find the large wooden balls, so I got my own. Needed additional time; (c) I did not complete exploring volume page - we did this at the beginning of the year. My students thought the overflow method was challenging and they enjoyed doing the activity; and (d) Lesson 6 - The sub did not give the density reading to students and I forgot to as well the next day.

Although two of the three inquiry teachers did not reflect that they had made modifications, Teacher 1 made some comments worth reporting: (a) "Lesson 2 - *Materials comment*- Oops I did not see the separate kits for floating logs, I had my students use the wood sticks in the main bags instead. *Timing comment*- We didn't have time to go over the analysis questions in class. We will review at the start of the next period. Kids finished the last analysis at home. They struggled with choosing items to test. Many groups wanted to test everything. A lot of the students got hung up on the warm-up question and what % of object is above water. They were confused when sticks didn't float 50% out of the water; (b) Lesson 3 - Kids spent a long time trying to make the neutrally buoyant object. They didn't finish the 2nd side in class. They loved this lesson. High engagement. Also 7th grade students are currently studying ratios in math so it was a good connection for them; (c) Lesson 4 – *Materials comment*- Didn't use crayons, small plastic pieces (not enough time). Students did well with this lab but had a hard time remembering to write observations on the lab sheet; (d) Lesson 6 – *Materials comment* - The 250 mL and the 100 mL grad cylinders are really off. Kids are getting answers that are >10mL different from the measurement with rulers. *Timing comment*- Groups at all different places/ speeds. This lesson felt too long. Kids were really off task in 8th grade and I stopped them before everyone finished. We moved onto next lesson for management reasons; (e) Lesson 7 –*Difficulty comment* - 8th grade - moved through the lesson much faster. Math skills or maturity of kids? 7th - forgot to pass back Comparing Cubes. This lesson took longer than I thought it would. Not sure if that was due to math skills of groups or their focus or what; and (f) Density of Liquid lab - Kids excited to do labs. (density of liquids lab) - The kids were kind of stumped to how to find volume. More than 1 group talking about water displacement and trying to add liquids together."

Summary

To summarize, there were mixed results in this study, with students in the inquiry group generally out-performing students in the traditional methodology group. Analysis occurred at three levels. When the learning gains for students who were assigned to the traditional methodology were compared to students who were assigned to the inquiry methodology, without regard to teacher or class, there were no significant differences for the Density Assessment, Density Task, and the Student Interview and Task Assessment. For the Qualitative Assessment and the Scientific Inquiry Assessment students in the inquiry group had statistically larger learning gains. When the analysis was performed at the matched teacher level, students in inquiry outperformed students in traditional classrooms. When the analysis was performed at the class level, students in high math classes had statistically larger learning gains with the traditional methodology, and students in low math classes had greater learning gains in an inquiry methodology. When a multi-level model was used to account for the nested structure of the data, it was found in the inquiry group students with the lowest math scores had the greatest learning gains, and in the traditional methodology the students with the highest math scores had the greatest learning gains. This cross level interaction was a major finding of the study.

Students' content and conceptual understanding of density improved over the course of the density unit, with students in both groups making statistically significant learning gains, moving away from misconceptions on density to accurate conceptions. Students in the traditional classes made the greatest learning gains at the qualitative level of density explanation, and more students in the inquiry group had a quantitative understanding of density at the end of the study than students in the traditional group.

CHAPTER VI

DISCUSSION

Major Findings

The results of this study demonstrated that overall student understanding and conceptions of density improved over the course of the intervention period, regardless of teaching methodology. This inference is supported by the large effect sizes seen for the pre-post gains seen for the four density assessments: (1) Density Assessment $g = +1.89$, (2) the Density Qualitative Assessment $g = + 2.10$, (3) the Density Task Assessment $g = +1.47$, and (4) the Student Interview and Task Assessment $g = +3.19$. It is also supported by the statistically significant learning gains as determined by independent samples *t*-test analysis. These findings follow the research completed by Smith et al. (1985, 1986, 1987, 1997), Kang et al. (2005), Hitt (2005) and Penner and Klahr (1996) who reported statistically significant learning gains for students when density was taught for conceptual understanding.

One advantage of the current study over these other studies was the relatively large sample size, the ability to match students for analysis, the number of varying assessments that included both qualitative and quantitative analysis, the comparison of two different teaching methodologies, and the analysis of the effect of students' math levels on learning gains within the methodologies. This study attempted to offer a comprehensive a look at how 7th grade students learn density.

A major strength of the study was that multiple pre- post- assessments were used to measure student learning gains. Using a variety of assessments to gain insight on the different aspects of learning was warranted. It also provided a rich body of observations and data that may help researchers understand how children learn complex abstract topics. The use of multiple assessments was modeled after Smith et al. (1987 & 1997) who used both student interviews and pre-post written assessments to analyze student learning gains on density. Each assessment was targeted to a different aspect of density learning.

Teaching to misconceptions and building qualitative then quantitative knowledge has been shown to be effective in other research studies (Hitt, 2005; Smith et al. (1985, 1996, 1987, 1997); Lee et al., 1990; Penner and Klahr, 1996) and it was fundamental to this dissertation study. The deliberate identification of the major misconceptions of density as found in the literature (Smith, 1987; Hitt, 2005; Keeley, 2011) was the basis for the lesson design and informed the assessment questions. Lessons 1 – 6 built student qualitative understanding of density, until finally in Lesson 7 the density formula was introduced and then used for the remaining lessons and the 3 quantitative crime solving labs, building quantitative knowledge. The model that was used for both lesson development and student assessment of learning gains is illustrated in Figure 56. All three of the aspects of student understanding of density shown in the model were analyzed for student learning gains.

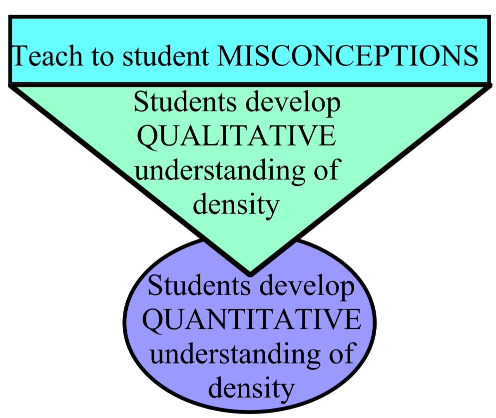


Figure 56. Model used for lesson and assessment development

One of the major misconceptions that students held prior to the intervention was the inability to distinguish between weight and density. The study was designed to address the weight/density misconception in both the treatment and comparison conditions. The Density Qualitative Assessment and the Student Interview and Task Assessment measured students' change from a weight-only view of density to a complete density and weight distinction. The results allow for an inference to be made that students in both groups made significant learning gains in their level of understanding, increasing their ability to make a weigh/density differentiation. These results mirror those found by Smith (1986) where 7th grade students made statistically significant learning gains in their ability to differentiate weight and density.

Other naïve conceptions about density were held by students prior to the intervention. These conceptions were captured in detail in the Density Qualitative Assessment where misconceptions were extensively coded and frequencies analyzed. Students in both conditions moved from having a large variety of inaccurate explanations for why objects sink and float to fewer, more accurate, explanations. Hewson and Hewson (1983) also found that when a unit on density was taught to students that was designed to promote conceptual change through experimentation and demonstrations, that students misconceptions were reduced.

One of the most pervasive misconceptions that remained after the intervention was the belief that heavy object sink and light objects float. This outcome was also seen by Smith (1987). Penner and Klahr (1996) stated that the most pervasive misconceptions about sinking and floating are hard to dispel even when middle school students have direct evidence to the contrary. Osborne and Cosgrovr (1983) also reported that students can retain their naïve views after instruction. Multiple opportunities for cognitive conflict must be provided to students who are undergoing conceptual change (Guzzetti et al., 1993). While this was done within the lessons for this study, for a few students, providing cognitive conflict was still not enough.

Coding student explanations and calculating their frequencies allowed the learning gains to be statistically analyzed using *t*-tests. In these analyses, it was found that students made statistically significant progress from predominately inaccurate explanations of sinking and floating phenomenon to accurate qualitative explanations.

While both methodologies were able to statistically significantly move students away from having misconceptions. It was found that students in the traditional methodology progressed predominately to qualitative explanations of density. Fewer students in the traditional methodology progressed to quantitative explanations. Students in the inquiry methodology made the greatest gains in their quantitative explanations. The potential effect of the difference in methodologies in progressing students to different endpoints in their understanding of density was a unique finding of this study.

Another area of growth in density understanding that occurred for both the treatment and the comparison conditions was the ability to complete the authentic task of calculating the density of three objects, as measured by the Density Assessment. Prior to the intervention, most students could not complete this task and did not even know how to begin. After the intervention, most students were able to successfully complete the task of calculating the density of three objects and accurately determine if the objects were made of similar materials. Students' pre- post- skill and performance levels for this task were analyzed and broken down into 11 skills and 18 performance levels. The detailed rubric that was developed as part of the study can help teachers formatively assess where their students are on the continuum of skills needed to make an accurate density calculation in an authentic task. This continuum of understanding of density as a task was also a unique contribution of this study.

Figure 57 provides a flowchart summary of the significant findings of the study. It includes: (a) the statistically significant outcomes of the four pre-post assessments (Density Assessment, Density Qualitative Assessment, Density Task, and Scientific Inquiry Task), (b) the three study levels (full study, matched teacher, and matched class), and (c) the different statistical tests that were run (*t*-test, HLM).

At the full study level, 50% of the analyses showed the inquiry group with statistically larger learning gains than the traditional group and 50% of the analyses showed no difference. Possible explanations for the lack of a statistical difference for student learning gains between the two methodologies for the Density Assessment and the Density Task will be discussed later in the paper. At the full study level, unavoidable biases in sample selection could not be corrected statistically, so results need to be interpreted with caution.

For 100% of the analyses run at the matched teacher level, the inquiry methodology had the largest student learning gains as measured by independent samples *t*-tests. Teachers were matched for student pre-test scores and ODE math performance. The effect size of the inquiry teaching methodology was moderate varying for the Density Assessment from $g = +.50$ for the same school comparison to $g = +.45$ for the different school comparison. The Density Task showed higher effect sizes at $g = +.62$ for the same school comparison to $g = +.54$ for the different school comparison. The finding that the inquiry methodology was associated with higher student learning gains is in line with a growing body of research (Backus, 2005; Berg, Bergendahl, & Lundberg, 2003; Bybee & Van Scooter, 2007; Echevarria, 2003; Geier et al., 2008; Krajcik et al.,1998; Krajcik et al., 2000; Lee, Buxton, Lewis, & LeRoy, 2006; Liu, Lee, & Linn, 2010; Marx et al., 2004; McCarthy, 2005; Schroeder et al., 2007; Singer, Krajcik, & Chambers, 2000; Songer, Lee, & Kam, 2002; Wise, 1996).

In addition to higher density learning gains, students in the inquiry teaching methodology for the matched teacher comparisons also had large effect sizes on the Scientific Inquiry Task where students' ability to communicate collecting and presenting data was measured, g = +.77 for the same school comparison and +.89 for the different school comparison. It was not unexpected that students in the inquiry group would score higher on creating data tables, recording data, and showing and describing their density calculations. The inquiry unit provided students with multiple opportunities for designing experiments and creating data tables to collect and organize their data. The opportunity to organize and report data was throughout the inquiry unit and was not embedded in the traditional unit where students filled in pre-made data tables. This may be one explanation as to why the inquiry methodology had a large effect on student performance as measured on the Scientific Inquiry Task post-assessment. Gengarelly & Abrams (2009) reported similar results with students, reporting that inquiry allowed students to experience how scientific knowledge was constructed and allowed them to build working understandings of how the scientific discipline worked. By assessing for the skill separate from the content it can be seen that the skill gains were greater than the content gains for students in the matched teacher comparisons.

	Density Assessment	Density Assessment	Qualitative Density Assessment	Density Task	Scientific Inquiry Task
	t-test	HLM	*t*-test	*t*-test	*t*-test
Full Study	No difference	NA	Inquiry	No difference	Inquiry
• Qualitative	No difference	NA	Traditional	Traditional	NA
• Quantitative	No difference	NA	Inquiry	Inquiry	NA
• High Math	NA	Traditional	NA	NA	NA
• Low Math (Novice)	NA	Inquiry	NA	Inquiry	NA
	t-test		*t*-test	*t*-test	*t*-test
Matched Teachers	Inquiry		NA	Inquiry	Inquiry
• Qualitative	Inquiry* 1/2		NA	NA	NA
• Quantitative	Inquiry		NA	NA	NA
	t-test		*t*-test	*t*-test	*t*-test
Matched Classes High Math	Traditional* 1/3		NA	Traditional* 1/3; Inquiry* 1/3	Traditional* 1/3
Matched Classes Low Math	Inquiry		NA	No difference	Inquiry
	t-test				

Matched Classes High Math	
• Qualitative	Traditional* 1/3
• Quantitative	Traditional* 2/3
Matched Classes Low Math	
• Qualitative	No difference
• Quantitative	Inquiry

• = not all matches showed significant results. Fraction indicates number of classes out of total that were significant; all means for the group followed pattern. NA = no test run

Figure 57. Results Flow Chart of Major Findings of the Investigation

When analyzing results from three pre- post-assessments for the qualitative understanding of density at the full study, matched teacher, and matched classroom level, the results showed an interesting trend. While 27% of the analyses showed that students in the traditional methodology had statistically larger learning gains, 64% showed no difference, and 9% indicated that inquiry was the methodology associated with the largest learning gains. For the quantitative understanding of density, 64% of the analyses showed the inquiry approach had improved learning outcomes while, 18% of analyses showed no difference, and 18% showed the traditional group was associated with the largest learning gains. This may be explained by the fact that both methodologies taught the qualitative aspect of density in great detail devoting 6 lessons to this aspect of density. The higher order thinking skills involved with an inquiry methodology (Afra, Osta, & Zoubeir, 2007) may allow students in inquiry to advance to a greater understanding of the quantitative aspects of density. This is an area of new research.

When looking at effect sizes for qualitative versus quantitative understanding of density as measured by student learning gains on the Density Assessment a more complex pattern emerges. For matched teachers, the effect size for both questions types was small, with the smallest effects being seen for the qualitative questions for the same school ($g = +.37$) and the different school comparisons ($g = +.27$). The effect size for the quantitative questions was slightly larger with the same school effect size at $g = +.48$ and the different school comparison at $g = +.37$. Please note that the matches at the same school involve students who are nearly identical in makeup for all demographic factors. Student populations at the different schools are more diverse. As a result, other factors besides those introduced by the intervention may be contributing to the difference in results. See Figure 58 for the *t*-test patterns (shown in color) and the effect sizes when comparing same school and different school outcomes for qualitative and quantitative questions on the Density Assessment.

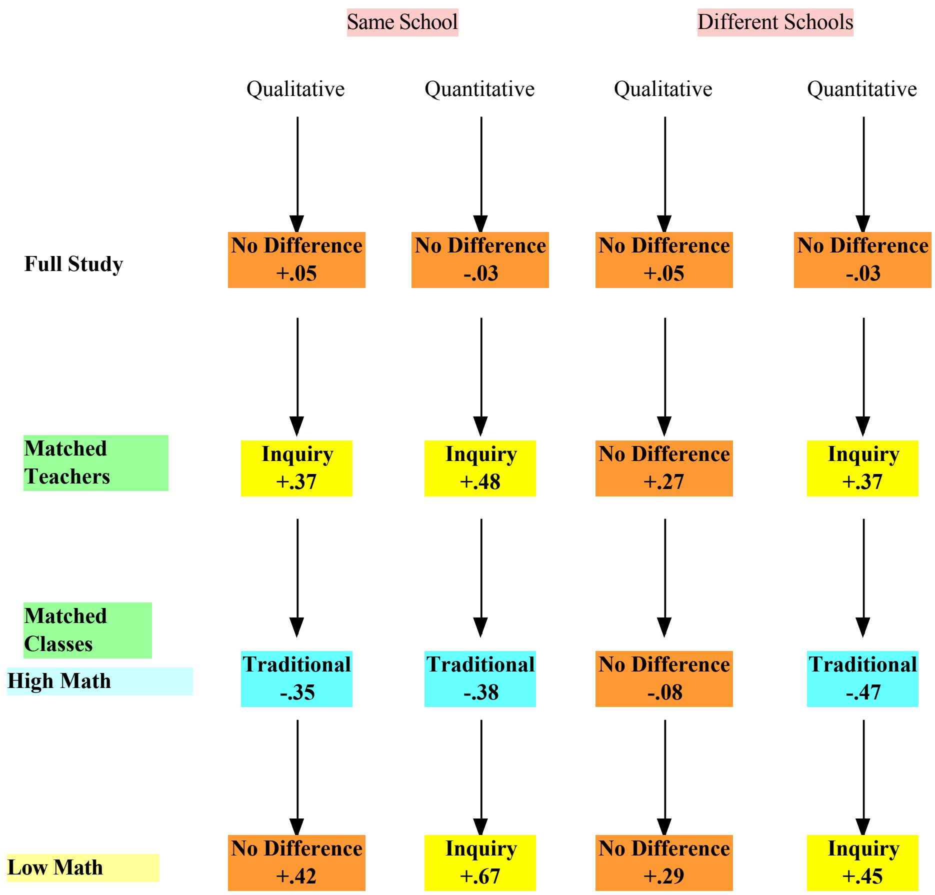


Figure 58. Qualitative versus Quantitative Patterns for Same Schools and Different Schools by Analysis Level. T-test patterns shown in color. Yellow= inquiry was statistically significant, blue= traditional methodology was statistically significant. Orange= no methodology was statistically significant. Effect sizes are shown in the colored boxes.

When looking at matched classes and at high and low math, a different pattern emerges. The effect size for both qualitative and quantitative questions on the Density Assessment was positive for low math classes and negative for high math classes. For every comparison, the effect size for the quantitative questions was greater than the effect size for the qualitative questions. The possibility that math may influence the effectiveness of a methodology for a specific question type warrants further investigation.

Performance on the Qualitative Density Task and the Density Task also support the inference that there was an effect of methodology on student's learning gains when the level of understanding of density was considered with students in the inquiry treatment moving to the highest level of understanding (the quantitative level). It was also interesting to note that students who were in high math classes were able to develop a quantitative understanding of density, regardless of teaching methodology. Smith (1985) also found that students in higher math classes had greater learning gains and understanding of density. Putting these two results together, it may suggest that the inquiry methodology might act as a mitigating force, assisting students who do not have a strong mathematical background in developing a deeper understanding of density.

At all levels, 58.8% of the analyses showed that students with high math ability had improved outcomes in the traditional approach; the remaining 41.2% showed no difference. Conversely, 76.9% of the analyses showed that low math students had improved outcomes with an inquiry approach and 23.1% showed no difference. The interaction of math ability and learning outcomes for density was seen in all assessments where student data were analyzed by prior math level, lending strength to the inference that students' math level affected their performance within a teaching methodology. The HLM multilevel analysis demonstrated that students in the traditional methodology with the highest OAKS math scores had the largest learning gains on the Density Assessment while students in the inquiry methodology with the lowest OAKS math scores had the largest learning gains.

Inquiry versus a Traditional Teaching Methodology

Quantitative Data

In this section, the findings related to the quantitative data are discussed, organized by data source.

Density Assessment

Selection bias. Although an independent samples *t*-test at the full study level for the Density Assessment showed no statistically significant pre-post learning gains for students in either teaching methodology, these results cannot be easily interpreted. The lack of significant results may have been influenced by the confounding variable of student math performance that was uncovered during the analysis. Students assigned to the inquiry group had a statistically significantly higher mean performance score on both the OAKS Math Performance Assessment ($M = 235.81$) and the Density Assessment pre-test ($M = 16.24$) prior to the intervention relative to the traditional group (OAKS Math, $M = 229.81$; Density pre-test, $M = 14.03$).

Statistically non-equivalent math ability between the two groups may have introduced a bias into the sample. Kang, Scharmann, Noh, and Koh (2005) found that logical thinking ability was a statistically significant predictor of success in the conceptual understanding of weight/density differentiation. Higher math ability may be associated with logical reasoning (Merrotsy, 2008), and may be advantageous to learning an abstract concept like density that uses a formula to calculate a quantitative value.

Demko, Ventre, and Lester (1985) found that scores in math were significant predictors of grades in chemistry, while House (1993) found that a minimum set of mathematical skills was necessary for passing an introductory course in chemistry.

The confounding variable of math performance was not discovered until after the study had been completed, when the researcher was given the 2011 OAKS math scores for the students in the study. The sampling had been balanced for the demographic factors to which the researcher had access prior to the study, including the frequency of students who were identified as talented and gifted (TAG), in special education (SPED), English language learners (ELL), and of Hispanic and non Hispanic ethnicities.

In the school setting where this study occurred, random assignment of students to a teaching methodology condition was not possible, as students needed to stay with their administratively assigned teachers. In a pilot study conducted by Holveck in 2007, teachers taught both methodologies, and treatment diffusion was thought to have occurred. As a result, for this study teachers were assigned to teach only one methodology in order to reduce the potential for treatment diffusion. For fidelity purposes, it was important to have teachers who were proficient in the teaching methodology they delivered to students. Songer (2002) and Liu, Lee, and Linn (2010) found that teacher experience and training with inquiry were important contributing factors to improved student outcomes in inquiry. With this research design, it was hypothesized that students would be given the highest quality instruction so that differences in student outcomes would be more likely attributable to the treatment and not to the teachers' ability or inability to deliver a specific methodology. Because teachers were assigned a methodology based on their teaching strength and preference, a statistically significantly higher score for the OAKS Math Performance Assessment for students in the inquiry group was not expected.

Equalization of sample. To increase the internal validity of the study and to bring greater confidence to the inferences that can be drawn from the data, an equalization approach was used. Differences in prior math performance were accounted for by matching an inquiry and a traditional teaching methodology teacher for mean student performance on the OAKS Math Performance Assessment and Density Assessment pre-test scores. This modification increased the homogeneity of the student populations being compared for learning gains (Babbie, 2007). Once identified, the relationship between teaching methodology and student understanding of density could be evaluated with greater validity. For all matched teachers, student learning gains on the Density Assessment was shown to be larger in the inquiry classes.

One disadvantage of matching at the teacher level was the resulting reduction in sample size from 479 students in the full study to 202 in the matched teacher comparisons. The reduction occurred as one inquiry and one traditional teacher were not able to be matched with any other teacher in the study based on their students' mean math ability. The reduced sample size has the potential to inflate sampling error (Babbie, 2007) and to decrease the generalizability of the study.

In order to identify equivalent groups for comparison, matching was also done at the class level. The rationale for matching at the class level was that each teacher in the study had science classes that had unequal distribution of students by math ability. This between-class variation in student math ability occurs as an artifact of a high-level math class being taught on a middle school team, thus affecting the composition of other classes on that team. As a result, when high-ability math students are in their advanced math class, the students in the science class tend to have a lower than average math performance ability.

Independent *t*-tests were used to identify classes that could be matched on OAKS math score. Identified classes were designated as either high or low math classes. For the matched comparison by class, high math classes were only compared to other high math classes and low math classes were only compared to other low math classes. The total number of student participants used in the class level matched analysis increased from the teacher-match to 353 students. Although the matched sample populations were more homogeneous on prior math performance, thereby enhancing internal validity, the tradeoff was a generalizable statistical analysis.

For the Density Assessment, the pattern that emerged for matched classes was: (a) students in the lower-performing math classes performed statistically better in the inquiry methodology, and (b) students in the high math classes performed statistically better in the traditional methodology. An HLM multilevel analysis at the full study level supported the results that were seen with the independent samples *t*-test for matched classes: Students with low math scores in the inquiry condition were shown to outperform their traditionally instructed peers, while students with high math scores in the traditional condition were shown to outperform their peers in the inquiry teaching methodology. This same pattern was repeated in the Density Task Assessment, for both the Density Task and the Scientific Inquiry Task. High math class students doing better in a traditional approach is supported by the findings reported by Baldwin and Coleman (2000), who showed that students who are academically gifted benefit from task-focused instructional practices where the emphasis is on mastery of clearly-defined tasks as seen in traditional teaching approaches.

Teacher effect. One question that could be asked is, "Are the HLM multi-level analysis and the *t*-tests measuring student performance or a teacher effect?" The best way to answer this question is to look at the same school comparisons where the high and low math classes for Teacher 2 are compared to those of Teacher 3. For these two teachers, the high math classes for traditional Teacher 2 performed statistically significantly better than the high math classes for inquiry Teacher 3. Conversely, the low math class of inquiry Teacher 3 outperformed the low math class of traditional Teacher 2. This finding lends strength to the inference that it is not a teacher effect that is being measured. If there were a teacher effect, then the expected outcome would be that for both the high and low math students, one teacher's set of classes would outperform the other's.

Ceiling effect. One explanation for the lack of statistically significant results at the full study level for the *t*-test analysis may be that a ceiling effect occurred. This would be a Type II error. When looking at the histogram of score distributions for the post-test, the mode was at the highest score level possible, 32 points on a 32-point assessment. A review of the frequency of score distribution shows that 17.1% of participants had a perfect score of 32 points. Figure 59 illustrates that the ceiling effect may have affected the inquiry group but not the traditional group for this assessment. Having a potential ceiling on the learning gains of the students may have reduced the ability of the assessment instrument to distinguish between the top performers, especially those who started out performing statistically significantly higher on the pre-test—the inquiry students. Because the ceiling effect may be impacting the dependent variable of post-test score, it cannot necessarily be concluded that the independent variable of teaching methodology had no relationship with student outcomes (Cramer, 2005) for the Density Assessment at the full study level where no significant difference in teaching methodology was observed.

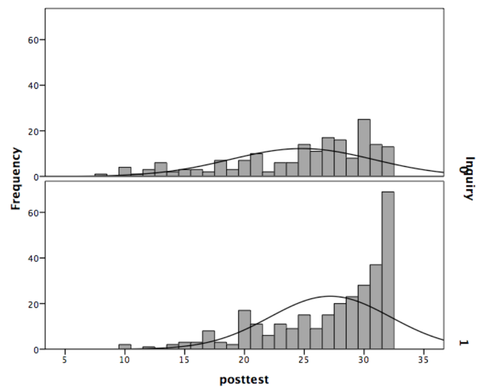


Figure 59. Ceiling Effect on the *Density Assessment* Post-test for Inquiry (1) versus the Traditional Group (0)

Seventh versus Eighth Grade Students

It is interesting to note that while the 8th grade students had significantly higher scores on the OAKS math performance and were a year older in grade and math level, they did not outperform their 7th grade counterparts on any assessment that measured density knowledge. When compared to other classes for math level, both of these classes would be characterized as high math classes. Previously in the analysis, the 7th grade class was compared to an equivalent 7th grade high math class that was traditionally taught. It was found that the traditional class had higher learning gains. There were no traditional 8th grade classes in the study against which to compare teaching methodologies.

It is worth noting that Teacher 1 has some special instructional circumstances, related to way in which classes are structured at the school, whereby this teacher retains the same students for both 7th and 8th grade. The project-based curriculum that is taught is rotated every other year. Each year, both the 7th and 8th grade students get the same curriculum, and the following year they get a different curriculum, rotating back and forth between 8th grade learning targets one year and 7th grade learning targets the next. Because of these special circumstances, the two classes of 8th grade students for Teacher 1 may not have had a density unit when they were in the 7th grade. This arrangement may help explain why the 7th and 8th grade classes had no statistically significant differences in pre-test scores. The finding that students in these two grades did not differ on their post-test performance was somewhat surprising, as most research on student conceptual understanding of density, including Smith et al. (1987), has found that students' grade did have an effect on their understanding of density. Previous researchers have posited that students in higher grades are generally able to think more quantitatively about density, which is an abstract non-observable property of matter (Hitt, 2005). It is unclear from the current study whether the finding that 8th-grade students did not significantly outperform 7th-grade students is a result of the specific teaching structure and rotating two-year curriculum used by Teacher 1, or perhaps an indication that one year's difference in grade level, in and of itself, is insufficient to cause a detectable difference in student ability to understand density.

Density Task Assessment

Density task. For the Density Task, there were no statistically significant differences between the two teaching methodologies at the full study level. At the teacher level, the inquiry methodology had statistically significantly better student outcomes than the traditional teaching methodology. At the class level, for two out of three classes matched for high math performance, the traditional group did better. For one of two classes matched for low math performance, the inquiry group did better. These results are similar to those found for the Density Assessment.

When the students were scored for the Density Task on the continuum of understanding of density, which had 18 performance levels instead of five, a slightly different pattern emerged. The refinement of the rubric allowed greater precision in assigning students to a level of proficiency. Greater learning gains were found at the novice level for the inquiry students, which supported previous findings of an inquiry methodology performance advantage for students with lower math scores. There were no differences between the inquiry and traditional groups at the *working towards* and the *nearly proficient* level. There were greater gains for the traditional students at the *proficient* level, but at the highest level, there were greater gains for the inquiry students.

In order to explore the possibility that the original rubric might not have been capturing the learning gains of the students at the highest level, a histogram that shows the score distributions for the *Density Task* post assessment prior to the adjustment to the rubric was created. In Figure 60, it can be seen that although the maximum score of five was achieved by more students in the inquiry group than in the traditional group, there does not seem to be a ceiling effect at the full study level.

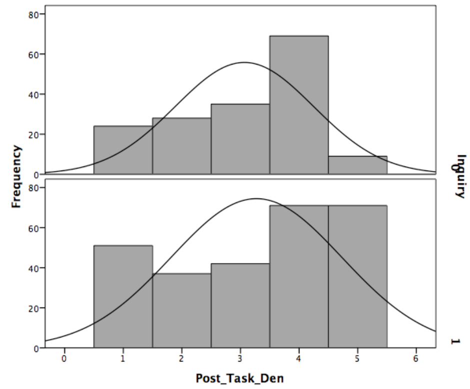


Figure 60. Histogram of Density Task comparing the post-test scores for the inquiry group (1) and the traditional group (0) *Density Task Assessment*

Another explanation might be that the continuum was more accurate in classifying student performance at the lower levels, and this allowed a more accurate calculation of the pre-post score difference.

Scientific inquiry task. The second assessment within the Density Task Assessment is the Scientific Inquiry Task. The results for the Scientific Inquiry *Assessment* show that students in the inquiry teaching methodology outperformed students in the traditional methodology at both the full study level and the matched teacher level. At the matched class level, the same pattern was seen as in the other density assessments. The two classrooms matched for low math performance had statistically better results for the inquiry methodology and one out of the three high-performing math classes had statistically significant better results for the traditional teaching methodology. It is interesting that a non-density, non-math based assessment would show the same pattern on this task as the other assessments with quantitative components. It would seem that the students who have been in the inquiry classrooms would do better on this assessment regardless of math level, as there is no math component in communicating procedures. Although there is some implied math knowledge in setting up a data table, students in the inquiry classes would have had much more experience doing this as part of the intervention.

Nonetheless it can be argued that reading ability might be more closely associated than mathematical ability with the ability to communicate in writing the steps of a procedure. As classes matched for math were also matched for reading, the results suggest that a teaching methodology's effectiveness may vary by a student's reading and math abilities. Students in both classes did have exposure to procedures and data tables that were part of the assessment. The only difference was that students in the inquiry group were asked to construct data tables independently while the students in the traditional classes had the data tables produced for them as part of the laboratory worksheet.

Qualitative Density Assessment

The *t*-test results for this assessment showed that students in the inquiry teaching methodology outperformed students in the traditional methodology. While performance on the assessment prior to the intervention did not show any statistically significant differences between the groups, these data need to be interpreted with some caution. Only two out of five teachers in the study gave this assessment before and after the intervention. The result was that only 179 students contributed data to the analysis of outcomes for this assessment. As the reduced number of students is due to teachers not giving the post-assessment and not to participants dropping out of the study, the internal validity threat of attrition is not a factor, although another threat to validity, that of teachers self-selecting to omit an assessment that was intended to be part of the study, was introduced. Even with the smaller sample size, it can be seen in Figure 61 that the pre-post test score differences were normally distributed for both the inquiry and the traditional groups, allowing some confidence in the inference that the inquiry methodology may have helped students perform better.

However, as mentioned, there is a validity threat to program adherence with teachers self-selecting to omit an assessment that was part of the study. Teachers who did not give the assessment justified their decision by saying that having three pre-post measures took up too much class time and that was why they had omitted it. This decision to omit an assessment created within the study two sets of teachers for each methodology, those who gave the assessment and those who did not. The loss of the control of this variable reduces the ability to accurately interpret student learning gains, as the assessment was a potential learning experience that could have affected student outcomes.

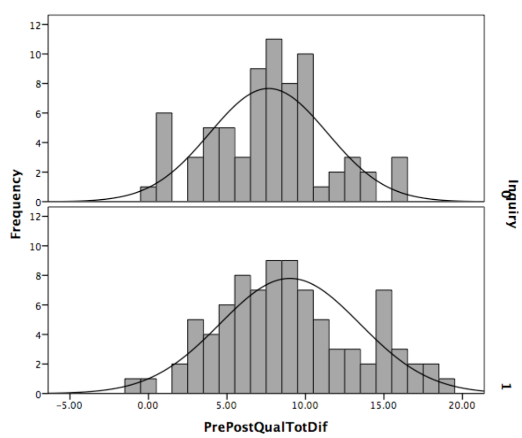


Figure 61. Histogram of pre-post score difference for inquiry (1) and traditional (2) groups for the *Density Qualitative Assessment*.

Even though the inquiry and the traditional group had no statistical differences on the *Qualitative Density Assessment* pre-test prior to experimentation, results that compare the two teaching methodologies must also be interpreted with caution. This is because these classes were not able to be matched for math prior to the assessment, and there are significant differences between the groups in terms of their math ability. Given the limited number of teachers completing this assessment, no matches for math ability could be made at the teacher or class level. The strength of the conclusions is thus weakened.

For the Qualitative Density Assessment, students did not have to calculate their answers using formulas or equations. However, students did need to give an explanation that was quantitative in nature to receive the highest score. An example of a quantitative answer to the question “Can objects that float in water, sink in another type of liquid?” would be, “Liquids can have different densities. The density of water is 1.0 g/mL and the density of mercury is 5.43 g/mL, making mercury more than five times as dense as water. If an object with a density of 2.0 g/cm^3 was placed in water it would sink and if it was placed in mercury it would float.” (Smith et al., 1987) found that students in higher grades and with higher math abilities were more likely to have quantitative explanations of density. In the current study, while it was found that the students in the inquiry class gave significantly more quantitative explanations of density, the fact that they also had higher math scores raises the question, was this outcome the result of the inquiry teaching methodology or was it the result of higher skills math skills, clustered by teacher? To test this question, all 179 students for the two teachers who had administered the Qualitative Density Assessment were designated as being either high-performing or low-performing for math using a cut score based on the mean score of students in the matched high math class. Students with an OAKS math performance score of 234 points and above were labeled *high math* and those with a score of 233 and below were labeled *low math*. These cut points were chosen based on analysis of math performance for the sample as a whole

Using a frequency table in SPSS for all students in the study, it was determined that 50% of student scores fell into the range of 204 – 233 and 50% of student scores fell into the range of 234 – 266. A histogram that shows the distribution of the high (1) and low (0) ODE math scores is shown in Figure 62.

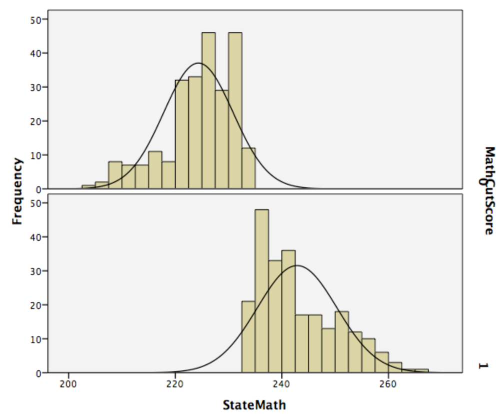


Figure 62. Histogram of the distribution of math scores in the high (1) and low (0) math groups

Once students were sorted into these two groups, based on math score, an independent *t*-test was conducted on students' learning gains to examine if, regardless of methodology, high math students (M = 9.17, SD = 4.38) outperformed low math students (M = 7.53, SD = 3.79). Results indicated that students in the high math group giving more quantitative explanations of density, $t(179) = 2.52$, $p = .013$. It was also found that the post-test score for this assessment had a moderately strong correlation with math level ($r = .479$, n = 175, $p < .05$). This finding may indicate that students' math level may be a predictor of their forming a quantitative understanding of density. Although exploring this possibility was not the purpose of this study, it is an area of future research that could be pursued.

Qualitative versus Quantitative Questions

Understanding of density involves both a symbolic abstract quantitative understanding and a qualitative component (Smith, Maclin, Grosslight, & Davis, 1997). Integration of these two components is believed to be essential for deep understanding of the concept (Smith et al. 1997). Density is formally defined as a quantitative ratio between an object's mass and its volume. It is calculated using the formula d = m/v (d = density, m =mass, and v = volume). Students also need to learn through their experiences that: (a) solid objects can have the same volume, but have different weights, (b) very small objects that weigh very little can be more dense than very large objects that weigh a lot, and (c) two objects that weigh the same but are made of different materials will have different densities. These qualitative concepts need to be taken into account when a student is learning about density (Smith et al., 1997). They provide the foundation for the formal quantitative understanding of density.

Density Assessment

It was found that at the full study level students in neither of the teaching methodologies significantly outperformed the other for the conceptual/qualitative or for the content/quantitative questions on the Density Assessment. At the matched teacher level, the inquiry group outperformed the traditional group for both matches for the quantitative/content questions and for one of the two matches on the conceptual/qualitative questions. At the matched high math class level, the traditional group outperformed the inquiry group for one of the three matches for the conceptual questions (the other two had no significant results) and for two of three matches for the quantitative/content questions (the third high math match had no significant results). For the low math classes, there were no statistically significant differences for the conceptual questions, but for the quantitative questions, the inquiry group outperformed the traditional group on both matched classes. These results mimic what was observed on other assessments

No differences were found between the two groups for the last set of questions that were focused on information taught only in the traditional lessons, even though there was a statistically significant difference between the pre-test (M = 1.79, SD = 1.14) and the post-test (M = 2.48, SD = .754); $t(479) = 5.19$; $p < .05$, when no consideration for methodology was taken into account. However, the number of questions may not have been adequate to determine differences between methodologies. One reason that the number was limited to three questions was that the full assessment already had 29 items prior to the addition of these questions and was already close the limit for what could be finished in the class time frame (as had been determined in two pilot studies). In addition, the quality of these three questions may not be as high as the other questions that were tested in the pilot studies conducted by Holveck in 2007 and 2009. Two of the questions were true and false questions that could have easily been answered correctly by guessing.

Qualitative Data

Density is often taught quickly, with a focus on the memorization of a formula and simple verification labs (DeMeo, 2001; Hitt, 2005). When density is taught this way, students can memorize the formula, but still not have a conceptual understanding of density (Hitt, 2005). An important part of this study was to understand what student conceptions of density were and how they changed as a result of the intervention.

Density Qualitative Assessment

Student understanding of concepts in science have been found to develop along a continuum during which they pass through intermediary views to reach more informed views (Khishfe, 2007). In this study, the Density Qualitative Assessment was used to examine student understanding of density by categorizing it into three levels: (a) Level 0 – misconceptions, (b) Level 1- qualitative understanding, and (c) Level 2- quantitative understanding. Students in both groups showed statistically significant improvement in moving to higher levels of understanding of density; however, this shift to higher levels of understanding of density did not occur evenly. Even though neither methodology had greater improvement at Level 0, students in both methodologies made significant improvement by reducing the number of misconceptions that they held. Students who had the traditional methodology showed the greatest improvement at Level 1. The inquiry group showed the greatest improvement at Level 2.

The Density Qualitative Assessment was useful for identifying students' conceptual confusions about density. A notable observation was that students could correctly circle the multiple-choice answer and then provide an explanation for that choice that was completely inaccurate due to a misconception that they held. It was fascinating to read student explanations and to find that several unusual explanations were held by more than one student. Prior to the study, I did not anticipate this broad range of explanations of density phenomenon that were often formed by students' naïve assumptions or an expanded theory based on their own observations (Khishfe, 2007). One example is a student explanation that objects are less dense because they are hollow or have air in them. This idea may have been formed from observing floating objects such as ping-pong balls, beach balls, empty milk jugs, etc. Students may expand on this idea to form a general rule that all hollow objects will float, not considering that a hollow steel ball might not float. Learning that it is not the “hollowness” itself that is important, but the ratio of the material of the object to the volume of air inside the object is an important step in changing this misconception (Lee & Kwok, 2010).

The change in student conceptions did follow a pattern seen by Smith et al. (1986), where students at the lowest level cannot distinguish between density and weight and at the highest level of understanding make a full weight/density distinction. This undifferentiated view of weight and density is the most common misconception that was seen on this assessment and it was the most persistent after the intervention. Instructional methodologies that help students differentiate between density and weight need to engage students' higher-level thinking skills and their prior knowledge of these concepts. (DeMeo, 2001). Misconceptions of density, such as that lower density is being caused by hidden air pockets, texture, size, or shape, were mostly dispelled by the intervention.

Another progression of understanding, beyond differentiating between weight/density, was the importance of understanding the role that the interaction between the density of an object and the density of a liquid plays in explaining the sinking and floating of objects. At the lowest level of understanding, students associate sinking and floating solely with the heaviness of an object (i.e., “heavy objects sink). Then students progress to understanding that it is the density of the object that is important. But some do not realize that the density of the liquid is also important, reporting that all liquids essentially act like water.

Next, students realize that not all liquids are the same. They may have made personal observations of liquids, for example, that some are “thicker,” like oil. This “thickness” is thought to affect sinking and floating. No student made observations that liquids could be “thinner” or less dense than water prior to the intervention. The qualitative understanding, that there is a relationship between the object and the liquid, is an important step in developing a higher level of understanding of density. However, this particular observation is flawed, because even though oil is more viscous than water, it is less dense, and objects that float in water will often sink in oil. This is one of the primary misconceptions in sinking and floating, that thickness of liquids provides “support” for floating objects.

Once students are able to confront their misconceptions and build a qualitative model that floating and sinking is dependant on the relationship between the density of the object and that of the liquid, they are able to progress to the final level of understanding, where they are able to determine that it is the quantitative comparison of the density of the object and the density of the liquid that allow one to make accurate predictions about sinking and floating of objects, a comparison that can be completed mathematically using a formula (Hitt, 2005).

Results were two-fold and follow those found by Smith et al. (1987) that: (a) students who had no conceptual understanding of density (Level 0) were able to move to a higher level of understanding where they could make the conceptual differentiation between weight and density, moving to a qualitative understanding that floating and sinking objects are dependent on both the density of the liquid and the density of the object (Level 1); and (b) students who already had the qualitative understanding of density (Level 1) were able to deepen their understanding and move to one that was quantitative, by using ratios of mass to volume to explain sinking and floating in mathematical terms (Level 2). The students who reached Level 2 were the inquiry students who were forced to confront their misconceptions throughout the unit, build models to explain their qualitative experiences, and had the mathematical ability to think about density abstractly in quantitative terms.

For some students to move to a more accurate conceptual understanding, they may need to be given a range of experiences that explicitly allow them to confront the misconceptions that they hold about density (Hewson & Hewson, 1983), allowing them to make modifications to their conceptual system (Smith et al., 1987). “Novices in a given subject area have very simple maps containing concepts that may contain misconceptions from a scientific point of view” (Gabel, 1999, p. 551). Hitt (2005) agrees that levels of understanding of density are interconnected and each level is necessary for concept mastery. Students first need to form an accurate qualitative science understanding as the basis of a concept in their long-term memory; then abstract quantitative concepts can be related to it. It is in this way that learning occurs. Without that concept in long-term memory, there is nothing to which to connect abstract information. When this occurs, the information may not be stored, and the student may not learn the concept (Johnstone, 1991).

Although Echevarria (2003) posited that disequilibrium can help dispel misconceptions and promote students’ construction of explanations that are conceptually accurate, not all students demonstrated the ability to construct conceptually accurate explanations. Some students in this study continued to hold their misconceptions even after the intervention. Shepardson and Moje (1999), Gabel (1999), and Johnstone (1991) all suggested that students who lack basic concept knowledge are less likely to be able to attain more well-developed understandings. Perhaps those students who entered into the study with a lack of knowledge and experience with density were not able to make gains. This is an area that can be explored further in future research. What experiences are needed for our lowest level learners so that they can make progress in learning complex topics like density?

Student Interview and Task Analysis

Although all but one student in the traditional group showed growth between the pre- and the post- interview and task analysis, no statistical differences were seen between the traditional and the inquiry group for conceptual understanding of density as measured by students' ability to make weight/density differentiation. Student results followed closely the results reported by Smith et al. (1986). At the end of the intervention, students had a good conception of material and understood that different materials have different properties that are consistent regardless of size or shape. They were able to identify objects that were made of the same material and associate that material with a unique density that was an innate property of matter for that object. During the paired comparisons and the density ordering task, all students were able to group objects that were made of similar material together.

Prior to the intervention, students with lower levels of understanding of density gave evidence that weight was a property of an object by giving its felt weight (Smith et al., 1987). Many students preferred using their hands to feel for the relative "heaviness" of an object, rather than using a freely available scale to get an accurate weight. This was particularly noticeable in the Mystery Material Task, where all objects were exactly the same size. Determining an accurate weight of the object using a scale, as opposed to a felt weight, would have given students the relative density of the objects. Students also looked at the heaviness of objects when making predictions for the sinking and floating task and were often quite surprised when a small marble sank and a large piece of wax floated. Finally, in the Effects of Transformations of Objects Task, some students needed to be given a larger piece of clay to add to their clay ball, as the small amount that was initially provided did not, "weigh enough to increase the heaviness of their ball." Smith et al. (1986) found a similar result.

During the post interview, students had familiarity with the tasks that were being asked of them and progressed through the series of tasks at much greater speed and with greater accuracy. While most students achieved a full weight/density differentiation after the intervention, some did not. When the pre-post interview results were analyzed to determine whether there was a relationship with math scores, the performance of students who had a high math level ($M = 3.11$, $SD = .60$) did not differ significantly from the performance of students with a low math level ($M = 3.12$, $SD = 1.36$); $t(15) = .028$, $p = .978$. These results contrast with Smith et al. (1987) who suggested that a student's math ability may be a factor, as seventh grade students with higher math abilities outperformed sixth grade students for a similar assessment. Currently then, it is inconclusive if math level relates to a student's ability to distinguish between weight and density.

Conclusions and Explanations

Unless students confront their misconceptions, it is difficult for conceptual change to occur (Driver & Erickson, 1983; Kang et al., 2005). Both the traditional and the inquiry lessons were designed to challenge prior conceptions of density with laboratory experiences that tried to promote cognitive disequilibrium. Previous research has shown that students who struggle with learning science benefit from hands-on science instruction (Scruggs & Mastropieri, 1994), but that the quality of those experiences was important. Students at all levels, but particularly students who struggle most, may benefit from an inquiry approach where they are forced to grapple with their misconceptions by engaging in activities that are structured to confront them, rather than focusing on procedures and outcomes, as is often done in traditional methodologies (Dalton et al., 1997).

In the inquiry methodology, discrepant activities were performed and experienced completely by the students themselves. With structured guidance, students were asked to make decisions about objects to test, how to organize information that was observed or measured, and to cope with finding patterns. Students in the traditional methodology had similar experiences, but they were either presented as procedural or confirmation labs, or they viewed discrepant events as teacher demonstrations. Students did not have to struggle with the organization of information. Even so, the lessons that were provided in the traditional methodology were more than teachers may teach in a traditional classroom, where density is typically taught in a few days (DeMeo, 2001; Hitt, 2005). Giving both the treatment and the comparison groups experiences that promoted cognitive dissonance may account for the large learning gains that were made by both groups and the lack of a difference for conceptual understanding between the different teaching methodologies.

Across the three pre-post assessments, several data patterns arose. At the full study level, the results were inconclusive as some differences were observed that could be attributed to improved student outcomes in an inquiry teaching methodology for two of the assessments (Density Qualitative and Scientific Inquiry Task). However, there were validity issues with the Density Qualitative Assessment due to it being an unmatched comparison. Further, the Scientific Inquiry Assessment did not measure learning gains for density.

While the Density Assessment showed no difference between the methodologies, this may be due to a Type II error, from a ceiling effect that was observed for students who had high math abilities and were in the inquiry group. The ceiling effect primarily impacted this one group as students who were assigned to the traditional and the inquiry groups were not equivalent for math ability prior to the study. Hence, even though the inquiry group had the highest overall mean on the post-assessment, they showed the least growth due to a high pre-assessment mean. This was also seen in the HLM multilevel analysis results where high math inquiry students made the least gains in the inquiry methodology.

A ceiling effect may help explain why at the class level, there was variation between the high and low math groups for the Density Assessment, but this possible threat to validity was not seen on the Density Task or the Scientific Inquiry Task, where high and low math students also had similar results and no ceiling effect was observed. For these assessments, however, the conclusion that inquiry has improved student outcomes may have more support, as 76.9% of the analyses that were performed showed that low math students had improved outcomes with an inquiry approach, while 23.1% showed that there was no difference between the teaching methodologies. Conversely, only 58.8% of the analyses showed that students with high math ability had improved outcomes in the traditional approach, and the remaining 41.2% showed no difference. These findings are similar to those reported by Blackwell, Trzesniewski, and Dweck (2007), who found that some high-performing math students prefer known outcomes where they are assured of their success. For such students, the more structured teacher-centered approach used in the traditional methodology might have proven beneficial.

By breaking down some of the qualitative assessments, it could be seen that the inquiry group did, in fact, make learning gains at the highest level for the quantitative understanding of density and were more likely to use a quantitative explanation of density when explaining sinking and floating phenomenon and when explaining how to determine the density of the three objects. These two assessments did not appear to have a ceiling effect, and the growth of the inquiry students at the quantitative level was captured.

At the matched teacher level, the inquiry methodology had larger student learning gains across all assessments. The fact that this pattern was seen for three separate assessments lends greater confidence to the conclusion that the relationship between teaching method and learning gains was valid, as the assessment types were quite different and measured both the conceptual and quantitative aspects of density. Internal validity was increased as teachers were matched for the pre-intervention and for the math ability of their students. Two of the teachers taught in the same school with nearly identical demographics, with the more experienced teacher teaching the traditional teaching methodology. The other match was for teachers at different schools who were also matched for math and for their students' pre-test scores. The student demographics in the classroom of these teachers were also similar. However, generalizability to a larger population may be impacted given that neither the teacher nor the student participants were randomly selected or assigned to the treatment and comparison group, and the sample size was relatively small.

A different pattern emerged at the class level whereby, students with low math did better in an inquiry methodology, and students with high math did better in a traditional methodology. Learning gain differences between the two treatment conditions may suggest that inquiry students who are forced to actively engage with their misconceptions through personal experience and structured decision-making may be more successful in moving to higher levels of density understanding as evidenced by the finding that for nearly every assessment, students did better in the inquiry methodology, particularly students who had lower math skills. It appears that those students who began with the least amount of knowledge of density were the ones who benefited the most. Similarly, McCarthy (2005) found that SPED students did significantly better using an inquiry approach than using textbooks and Dalton, Morocco, Tivan, and Meed (1997), found that students with learning disabilities showed improvement, as did their general education classmates, when using inquiry methods. Critical thinking through guided inquiry is thought to be important for students with specialized learning needs, as they benefit from structured active learning experiences (McCarthy, 2005).

It was hoped that the extensive categorizing of student misconceptions about density that was part of this study may help in the identification of student misconceptions in the classroom, resulting in quicker identification and targeted instruction to dispel such misconceptions. For example, giving a student a hollow ball that is heavy and will sink, might help dispel the misconceptions of hollowness and promote the idea that density is dependent on the ratio of the amount of material to the total volume it occupies. Identifying misconceptions through formative assessment might help teachers design instruction to move more students to higher levels of understanding of density.

Limitations

Validity. Threats to internal validity can weaken the confidence one can have in the results of a study. Internal validity was undermined when the conclusions that are drawn from an experiment do not accurately reflect what has transpired in the experiment itself. Internal validity is concerned with quality issues that might influence the outcome of the study, and it is threatened whenever anything other than the experimental stimulus can affect the dependent variable (Babbie, 2007). For this study, there are several internal validity threats. The first was the lack of a random assignment of students and teachers to the treatment conditions and the observation of a statistically significant difference in the prior math performance of students in the treatment groups. Consequently, teachers and classes needed to be matched using statistical methods. The failure to randomize in sampling follows the trend that was found by Schroeder et al. (2007) where it was found that only 4.8% of studies in a meta-analysis on inquiry effectiveness were based on a true experiment. For this study and others, the lack of true experimental studies was attributed to the difficulty of conducting randomized studies with students and teachers in a school setting. As a result, a true causal relationship between scientific inquiry as an instructional strategy and student-learning outcomes is difficult to establish.

Another validity issue was associated with the Density Task Assessment, where a ceiling effect was observed and the true learning gains for the highest learners may not have been accurately captured. In the Qualitative Assessment, several validity issues should be mentioned. The nonequivalent prior math scores between the classes of Teacher 1 and Teacher 4 present a possible validity issue, as the groups are statistically different for math, even though they were equivalent for the pre-test scores. This was a potential sampling bias.

Another major validity threat was the lack of teacher fidelity to the lesson plans. Teachers self-reported making adjustments to the pacing and to the lessons themselves. Because no formal observations of the teachers occurred, this lack of program adherence may have impacted student outcomes. In addition, three teachers (two assigned to the inquiry methodology and one assigned to the traditional methodology) self-selected to not administer the Density Qualitative Assessment. This produced a difference between the groups that may have threatened internal validity.

Finally, in the design of the units a tension occurred between the need to keep the content for the inquiry and the traditional units the same, while at the same having two different methodologies to deliver that information and experience to students. In the two previous pilots, this fine line of having similarly paced units with similar content was not as successfully completed. One theme that ran through both units was providing opportunities for conceptual change. As a result, the traditional lessons, which had many labs that allowed for students to have opportunities to experience discrepant events, may not have truly represented a traditional approach that is seen in many classrooms where students read textbooks and write down teacher notes. Rather, it may be viewed as more of a hybrid approach that incorporates some of the traditional pieces such as reading, taking notes, and teacher demonstrations, with laboratory experiences that were designed to match the experiences that students in the inquiry approach had, except they were proscribed and not inquiry-based. So this was perhaps the greatest validity issue of the study, that the comparison groups were not given a true traditional teaching methodology. Part of the rationale for the choice to design the traditional lessons the way that they were, was that teacher recruitment for a pure traditional approach would have been difficult. Accommodations needed to be made to provide lessons that teachers would want to teach their students.

Reliability. Another limitation was the researcher-developed assessments used in this study. Although the Density Assessment and Interview and Task Analysis were both based on similar assessments used by Smith et al. (1987), there was no published reliability or validity data for these instruments. Measurement unreliability potentially compromises the results that are being reported and the conclusions that are being drawn through both random and systematic error. Random error is caused by factors that can affect measurement in ways that do not affect the entire sample. It does not affect the average score, but rather the variability around the mean. Systematic error can affect a variable across the entire sample, affecting the distribution of the variable in either positively or negatively and moving the mean up or down. Both these sources of error might be present in the research-developed assessments used in this study. However, because the tests were formulated to match the instructional practices and content that were investigated, were based on assessments used in other research, and were previously pilot-tested by the researcher, there was some evidence to support the adequacy of the assessments for capturing density knowledge, reducing concerns related to systematic error. For example, the Density Assessment that was used in this study had been used in two previous pilot studies by the researcher. The Density Task and Scientific Inquiry Task had been used in one previous pilot. The Interview and Task Analysis was the only assessment that the researcher had not used before.

Reducing measurement error in scoring the assessments and entering the data was a more difficult task due to the number of assessments that had to be scored and the amount of data that needed to be entered into SPSS. Although it would have been ideal to have worked with another researcher to co-score the assessments, this was not a practical possibility. The reliability of the scoring for the multiple-choice Density Assessment was the highest for all the assessments, as teachers and the researcher scored answers for the pre- and post-assessment, so the total scores that were assigned to each participant were double-checked. The assessment was also a multiple-choice assessment that had clear correct or incorrect answers, also contributing to the reliability of the scoring.

There was less control of the reliability of scoring for the qualitative assessments, as only the researcher scored them. Therefore, there was no inter-rater reliability. There was potential for greater measurement error on these assessments because judgments on qualitative information are more likely to be prone to bias, creating a potential for systematic error on these scores. For the assessments that were rated using a rubric

(Density Task Assessment, Scientific Inquiry Assessment, and Qualitative Assessment), the rubric did serve as a form of calibration for the researcher. In particular, for the Density Task Assessment, the original 5-level rubric was deemed inadequate for consistent assignment of scores, so it was expanded into a more detailed 18-level rubric in an effort to gain greater accuracy in assigning a correct score to the student assessment. This expansion was accomplished by coding a large number of student responses. These coded student responses were then categorized to create the continuum of density understanding. In turn, this detailed continuum, with student responses as examples at each point along the continuum, allowed greater accuracy and consistency in scoring student work as a single scorer.

For the Interview and Task Assessment, student interviews were recorded. After conducting the interview, the accuracy of the written comments was checked and adjusted. A detailed rubric was created that allowed consistent scoring of student responses. However, only one rater listened to the recordings and completed the scoring. No calibration of the rubric occurred.

Generalizability. Shadish, Cook, and Campbell (2002) define external validity as the "inferences about the extent to which a causal relationship holds over variations in persons, settings, treatments, and outcomes" (p. 83). External validity thus addresses generalization issues, which can be diverse. Generalizability of this study was limited because of the relatively small sample and the fact that the sample was recruited from a single district in a single geographic location, even though student demographics were diverse and representative of schools in the Pacific Northwest. Generalizability may have been limited further as the sample size was reduced to create greater uniformity between the comparison sample groups. As a result of trying to increase the internal validity of the study by statistically matching teachers and students for ODE math scores, generalizability was sacrificed. When a reduced number of select participants are included in an analysis, strong generalizable assertions about results cannot be made.

Fidelity. There were several ways that the fidelity of implementation was monitored for this study. Detailed lesson plans were given to teachers along with a training on the unit and materials. All materials that were required for the study were provided, sorted by lab for ease of use. Teachers were asked at the end of each lesson to reflect and self-report on any modifications that they made to the lessons for: (a) content, (b) materials, (c) timing, and (d) difficulty. All teachers completed the daily lesson reflections. Pacing was accounted for by teachers submitting their calendars. However, all of these fidelity measures relied on teachers delivering lessons as written and self-reporting accurately. Formal class observations of teacher delivering the intervention were planned but not carried out due to the time constraints of the researcher. Monitoring the implementation through observations for program adherence would have allowed the researcher to determine if teachers were delivering the intervention as planned.

From the lesson reflection, the two teachers in the traditional methodology condition self-reported that they made the greatest adjustments to the lessons and they also rated the lessons to be greater in difficulty than the inquiry teachers. Although the modifications that were reported were minor and supplemental to the main lesson, the adjustments to the lessons that were made by the traditional teachers may have affected the outcomes of the students. As a result, learning gains that were measured for the traditional teaching methodology may have reduced validity, as learning gains may be attributed to the supplemental materials or modifications that the teacher made to the materials rather than the intervention. These changes to the lesson plans also make the results between teachers less reliable, as teachers were customizing the intervention to fit their class needs. Because the data were self-reported for the lesson reflections, it was not known if the traditional teachers actually made more modifications than the inquiry teachers to the lessons, or were simply more truthful in reporting the changes they had made. Both the traditional and the inquiry teachers increased the length of time for some lessons, with the inquiry teachers saying that the lessons were too long at a slightly higher frequency. However, as all teachers finished the unit in exactly 19 teaching days, this effect was reduced. Because these data were gathered through teacher self-reporting, the accuracy of the calendars can not be confirmed.

Recommendations and Implications

This research showed that middle school student conceptions about complex science topics such as density can be changed when misconceptions are explicitly addressed and taught to during a teaching unit that focuses on providing experiences that promote conceptual change. New resources to help teachers assess for student misconceptions in science classrooms are becoming more available (Keeley, 2011). In order for teachers to change their practice, they must see the urgency and need for doing so. School districts also must realize that the need for change is imperative and prioritize putting resources in the form of teacher professional development towards that change. The implementation of basic formative assessment practices for the evaluation of student misconceptions prior to, during, and after instruction would be a good place to start to increase student learning (Keeley et al. 2005).

Middle school students moved from their naïve theories to qualitative understandings to more formal quantitative understandings of density. This process can be used to teach a variety of topics where students hold major misconceptions and needs to be used more often in our schools. The extensive coding of student misconceptions showed that students held many inaccurate conceptions of density prior to the intervention. The finding that, regardless of which methodology used, students' conceptual understanding of density improved over the course of the intervention suggests that teachers may find it beneficial to be more deliberate in how they design units to accomplish conceptual change, moving away from conformational labs and textbook-based instruction that rely heavily on memorization of facts and moving toward engaging students in critical thinking. In this way conceptual change can occur.

National and state science standards focus on the need for inquiry as a way of engaging students in critical thinking in the classroom. Teachers are told that the future of our country depends on creating a workforce with problem solving skills (Carter, 2007: NAS, 1996; Phillips, 2007; Rutherford, 1990). Yet inquiry which actively engages students in critical thinking and problem solving is not frequently performed in the science classroom, as it is viewed by teachers as being too time consuming and too difficult for students (and themselves) to do (Singer, Marz, & Krajcik, 2000; Zion, Cohen, & Amir, 2007)). Also, inquiry is often taught as a stand-alone practice, unrelated to the content standards that also need to be taught (Gengarelly & Abrams, 2009). Guided inquiry taught in a specific sequence of content lessons could be a valuable tool for engaging students in critical thinking about a particular topic, where their misconceptions are confronted and increasingly rigorous interaction with the content was deliberately built throughout the unit. The combination of teaching for conceptual change combined with an inquiry methodology was a novel approach to teaching a complex topic like density. This approach can be used with other complex topics where known student misconceptions can be addressed and qualitative and then quantitative conceptions built. Topics like photosynthesis and respiration, electricity, force and motion would be appropriate for this methodology.

As student diversity and class size increase in our public schools, finding and implementing teaching strategies that help a diverse group of students is becoming ever more important. The results from this study, particularly those of low performing math students indicate that this approach has promise in addressing a pressing need in our schools, reaching students who typically struggle in the traditional science classrooms with curricular material that is engaging and rigorous. It was seen in this study that the learners who struggled the most, in this case, the low math students, did the best in the inquiry methodology. In fact, the students with the lowest scores for OAKS prior math performance had the greatest learning gains when taught using an inquiry methodology. Inquiry also helped students achieve a quantitative level of understanding of density and make a weight/density differentiation. The results of this study suggest that inquiry instruction can fit the needs of a diverse classroom and may help a variety of differently-abled students move to more advanced ways of conceptualizing density. While this study added to the growing body of research on the effectiveness of inquiry teaching, very few studies have shown that inquiry helps the most at risk students make significant learning gains.

The observation that teaching methodology interacted with math performance, where high math students did better in a traditional methodology and low math students did better in an inquiry methodology, demonstrates the challenge that accompanies attempts at aligning teaching practice with student need. No easy answers exist. Recommendations for further work would be to explicitly study the cross level interaction seen in this study. In addition, the refinement of the Density Assessment to better measure student learning gains without a ceiling effect is recommended for future studies as well.

The work found in this dissertation was important because the scope of study allowed a look into the varied factors that can affect how middle school students learn complex topics. The cross level effect that clearly shows that students that are traditionally viewed as incapable of completing the higher level thinking found in the inquiry methodology clearly benefited from learning about density this way. With evidence showing that all students benefited at the matched teacher level, a call for change in our schools may be warranted. Science educators realize that the complex nature of the world that all of our students will be living in as adults requires us to provide an equitable education to all students, instead of tracking students and making assumptions of what they are capable or not capable of doing. We need to set the bar high. While it was seen, when classes were matched for math level, that students in high math did better in traditional classrooms, this is not a call to arms to revert back to old ways of teaching. These students need to learn to problem solve and engage in critical thinking as much as other students.

Marrying brain-based research on how students learn, with the best teaching practices provides hope that students in our increasingly diverse classrooms will be given the opportunity to excel so that their futures are not limited by their education. To solve the problems of the future we need all of our diverse children's minds engaged in moving us forward.

Conclusion

Although findings in this study were somewhat mixed, with some analyses favoring students who received instruction using the traditional methodology and others students who received instruction using the inquiry methodology, two clear findings emerged. First, the study provides clear evidence that students representing diverse backgrounds and a range in reading and mathematics ability can gain a deeper understanding of one of the more complex science topics covered in middle school: density. A feature found in the instruction provided to both the treatment and the comparison groups in this study was a focus on exposing students' misconceptions about density and helping them create new, more scientifically-grounded, explanations for the concepts being covered. This particular approach to teaching may, in the end, be just as important as whether students or their instructors are guiding the learning experience through hands-on, open-ended labs or more-structured, guided demonstrations. Second, the study provides evidence in support of the use of the various assessments created by the researcher for use in this study as tools to measure students' understanding of density. The combination of quantitative and qualitative assessments of students' density understanding provides a rich source of information for understanding student misconceptions and accurate understanding of various aspects of density. These tools, perhaps even more than the direct findings themselves, provide a contribution to the field.

APPENDIX A

INFORMATIONAL LETTER TO PARENTS (ENGLISH)

Beaverton SCHOOL DISTRICT
creating pathways to the future for all students

School name

School address

Beaverton, OR 97008

Dear Parents,

Your child is invited to participate in a research study that will be conducted as part of a dissertation research project through the University of Oregon. The study will involve comparing two different teaching methodologies on student content gain and conceptual understanding of density. Some students will be learning about density using an inquiry approach and others will be learning about it through a more traditional approach. Both curriculums will be engaging to students.

If you decide to allow your child to participate, your child will be asked to participate in normal classroom activities. Some students will be selected to participate in a weight/density task assessment, which will be audio-taped. Data will be collected for all participating students from a pre-test and post-test on density as well as for three lab activities.

While participating in this study, it is possible that you or your child may feel uncomfortable with audio-taping. If they express this concern, the audio-taping will be stopped. Data collected from this study may be presented at research conferences, in academic journals, and to other professionals in the field.

Your child will not receive any direct benefit from taking part in this study, but the study will help to increase knowledge that may help others in the future.

Any information about teaching science obtained in connection with this study that can be used to identify you or your child will be kept confidential by coding each student's data using an arbitrary number that is not directly related to them in any way.

Your child's participation is voluntary. Your child does not have to take part in this study, and it will not affect your child's grade. You may also withdraw your child from this study at any time without affecting your child's course grade. If you have concerns or problems about participation in this study or the rights of a research subject, please contact the Human Subjects Research Review Committee, Office for the Protection of Human Subjects, University of Oregon, Eugene, OR 97403, (541) 346-2510. If you have questions about the study itself, contact Susan Holveck (503) 642-7352 or my advisor Dr. Keith Zvoch.

If you would like your child to not participate in this study, they will participate in normal classroom activities along with the rest of the class; however, their data will not be included in this study. Unless I hear from you, I will assume your consent.

I am very excited to have your child participate in this study.

Thank you,

Susan Holveck (The Researcher)

Please sign and return only if you do <u>NOT</u> want your child to participate in the study.

- I do not want my child to participate in this study.

______________________________ __________________________ ________

Student's Name Parents/Guardian's Signature

Date

APPENDIX B

INFORMATIONAL LETTER TO PARENTS (SPANISH)

Beaverton
SCHOOL DISTRICT
creating pathways to the future for all students

School name

School address

Beaverton, OR 97008

Querido Padre/Madre de Familia:

Su hijo(a) está invitado a participar en un estudio de investigación que será conducido como parte de un projecto de tesis doctoral en la Universidad de Oregon. El estudio consistirá en comparar dos diferentes metodologías pedagógicas basadas en el aumento de la adquisición de conocimiento de los estudiantes y en la comprensión del concepto de la densidad. Algunos estudiantes aprenderán acerca de la densidad por medio de un enfoque de investigación y otros aprenderán a través de un enfoque más tradicional. Los dos métodos serán de interés para los estudiantes.

Si usted decide permitir que su hijo participe, su hijo tendrá que participar en las actividades de la clase normal. Algunos estudiantes serán selccionados para participar en una evaluación de los conceptos de peso/densidad, que serán grabadas en audio. Datos serán obtenidos de todos los participantes en la investigación por medio de una prueba administrada antes y después de la lección en densidad asi como por medio de tres actividades de laboratorio.

Al participar en este estudio, es posible que usted o su hijo se sientan incómodos con la audio-grabación. Si se expresa esta preocupación, la audio-grabación se detendrá. Los datos recogidos en este estudio podrán ser presentados en conferencias de investigación, en revistas académicas, y con otros profesionales en el campo.

Su hijo no recibirá ningún beneficio directo por su participación en este estudio, pero el estudio ayudará a aumentar los conocimientos que pueden ayudar a otros en el futuro.

Cualquier información sobre la enseñanza de las ciencias obtenida en relación con este estudio que se pueda utilizar para identificarle a usted o a su hijo se mantendrá confidencial mediante la codificación de los datos de cada alumno con un número arbitrario que no esté directamente relacionado con ellos de ninguna manera.

La participación de su hijo es voluntaria. Su hijo no tiene que participar en este estudio, y esto no afectará su calificación. También puede retirar a su hijo de este estudio en cualquier momento sin afectar la calificación de su hijo. Si tiene dudas o problemas acerca de la participación en este estudio o los derechos de un sujeto de investigación, por favor póngase en contacto con el Human Subjects Research Review Committee, Office for the Protection of Human Subjects, University of Oregon, Eugene, OR 97403, (541) 346-2510. Si usted tiene preguntas sobre el estudio, favor de ponenerse en contacto con Susan Holveck (503) 642-7352 o con mi asesor Dr. Keith Zvoch.

Si desea que su hijo no participe en este estudio, el/ella participará en las actividades de la clase normal junto con el resto de la clase, sin embargo, sus datos no serán incluidos en este estudio. A menos que usted indiquen lo contrario, voy a asumir su consentimiento.

Estoy muy emocionada de que su hijo participe en esta investigación.

Gracias,
Susan Holveck (la investigadora)

Favor de firmar y regresar sólo si <u>NO</u> quiere que su hijo participe en el proyecto de investigación.

- o Yo no quiero que mi hijo participe en la investigación.

____________________________ ________________________ ________

Nombre del estudiante | Firma del padre o guardián | Fecha

APPENDIX C

WEIGHT/DENSITY DIFFERENTIATION TASK ASSESSMENT AND INTERVIEW

Name____________________________________ M/F Date_______________

I. Sorting by Materials

Materials: set of cylinders (1 1/2 " diameter) made of plastic, aluminum, and steel
Plastic: 1, 2, 3 Al: 1, 2, 3 Brass: 1, 2, 3
Teacher Interviewer Dialogue:
"Some of these objects are made of different materials and some are made of the same material. Can you sort them into groups according to the kind of material they are made of?"

circle if correct: plastic aluminum brass

Other ____

Names: P1, P2, P3 AL1, AL2, AL3 BR1, BR 2, BR 3
"Tell student names and correct any mistakes"

II. Paired comparison of weights and objects

Materials: digital scale, same set of cylinders

Teacher Interviewer Dialogue:
"Now I'm to ask you some questions about the WEIGHTS of these objects. I'll show you two objects at a time and ask you whether one of them is heavier or whether they are the same weight. I want you to think carefully about your answer. So for each problem, I want you to take these objects in your hands, and put them on the digital scale before giving your answer."

Is one of these objects heavier or do they weigh the same? (If one is heavier? Ask: Which one is heavier? (Repeat question as needed) Highlight is the heavier object.

Paired Combination	Description	Check if correct	Notes- if not correct
BR2; AL2	Same size, different material		
PL2; PL3	Same material – different size		
BR1; AL3	Equal Weight – different material		
PL4; AL1	Large heavy PL, small AL		
AL3; BR1	Large heavy AL, small St		
AL1; PL1	Same size, different material		

"Very good. How did you know when an object was heavier?"

III. Paired Comparison of Density of Materials

Materials: Postage Scale. Same set of materials

Teacher Interviewer Dialogue: "Now I'm going to ask you different questions about these objects. You've already sorted these objects by the kind of material they are made of: Some are plastic, some aluminum, some brass. Now I'm going to ask you about the heaviness of the kind of material an object is made of."

Question: " Is one of these objects made of a heavier kind of material or not?"

Paired Combination	Description	Check if correct	Notes- if not correct
BR3; AL3	Same size, different material		
PL1; BR1	Same size, different material		
CO1; AL4	Equal Weight – different material		
CO1; PL4	Equal Weight – different material		
AL1; AL2	Same material – different size		
BR1; BR3	Same material – different size		
PL3; CO1	Large heavy PL, small AL		
AL3; BR1	Large heavy AL, small ST		

"Very good. How did you tell which object was made of a heavier kind of material?"

IV. Mystery Materials

Materials: Balance Scale. Three regular objects: 1" cubes of white plastic, aluminum, brass. Three 1" cubes of new materials (A (copper), B (wood), C (brass)) that are covered in contact paper.

Teacher Interviewer Dialogue: Here is a balance scale (Check to make sure that students know how to use it) and three new objects made of plastic, aluminum, and steel.

There are also three new objects that are covered up. Your job is to figure out what kind of material they are made up of.

A (Copper) – "Could this material be made of plastic, aluminum, or brass or must it be made of something else? How do you know?" Note strategy and explanation.

B (Wood) – "Could this material be made of plastic, aluminum, or brass or must it be made of something else? How do you know?" Note strategy and explanation.

C (Brass) – "Could this material be made of plastic, aluminum, or brass or must it be made of something else? How do you know?" Note strategy and explanation.

V. Ordering by Weight and Density

Materials: Balance scale, black plastic cylinder- wooden cube (equal weight), 1" plastic cube, 1" Al cube, large plastic cylinder that is equal in weight to small Cu cylinder, 1" Cu cube

Teacher Interviewer Dialogue: "I'd like you to order these 7 objects according to their WEIGHT. Put the lightest object here, the next heaviest object here, and so on. If they are the same weight, put them together. Think about it as carefully as possible. "

Order should be:

Wooden block = black plastic,….. Sm Al cylinder …small Cu cylinder= large plastic cylinder ….. ..1" plastic cube…. 1" copper cube

Did student get it correct? Y/N

Strategy:

____
____

Make sure before conclusion of this part, that the student knows that the Small Al and the mystery Cube A (wood) are the same weight.

Teacher Interviewer Dialogue:
"Now I would like you to order these objects in a different way. Order these objects according to the DENSITY of the material that they are made of. Put the object (or objects) that are made of the densest materials here, the next densest material here, and so on. If some objects are made of materials that have the same density, please put them together."

Order should be:

Wood cube….Lg wh plastic cylinder=wh cube…. Bk plastic cylinder ….sm cylinder AL….. Sm Cu cylinder=1" Cu cube

Did student get it correct? Y/N

Strategy:____
____
____
____

"How did you know where to place them?"
____
____
____

VI. Modeling

Materials: Same 7 objects as above in Task V, pencil, markers, and paper

Teacher Interviewer Dialogue:: You have ordered these seven objects by weight and by density. Please draw a picture of each object that gives information about its size, weight, and density."

"How have you shown their size?"
____
____
____

"How have you shown their weight?"
____
____
____

"How have you shown their density?"

____
____
____

VII. Sink and Float

1. Materials: Set of 9 objects: one kind of floating wood (of two different sizes), golf ball and ping pong ball; large and small pieces of clay, large and small marbles, Al cylinder.

Teacher Interviewer Dialogue: "Here are some different objects. Why don't you put them in the water to see if they sink or float?"

"What types of things sink and what types of things float? Can you make up a general rule which allows us to predict what will sink and what will float?"

____
____
____
____

2. **Materials:** Bring out large and small pieces of wax, large and small Al. State materials. Order by relative weights using BALANCE SCALE. Put small WAX and large AL in water.

Teacher Interviewer Dialogue:
"So the large AL sinks and the small wax floats. Now if we were to put the big WAX and the small AL in the water. What so you think will happen?"

Large Wax…… (sink…..float)…………… Reason
____
____
____

Small Al.…… (sink…..float)…………… Reason
____
____
____

3. **Materials**. Bring out plastic and jar of fresh and salt water. Show that the plastic floats in one jar, but not in the other.

Teacher Interviewer Dialogue: "Here is a piece of plastic. If I put it in here, it floats. But if I put it in here, it sinks. How can that be?"

____
____
____
____

(Bring out a glass of oil)

Teacher Interviewer Dialogue: "This glass has oil in it. If I put the plastic in the oil, do you think that it will sink or float?

Sink………float……….

Reason____
____
____
____
____

(Show them that it sinks in oil)

If predicted wrong then ask "In fact, the plastic sinks in oil. How can that be?"

____
____
____
____

4. Bring out 2 same size pieces of CLAY and 2 small pieces of WAX

Teacher Interviewer Dialogue:

"Here are two same size pieces of clay and they weigh the same." Put on the balance scale.

"Now I'll put one of these pieces of clay in-between these two pieces of wax." Show them that the clay/wax piece clearly weighs more than the small clay piece alone.

"When I put the small clay in water, it sinks" Show them

"If we put this heavier object in water (Clay stuck between wax pieces), do you think that it will sink or float?"

Sink………float……….

Reason____
____
____

Do experiment and show that the clay/wax FLOATS

If predicted wrong then ask "The clay ball sinks, but the heavier object made of clay and wax floats. How can that be?"

5. Materials: Small clay, clay/wax, candle

Teacher Interviewer Dialogue:
"Could you order these objects by how much they weigh?"

correct order candle………………small clay………………..clay/wax
yes/no

Teacher Interviewer Dialogue:
"Now could you order these objects by the density of their materials?"

correct order candle………………clay/wax………………..clay
yes/no

VIII. Effects of transformation on objects and materials

1. CLAY (Bring out a ball of clay. Add a little bit of clay)

Teacher Interviewer Dialogue:
(a) "Did I change the AMOUNT of clay in the ball?"

Yes (more)………Yes (less)

Reason

No…….. "Show me how much to add to change the amount of clay? (Have them tell you the amount and then add that amount for the rest of the questions.)

Teacher Interviewer Dialogue:
(b) "Did I change the WEIGHT of the clay ball when I added that little piece?"

Yes (heavier)………Yes (lighter)
Reason

No…….. "Show me how much more clay I need to add to make it heavier"

Teacher Interviewer Dialogue:
(c) "Did I change the DENSITY of the clay in the ball when I added that little piece?

Yes (denser)………Yes (less dense)
Reason

No……..Reason

APPENDIX D

SCORING SHEET FOR WEIGHT/DENSITY DIFFERENTIATION TASK

ASSESSMENT AND INTERVIEW

ID________________________________ Teacher________________ Date_________

Scoring Sheet for Task Analysis Pre ________ Post_____

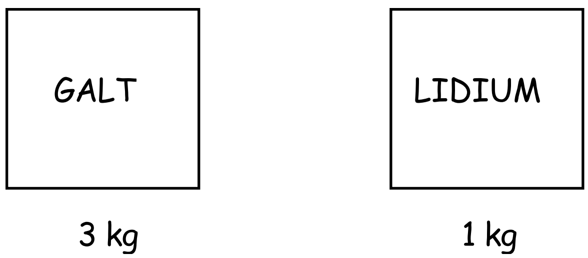
	Name of Task	**Type of Task**	**Pattern on Task**								
			Number correct								
I.	Sorting by Materials	Ordering	All		2/3			1/3			0
	Paired comparison of weight and objects		All	5/6		4/6		3/6	2/6	1/6	0
	Paired Comparison of Density of Materials		All	7/8	6/8	5/8	4/8	3/8	2/8	1/8	0
	Mystery Materials*		All		2/3			1/3			0
	Ordering by Weight		Correct	6/7	5/7	4/7		3/7	2/7	1/7	Incorrect
	Ordering by Density*		Correct	6/7	5/7	4/7		3/7	2/7	1/7	Incorrect
Ordering Rating * = Critical comparison			Clear Distinction	Beginning W/ D Characterization				Weight alone			
II.	Modeling	Modeling	All shown and accurate	Two distinct dimensions- but mix up weight and density					Only weight; only density		
Extensive (# dots=weight), Intensive codes (intensity = density) v. Neutral codes (ordering/labeling)			Use extensive/ intensive accurately	Use several types – W/D distinctions not always clear					Use one type No distinction		
Modeling rating			Clear Distinction	No clear distinction between W/D					No distinction W/D		
III.	Sink and Float - rule	Sink Float	Density rule	Weight/density rule					No rule/weight rule		
	Al/Wax*		2/2	½					0		
	Salt water		Density explanation	Weight/ density explanation					Weight only or no explanation		
	Oil		Density explanation	Weight/ density explanation					Weight only or no explanation		
	Clay/wax*		Density explanation	Weight/ density explanation					Weight only or no explanation		
	Sort objects by weight		Yes						No		
	Sort objects by density*		Density Patterns			Weight /Density Patterns			Weight patterns		
Sinking and Floating Rating * = Critical comparison			Density Patterns			Weight/ Density Patterns			Weight patterns		
IV.	Effects of transformations of objects on materials - change	Adding Materials	Weight increases because added more clay, density did not increase because the same material was added			Weight increases because more clay is added, but unsure if density increases			Both mass and density increase because more clay is added		
Adding Materials Rating			Clear distinction			Beginning distinction			Make no distinction		

Level of understanding = ___________________________________
APPENDIX E

DENSITY ASSESSMENT

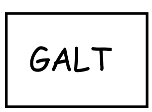
Multiple Choice
Identify the letter of the choice that best completes the statement or answers the question.

____ 1. Here are two solid objects made of different materials. One is made of GALT and the other is made of LIDIUM. Both are the same size but weigh different amounts. Which object is made of a denser material?

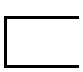


a. GALT
b. LIDIUM
c. They have the same density
d. Not enough information given

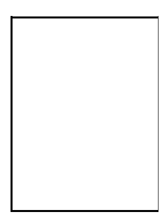
____ 2. Here is another object made of GALT

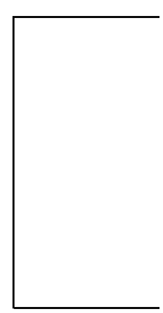


Imagine an object made out of LIDIUM that weighs the same as the object made of GALT. Which of the following objects made out of LIDIUM would weigh the same as the GALT object above?

a. 

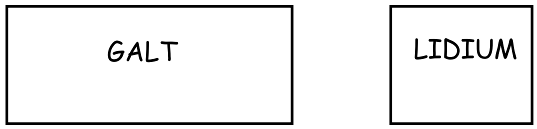
b. 

c. 

d. 

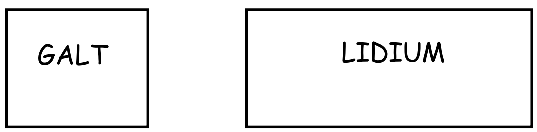
____ 3. Here are some additional pairs of objects made of GALT and LIDIUM. Decide if the objects in each pair weigh the same or if one of them is heavier.

The object made of GALT is 2 times the size of the object made of LIDIUM.



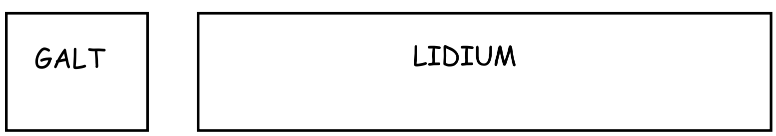
a. GALT is heavier
b. LIDIUM is heavier
c. Both objects weigh the same

____ 4. The object made of LIDIUM is 2 times the size of the object made of GALT.



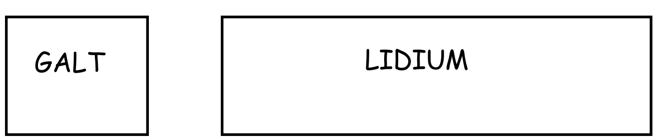
a. GALT is heavier
b. LIDIUM is heavier
c. Both objects weigh the same

____ 5. The object made of LIDIUM is 4 times the size of the object made of GALT



a. GALT is heavier
b. LIDIUM is heavier
c. Both objects weigh the same

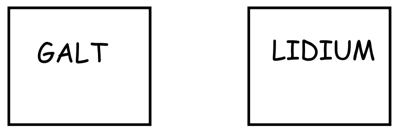
____ 6. The object made of LIDIUM is 3 times the size of the object made of GALT



a. GALT is heavier

b. LIDIUM is heavier
c. Both objects weigh the same

___ 7. These two objects of GALT and LIDIUM are both the same size.

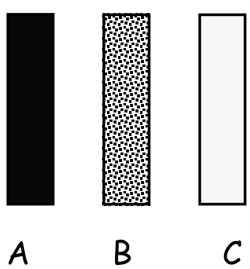


a. GALT is heavier
b. LIDIUM is heavier
c. Both objects weigh the same

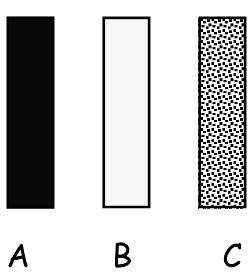
____ 8. Consider the following three objects made of different materials: wood (A), aluminum (B), and steel (C). The objects are all the same size. The one made of steel is heavier than the one made of aluminum, and the one made of aluminum is heavier than the one made of wood.

Which of the following set of pictures best represents these three objects?

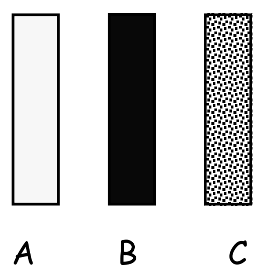
a.



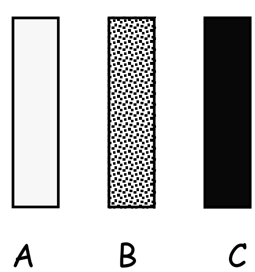
b.



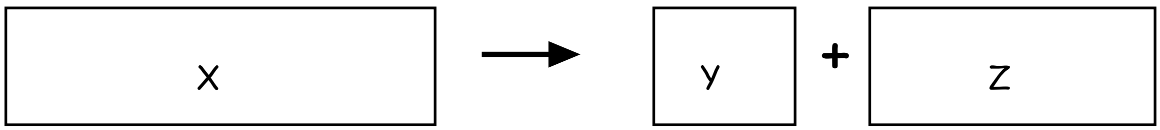
c.



d.



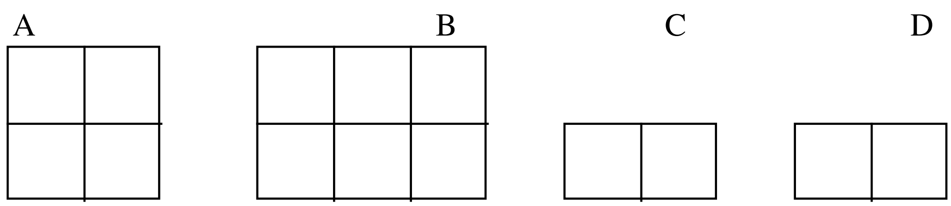
____ 9. Here is a block of wood (X) which is cut into two pieces (Y + Z).



Which of the following statements is true?

a. Block X has the greatest density
b. Block Z is more dense than Block Y
c. Both a and b are correct
d. They all have the same density

____ 10. Here are four objects which have the following sizes and weights:
(hint 1 cube unit = 1 cm3)



	A	B	C	D
Size:	4 cube units	6 cube units	2 cube units	2 cube units
Weight:	12 grams	12 grams	6 grams	8 grams

Think about whether any of these objects could be made of the same material. Which of the following is the correct statement.

a. Objects A and B could be made of the same material because they are the same weight.
b. Objects C and D could be made of the same material because they are the same size
c. Objects A and C could be made of the same material because they have the same weight per unit size.
d. None of the above could be made of the same material.

____ 11. What is the density of the material in object A?

a. 12 g/cm3
b. 3 g/cm3
c. 8 g/cm3
d. 1/3 g/cm3

____ 12. What is the density of the material in object D?

a. 8 g/cm3
b. 2 g/cm3
c. 4 g/cm3
d. 1/4 g/cm3

____ 13. You have two objects: Object X and Object Y. Both objects weigh 56 grams, however object X displaces 22 ml of water and object Y displaces 36 ml of water. Which object is the most dense?

a. X
b. Y
c. Both are the same density
d. You can not tell from the information given

____ 14. The density of gold is 19.3 g/cm3 and the density of silver is 10.5 g/cm3. If you had a 10 cm3 of each, which would weigh more?

a. Gold
b. Silver

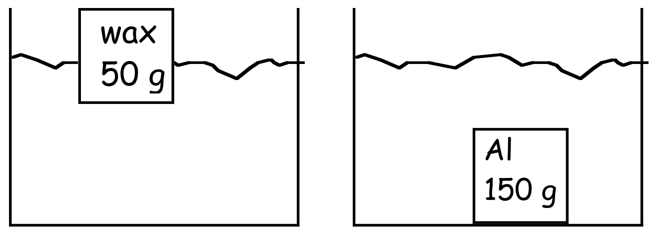
____ 15. You have a table of densities that you are using to identify an unknown shiny metal. You know that the densities of barium= 3.51 g/cm3, cobalt = 8.9 g/cm3. iron = 7.8 g/cm3. You determine the mass to be 667 grams and the volume to be 74.9 cm3. What kind of metal do you have?
a. Barium
b. Cobalt
c. Iron

____ 16. A cup of metal beads was measured to have a mass of 425 grams. By water displacement, the volume of the beads was calculated to be 48.0 cm^3. Given the following densities, identify the metal

gold 19.3 g//cm3
silver 10.5 g/cm3
bronze 9.87 g/cm3
copper 8.85 g/cm3

a. gold
b. silver
c. bronze
d. copper

____ 17. Here are two pieces made of WAX and ALUMINUM in a tub of water. The ALUMINUM piece weighs 150 grams and the WAX piece weighs 50 grams. When they are placed in water, the WAX floats while the ALUMINUM (Al) sinks.



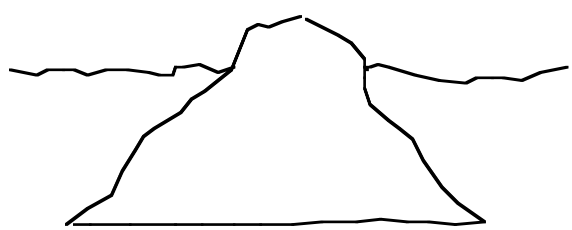
If a very small piece of aluminum weighing only 2 grams were put into the water it would

a. Definitely float
b. Definitely sink
c. Can't tell whether it would sink or float from the information given.

____ 18. If a very large piece of wax weighing more than 200 grams were put into the water it would

a. Definitely float
b. Definitely sink
c. Can't tell whether it would sink or float from the information given

____ 19. Here is a large iceberg floating 9/10ths below the water.



A small piece of the iceberg breaks off.
Choose the correct statement

a. The little piece will float with 9/10th of it above the water.
b. The little piece will float with 9/10th of it below the water
c. The little piece will sink
d. Can't tell from the information given

____ 20. What is the density of a board whose dimensions are 5.54 cm x 10.6 cm x 199 cm and whose mass is 28600 g?

a. 13.55 g/cm3
b. 5.46 g/cm3
c. 3.21 g/cm3
d. 2.45 g/cm3

____ 21. Will the board in problem #20 sink or float in water?

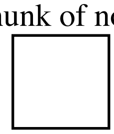
a. Sink
b. Float
c. Not enough information given

____ 22. If the piece of wood in problem #20 was placed in mercury which has a density of 5.47 g/mL would it sink or float?

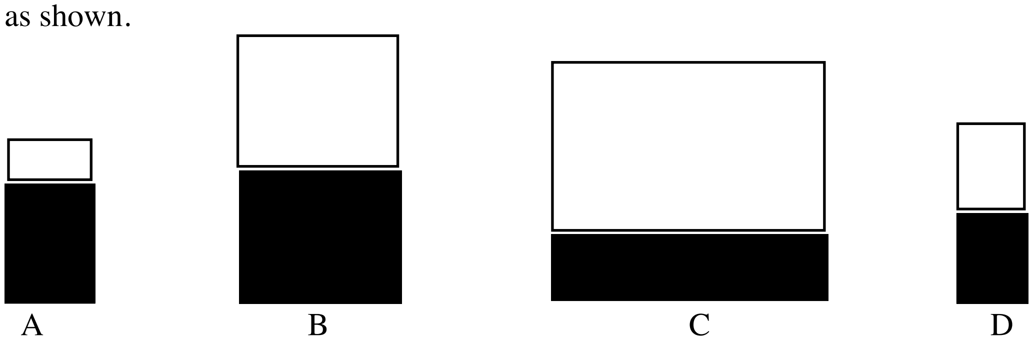
a. Sink
b. Float
c. not enough information

____ 23. Here is a chunk of very dense material

Here is a chunk of not so dense material



The following objects were made by combining the two materials in different proportions as shown.



Do these objects have the SAME average density?

a. Yes, ALL of them do.
b. A and C have the same average density
c. B and C have the same average density
d. B and D have the same average density
e. None have the same average density

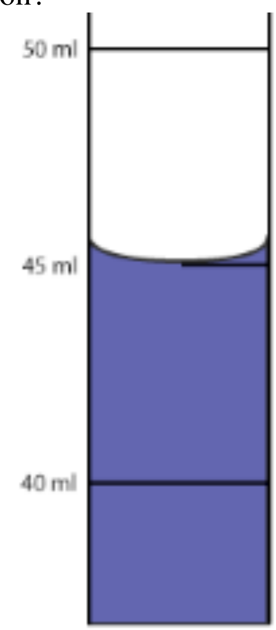
____ 24. In the above example, which object has the greatest average density?

a. A
b. B
c. C
d. D

____ 25. In the above example, which object has the least average density?

a. A
b. B
c. C
d. D

____ 26. The volume of a solution was measured in a graduated cylinder that is shown below. If the mass of the solution is measured to be 60.75 grams, what is the density of the solution?



a. 0.75 g/mL
b. 0.96 g/mL
c. 1.35 g/mL
d. 2.27 g/mL

____ 27. If the liquid in the above question was placed in a graduated cylinder with water, would it sink below the water or float above it?

a. sink below water
b. float above water

____ 28. You are trying to determine the density of an irregularly shaped object. The object displaces 55 mL of water and has a mass of 115.2 grams. What is its density?

a. 1.85 g/cm3
b. 2.09 g/cm3
c. 0.47 g/cm3
d. 0.98 g/cm3

____ 29. You have 4 liquids A, B, C, and D with different densities.

A = 0.89 g/mL
C = 2. 02 g/mL
B = 0.67 g/mL
D = 1.23 g/mL

These liquids are put into a graduated cylinder so that they form layers with the densest liquid on the bottom and the least dense liquid on the top. You drop in an object with a density of 0.74 g/mL. Between which two layers will it float?

a. between layers A and B
b. between layers A and C
c. between layers A and D
d. between layers D and C

____ 30. TRUE/ FALSE Density is affect by gravity.

____ 31. Volume describes how much space matter occupies

____ 32. Properties that describe how an object taste, looks, feels, etc. are called

a. Chemical Properties
b. Density Properties
c. Physical Properties
d. Mass Properties

Density Test Post-Assessment
Answer Section

MULTIPLE CHOICE

1.	A
2.	D
3.	A
4.	A
5.	B
6.	C
7.	A
8.	D
9.	D
10.	C
11.	B
12.	C
13.	A
14.	A
15.	B
16.	D
17.	B
18.	A
19.	B
20.	D
21.	A
22.	B
23.	D
24.	A
25.	C
26.	C
27.	A
28.	B
29.	A

APPENDIX F

DENSITY TASK ASSESSMENT

Name____Date________Core_____

Pre- Post-Density Task Assessment

This assessment is to be done individually without help. It is an assessment of your understanding of the basic principle of density using a set of three objects that will be given to you.

Question: What is the density of the three objects?
Materials: Two cubes and one rectangular object that look the same, ruler, scale.
Task: You will be evaluated on your data collection procedures, the accuracy of your answer to the question, and your ability to demonstrate your understanding of density.

Below are the rubrics that you will be evaluated by:

Learning Target	Novice	Working Toward	Nearly Proficient	Proficient	Highly Proficient
7.3S.1 Scientific Inquiry- Data Collection	Student collects data that is inconsistent with procedures. Student attempts to display data, but displays are significantly incorrect. Data tables lack titles.	Student collects relevant and reasonable data consistent with procedures, with inaccuracies. Student displays data in an unorganized char/table. Units are incomplete or incorrect. Data tables include irrelevant titles.	Student collects relevant, accurate and nearly sufficient data consistent with procedures. Student displays data in an organized chart/table, but units may be incomplete or incorrect. Data tables include incomplete titles.	Student collects relevant, accurate and sufficient data consistent with procedures. Student correctly and accurately displays data labeled with appropriate units in an organized chart/table. Data tables include relevant titles.	Student collects relevant accurate and clearly sufficient data consistent with procedures. Student correctly/ accurately displays data labeled with appropriate units in an organized chart/table that facilitates analysis. Data tables include titles addressing the variables.

Learning Target	Novice	Working Toward	Nearly Proficient	Proficient	Highly Proficient
Density	Student only provides weight of objects or does not attempt task.	Student shows the beginnings of understanding of the relationship between mass, volume, and density. Provides weight of objects and part of a volume measurement. All 3 aspects (L, H, W) of objects are not measured. Density may be calculated as D = M*V.	Student shows understanding of the relationship between mass, volume, and density. However, they do not show how this physical characteristic can be used to determine whether one material is the same as another.	Student shows understanding of the relationship between mass, volume, and density, and how this physical characteristic can be used to determine whether one material is the same as another. States that cube and rectangle are same density	Student shows in-depth understanding o the relationship between mass, volume, and density, and how this physical characteristic can be used to determine whether one material is the same as another. Explicitly states that cube and rectangle are same density. Calculations/ measurements are exactly correct.

		Measure in inches.			

APPENDIX G

TEACHING METHODOLOGY PREFERENCE SURVEY

Teaching Methodology Preference Survey

For the purpose of the survey use the following definitions for teaching methodologies:
Traditional: Students read textbooks, take notes, complete worksheets, define vocabulary, and perform procedural labs. Student memorization of facts is important. There is a greater focus on the teacher being the expert and the deliverer of content information. Questioning strategies used by the teacher are used to elicit correct factual answers. Most classroom interactions are teacher-student
Inquiry-based: Students discover information through open-ended labs. The teacher is a guide and provides information as questions arise. Textbooks and readings are used as a reference to answer students questions as they experiment, but are not the focus of the class. Questioning strategies are used to get students to reflect and think on process and conceptual understanding. Most classroom interactions are student-student.

Record your response to the following statements:
1 = strongly agree 2 = somewhat agree 3 = somewhat disagree 4 = strongly disagree

Statement	**1**	**2**	**3**	**4**
I am most comfortable in a student-centered classroom	1	2	3	4
I am most comfortable in a teacher-directed class room	1	2	3	4
I am most comfortable in a classroom that is a combination of teacher-directed and student-directed activities	1	2	3	4
I use scientific inquiry frequently in my classroom (at least one time per unit)	1	2	3	4
I am comfortable with the process of scientific inquiry, even if I do not use it frequently in my classroom.	1	2	3	4
I would say that I primarily teach using inquiry-based methods	1	2	3	4
I would say that I primarily teach through traditional methods	1	2	3	4
I am concerned about the potential for off-task student behavior during the inquiry lessons	1	2	3	4
I can teach using inquiry-based methods	1	2	3	4
I can teach using traditional teaching methods	1	2	3	4
Total				

Any other information that you would like me to know?

APPENDIX H

TEACHER TRAINING SURVEY

Name:
Date of training:
Years you have taught science:
Degrees (list all):

Record your response to the following statements:

1 = strongly agree   2 = somewhat agree   3 = somewhat disagree   4 = strongly disagree

Statement	1	2	3	4
I understand what is expected of me as a teacher participant in this study	1	2	3	4
I think that I will be able to teach most of the lessons as they are written	1	2	3	4
I think that I will have to make a large number of modifications to the lesson so that I can teach them	1	2	3	4
The amount of work that is involved in teaching this unit looks reasonable	1	2	3	4
I have the materials that I need to teach the density unit	1	2	3	4
I am comfortable participating in a research study	1	2	3	4
I am confident in my understanding of the concept of density	1	2	3	4
I am confident in my ability to teach density	1	2	3	4
If the lesson is not working and students are not engaged or there are behavior issues, I will modify the lesson to suit my classroom needs	1	2	3	4
If I make lesson modifications, I will be comfortable communicating those modifications to the researcher in the *Teacher Self-Reflection Rubric*	1	2	3	4
I am familiar with and can use the materials that were given to me for the labs	1	2	3	4
I have access to the supplies that I need to do the labs that are not being supplied by the researcher (balances, beakers, graduated cylinders, tubs for water)	1	2	3	4
I consider myself to be an expert teacher	1	2	3	4
Total				

APPENDIX I

POST TEACHER SURVEY

Post Teacher Survey

Record your response to the following statements:
1 = strongly agree   2 = somewhat agree   3 = somewhat disagree 4 = strongly disagree

Statement	1	2	3	4
Students were engaged in the lessons of the density unit	1	2	3	4
I was able to teach most of the lessons as they were written	1	2	3	4
I had to modify some parts of the lessons, but the changes were not significant or reflected minor timing issues to suit my class schedule	1	2	3	4
I had to make major changes to several of the lessons because my students were not able to complete them as written	1	2	3	4
I had to modify most of the lessons to suit my classroom needs.	1	2	3	4
I accurately communicated any modifications to the lessons in the *Teacher Self-Reflection Rubric*	1	2	3	4
I understood the purpose of the different categories of density materials for the labs and why the materials for a given lab were chosen to be used	1	2	3	4
My students were able to use the materials in the labs	1	2	3	4
I had access to the supplies that I needed to do the labs that were not supplied by the researcher (balances, beakers, graduated cylinders, tubs for water)	1	2	3	4
I had a positive experience participating in the study	1	2	3	4
My students had a positive experience participating in the study	1	2	3	4
I will teach this unit again	1	2	3	4
I feel that my students made gains in their understanding of density as a result of this unit.	1	2	3	4
Total				

APPENDIX J

TEACHER OBSERVATION FOR FIDELITY OF IMPLEMENTATION

<table>
<tr><td>Length of class:</td><td>Length of observation:</td></tr>
<tr><td>Period:</td><td>Time of day:</td></tr>
<tr><td>Number of students:</td><td>Date:</td></tr>
<tr><td>Lesson Title:</td><td>Inquiry or traditional:</td></tr>
<tr><td colspan="2">Classroom Desk Arrangement: Desks in rows and columns ____ Desks in groups___ Desks in circle___</td></tr>
<tr><td colspan="2">General description of classroom. Note any unusual circumstances:</td></tr>
</table>

1 = With Fidelity	2 = Mostly with fidelity, minor changes to lesson	3 = Little to no fidelity, major changes to lesson
The teacher evidenced careful implementation of the lesson, eliciting many appropriate student responses. The teacher was clear, and kept a sustained focus on the purposes of the lesson.	The teacher evidenced some deviation in the implementation of the lesson, eliciting some appropriate student responses. The teacher was sometimes clear and focused on the purposes of lesson.	The teacher evidenced little or no understanding of the implementation of the lesson, major changes were made, that elicited minimal appropriate student responses. The teacher was unclear and unfocused regarding the purpose of lesson.

<table>
<tr><td colspan="3">Observation of the fidelity of implementation:
1 = with fidelity   2 = minor changes   3 = major changes</td></tr>
<tr><td rowspan="2">1.</td><td>The lesson plan was implemented as written</td><td>1 2 3</td></tr>
<tr><td colspan="2">Comments:</td></tr>
<tr><td rowspan="2">2.</td><td>The materials that were designed to be used with the lesson were used</td><td>1 2 3</td></tr>
<tr><td colspan="2">Comments:</td></tr>
<tr><td>3.</td><td>The materials were used appropriately as written in the lesson</td><td>1 2 3</td></tr>
</table>

	Comments:

Teacher and Student Behaviors
1 = most of the time 2 = some of the time 3 = very little of the time

4.	The students were engaged in the lesson	1 2 3
	Comments:	
5.	The teacher noticed if students were not engaged in the lesson and took action	1 2 3
	Comments:	
6.	The teacher spoke clearly and could be understood. Information given to students was coherent. Instruction made logical sense.	1 2 3
	Comments:	
7.	Teacher seemed confident as they taught the lesson	1 2 3
	Comments:	

APPENDIX K

TEACHER SELF-REFLECTION RUBRIC

Teacher Reflection for Lesson #_____________________ Date taught____________

1. Lesson plan

- ◻ I followed the lesson plan as it was written
- ◻ I modified the lesson plan to meet the needs of my students
  - ◻ I added the following (please give the reason if you have time)

  - ◻ I did not use the following (please give the reason if you have time)

2. Materials

- ◻ I used the materials for the lesson that were provided
- ◻ I modified the materials that were provided for the lesson
  - ◻ I used additional materials (please give the reason if you have time)

  - ◻ I did not use these materials (please give the reason if you have time)

3. Timing

- ◻ The length of the lesson fit my class time.
- ◻ The length of the lesson was too long for my class time.
- ◻ The length of the lesson was too short for my class time.
- ◻ Comments:

4. Difficulty

- ◻ The difficulty of the lesson was appropriate for my students.
- ◻ The lesson was too difficult for my students.
- ◻ The lesson was too easy for my students.
- ◻ Comments:

5. Additional comments

APPENDIX L

QUALITATIVE DENSITY ASSESSMENT

Name ______________________________ Date ________ Core ________

Density Assessment

Use words and pictures to explain your thinking

Why do objects float or sink?

Does mass alone explain why objects float or sink when placed in water?

(a) Mass alone explains floating and sinking
(b) Mass alone does not explain floating and sinking

Explain your thinking:

Does volume (or size) alone explain why objects float or sink when placed in water?

(a) Volume alone explains floating and sinking
(b) Volume alone does not explain floating and sinking

Explain your thinking:

Does density explain why objects float or sink when placed in water?

(a) Density explains floating and sinking.
(b) Density does not explain floating and sinking.

Explain your thinking:

What is denisty?

Is it possible to combine two materials that have different densities (one sinks and one floats in water) into a new object that has a density that is different from the original materials?

(a) It is not possible to combine materials to form a new material that has a different density
(b) It is possible to combine materials to from a new material that has a different density.

Explain your thinking:

Can objects that float in water, sink in another type of liquid?

(a) Objects that float in water, float in all liquids
(b) It is possible for the sinking and floating behavior of objects to change if you put the object in a different type of liquid

Explain your thinking

True or False. When an object sinks or floats, it is dependent on the relationship between the density of the object and the density of the liquid.

Explain your thinking.

APPENDIX M

SCORING RUBRIC FOR DENSITY QUALITATIVE ASSESSMENT

Student ID_______________________________________Teacher______________

<u>Scoring for Qualitative Density Assessment</u>

Scoring for explanation

2	1	0
Explanation is accurate with supporting details and examples	Explanation is partially accurate. Supporting details and examples may be lacking. Some gaps in understanding may be evident.	Explanation is inaccurate or too brief to demonstrate understanding. Explanation does not answer question.

= correct answer

Questions	Answer		Explanation			Answer type		
Does mass alone explain why objects float or sink when placed in water	a	b	2	1	0	Words + drawings	Words only	Drawings only
Does volume (or size) alone explain why objects float or sink when placed in water	a	b	2	1	0	Words + drawings	Words only	Drawings only
Does density explain why objects float or sink when placed in water	a	b	2	1	0	Words + drawings	Words only	Drawings only
What is density?			2	1	0	Words + drawings	Words only	Drawings only
Is it possible to combine two materials that have different densities (one sinks and one floats in water) into a new object that has a density that is different from the original materials	a	b	2	1	0	Words + drawings	Words only	Drawings only
Can objects that float in water, sink in other types of liquids?	a	b	2	1	0	Words + drawings	Words only	Drawings only
When a object floats, it is dependant on the relationship between the density of the object and the density of the liquid	True	False	2	1	0	Words + drawings	Words only	Drawings only
Total	____/6		____/14					

Qualitative Density Proficiency Score

	Highly proficient	**Proficient**	**Nearly Proficient**	**Working Towards Proficiency**	**Novice**
Answer Score	6/6 correct	6/6 correct	5/6 correct	4/6 correct	3/6 or less correct
Explanation Score	14	11-13	8-10	5-7	0-4
Total Score	19 - 20	16 - 18	12 - 15	8 - 11	7 and below
Answer type	Words and drawings indicate a detailed understanding of density. Multiple examples given.	Words and/or drawings indicate an understanding of density, but some supporting details may be lacking	Words and/or drawings explain density concepts. Examples and explanations are brief.	Only words or only drawings used. Understanding of density has clear gaps. Does not distinguish between mass/density. Knows volume does not affect sinking/floating	Only words or only drawings used. Major inaccuracies. Believe mass and volume both affect whether an objects sinks or floats

APPENDIX N

STUDENT ASSENT FORM

My name is ____ and I am going to participate in the density study that Mrs. Holveck is doing at my school.

I understand that all of my scores will be confidential. My name will never be associated with my scores or mentioned in the study.

I can ask my teacher or Mrs. Holveck for help at any time. If I do not want my scores to be used in Mrs. Holveck's study, I can tell her or my teacher.

Date ______

My signature____

☐ It is OK to audio tape me if I am chosen to do the task assessment

APPENDIX O

TREATMENT DENSITY LESSONS, TEACHER NOTES, AND KEYS

Lesson #1 – Scientific Inquiry Teaching Methodology

Properties of Matter

Teacher Notes

Introduction: The goal of this lesson is to familiarize students with the properties of matter. They will learn that everything that they touch, taste, and see is made of matter and that matter has characteristic properties.

Learning Objective: Students will identify properties of matter and sort objects by those properties.

Materials Needed:
1. *Comparing Cubes* Worksheet
2. *Properties of Matter* Lab Sheet
3. *Properties of Matter Word Search* Worksheet
4. Sets of objects (see below). Each table/lab group should have one set of materials in a basket that is on their desk.

Here is a suggested object list:

Various sizes, shapes, colors of wood	Wax	Cork	Feather	Bolt
Various types of balls, approx the same size (golf balls, ping pong balls, Styrofoam balls, wood)	Construction paper, sand paper	Ivory soap piece	Steel ball (same size as large wooden ball)	Feather
2 cylinders, different materials, same weight, different size	Button	Dial Soap piece	Acrylic beads	Nail
Fishing weights	Rocks	Pom-pom ball	Yarn	Rubber band

Lesson Plan
1. Begin the lesson with a formative assessment probe- *Comparing Cubes*. Students write ideas down on paper and then share with a partner (Think-pair-share). Open up the discussion to a larger group of students and then to the entire class. **Teacher does not tell students what the correct answer is at this time.** Have students save these worksheets. *(or you collect and save them to return later.)* They may not know what all the concepts mean at this time. Come back to this later in Lesson # 7 - *Calculating Density* when have an understanding of the quantitative definition of density.
2. **Background**: PROPERTIES OF MATTER- (Adapted from Cribb and Duane, 2010). Teacher Dialogue: say to students as an introduction. My thought on this part of the lesson is to run it as a discussion. Students do not need to take notes as you are just introducing ideas and eliciting prior knowledge. If you are more comfortable writing their response down on an overhead or on the whiteboard, that is OK.

a. **If you had an unknown substance in front of you, how would you describe it? How would your descriptions help you identify it?** (Can have students look at materials on desk that will be used for the lab) You could describe its size, its shape, whether it is soft or hard, smooth or rough. Every object has characteristics that help identify it.
b. **Ask students to define the word "matter"** (It is optional for you to review some of the popular uses of the word) Popular uses, "What is the matter with you?", "Matter of fact", "It is only a matter of time", "To make matters worse…" How could this use of the word matter relate to science?
c. **Define matter:** Anything that has mass and takes up space. Matter takes up space and has a certain size. It is anything that has mass and volume. It is something that you could see, smell, feel, or even taste. It is something that you can hold in your hand. Matter itself consists of various atoms and molecules, can be pure or impure, seen or not seen, living or non-living. Plants, animals, rocks, water, salt, gold, air, oxygen are all examples of matter. They all consist of atoms and molecules and they all take up space.
d. **Ask students to list things that are made up of matter.** Write their answers on the board.
e. **Are there similarities between these objects? Differences? Describe**
f. **All objects have different properties that can be used to identify them.** These characteristics of matter describe the object – or define the object. Characteristics of matter can be either physical properties or chemical properties.
g. **Physical properties**. Physical properties describe how the object looks, feels, tastes, etc. They are descriptions of what it is. Physical properties of matter include its mass, weight, volume, and density. It also specifically describes its odor, shape, texture, and hardness. In addition, physical properties describe whether the object is a solid, a liquid, or a gas – its phase of matter at room temperature.
    1. **Mass-** the amount of matter in an object. The mass of an object does not change from place to place.
    2. **Weight -** The weight of an object is determined by the force of the pull of gravity on the mass of the object. Because weight is based on the force of gravity, an object's weight may change from place to place. If you weigh 120 lbs on Earth, your weight will be 20 lbs on the moon, since the Earth's gravitational force is 6 times stronger than that of the moon.
    3. **Volume-** Volume describes how much space matter occupies.
    4. **Density-** Density is the mass per unit volume of an object and it allows you to compare different types of matter.
h. **Chemical properties.** Chemical properties describe how a substance can change into other new substances. Another way of phrasing that, chemical properties describe how reactive the substance is with other substances, and sometimes even tell what specific substances with which it reacts. An example of a chemical properties is flammability or the ability to burn, or that acids

and bases will react together (baking soda and vinegar will react together to form bubbles of carbon dioxide)

i. **"Mass, weight, volume, and density are properties of matter. What are other properties of matter?"** Students share in their groups and brainstorm ideas, then ask groups to share with you and write down student responses to share with class. Students can view objects on table for lab today to trigger responses. (Possible answers: texture, color, weight/mass, volume, melting point, boiling point, freezing point, reflectivity/shininess, temperature, density, solubility, malleability, ductility, hardness, softness, flammability, electrical conductivity, elasticity, size of atoms, type of atoms, sinking/floating, state of matter – solid, liquid, gas, plasma). All of these characteristics can be used by students to describe and group objects in this lesson.

j. **Characteristic properties of matter –**these are the specific properties of an object that cannot be changed without changing the nature of the substance. Examples are: Density, melting point, boiling point, conductivity, and heat capacity. (Some physical properties of matter can be changed without changing the substance. i.e. weight, mass, color, texture – these are not characterisitic properties)

k. **"Today you are going to practice your observational skills and describe the properties of a set of objects. You are then going to group objects by different properties."**

1. Each table group gets a collection of 20 or more objects. Each group should get an identical set of objects.
2. Part A: first = individual; second =work with partner
3. Part B: first = individual; second = share with table group; third = share as whole
   class
4. Part C: first = table group sorts 2 or 3 different times; second = table groups share out with whole class; suggested you have them show their groupings on the overhead or document camera.
5. Wordsearch- This is an optional vocabulary exercise. Students can complete it as homework.

Name____Date______ Core_______

Properties of Matter

How do the properties of matter vary in objects and how can they be used to describe and group objects together?

Part A. Doing observations – Pick 10 objects and describe their properties of matter. Notice that each object has a unique set of properties that distinguishes it from other objects. Create a data table to organize your observations. In addition to noting the object's physical properties, please note if the object is heavy or light for its size.

Which object that you described do you think was the heaviest for its size and which was the lightest for it size? Explain your thinking using words and pictures. Share with your partner. Do you agree?

Part B: *Look at all of the objects in the basket.*

1. What are some of the properties that some of the objects have in common?

Part C: *Sort objects according to properties.*

1. Using all of the objects in the basket (not just the 10 you described), divide the objects into groups so that each object in a group shares a similar property. List the properties that you sorted your objects by here. Every object needs to be in a group.

2. Try sorting again, using a different set of properties List how many different ways you can sort the same group of items. List the properties that you sorted them by.

Part D: *Answer these questions*

1. T/F If two objects have the same size but different weights, the heavier object is made of a heavier kind of material. Explain your answer.

2. T/F If two objects have the same weight but different sizes, then the smaller object is made of a heavier kind of material. Explain your answer.

3. T/F If two objects are made of the same material, equal-sized pieces would have the same weight. Explain your answer.

Name____

Properties of Matter Word Search

S	C	D	P	P	Y	O	Q	C	L	L	J	R	P	Y
O	D	I	I	R	J	T	O	D	A	I	E	Q	T	S
L	F	Y	T	L	O	L	I	C	Z	A	Q	I	D	S
U	O	T	Z	S	O	P	I	L	C	N	L	U	D	E
B	K	I	H	R	I	S	E	T	I	I	G	E	I	N
I	S	L	M	G	Y	R	I	R	B	T	N	G	E	D
L	O	I	O	H	I	V	E	A	T	S	C	M	A	R
I	F	B	P	W	I	E	M	T	I	I	U	U	O	A
T	T	A	M	T	X	M	W	T	C	L	E	D	D	H
Y	N	E	Y	G	A	S	Y	Z	O	A	O	S	K	S
Y	E	L	L	L	E	M	S	V	U	B	R	H	D	S
Y	S	L	F	C	H	E	M	I	C	A	L	A	I	A
A	S	A	R	E	R	U	T	X	E	T	J	P	H	M
H	T	M	S	S	E	N	H	G	U	O	R	E	B	C
N	C	O	N	D	U	C	T	I	V	I	T	Y	B	Y

Mass	Chemical	Softness
Weight	Properties	Hardness
Volume	Characteristic	Conductivity
Density	Color	Reactivity
Odor	Roughness	Smell
Shape	Malleability	Solid
Texture	Ductility	Liquid
Hardness	Flammability	Gas
Physical	Solubility	

Write the definitions for four words on the back of this sheet. Pick words where you are unsure of the meaning.

Keys and Extended Information

1. Comparing Cubes

Purpose: This formative assessment probe is used to elicit students' ideas about what properties of matter will change if the amount of material in an object changes.

Explanation: ***The best response is A***. The larger cube contains a greater amount of the same material, so its mass is greater. Mass is a property that depends on the amount of material. Melting point and size of atoms do not vary with the amount of material, so these would remain the same. Density is similar. It is expressed as a ratio of the mass to the volume, the proportion of mass and volume remains constant when comparing cubes of different sizes that are made out of the same material. Since the degree to which a solid object floats in water depends on the density of the material and the two cubes have the same density the larger cube is not more likely to float or sink in water than the smaller cube.

Middle School Students: The term characteristic property is introduced at this level in the national science standards. Students learn that characteristic properties are useful in identifying and comparing different substances. These properties can be observed without changing the identity of the matter. The properties that are most useful in identifying a substance are its characteristic properties.

2. Properties of Matter – Answers to Questions

Part B

1. What properties do some objects have in common? *Answers vary*
2. Which objects were easiest to describe? Which were hardest? Why? *Answers vary*
3. Which objects appear to be heavy for their size? *The metal objects*
4. Which objects appear to be light for their size? *Ping pong ball, feather*

Part D: *Answer these questions*

1. T/F If two objects have the same size but different weights, the heavier object is made of a heavier kind of material. Explain you reasoning *True. You could weigh the two objects that are the same size. The heavier object should have a greater weight.*
3. T/F If two objects have the same weight but different sizes, then the smaller object is made of a heavier kind of material. Explain you reasoning. *True. Find an object that is of the same material as the smaller object, but is also the same size as the larger object. Then weigh them. The object that is of the heavier material will weigh more.*
4. T/F If two objects are made of the same material, equal-sized pieces would have the same weight. Explain you reasoning *True. Weigh two objects that are the same size and the same material. They should weigh the same.*

Wordfind Solution

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S C D P + Y + + C L L + R + Y
O + I I R + T O + A I E + T S
L + Y T L O L I C + A Q I + S
U + T + S O P I L C + L U D E
B + I H R I S E T I I + E I N
I S L + G Y R I R B T N + E D
L O I + H I V E A T S C M + R
I F B P + I E M T I I U U O A
T T A + T + M W T C L E D D H
Y N E Y G A S Y + O A O S + S
+ E L L L E M S V + + R H + S
+ S L F C H E M I C A L A + A
+ S A + E R U T X E T + P H M
+ + M S S E N H G U O R E + C
+ C O N D U C T I V I T Y + +
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(Over,Down,Direction)
ROUGHNESS(12,14,W)
CHARACTERISTIC(15,14,NW)
CHEMICAL(5,12,E)
COLOR(9,1,SW)
CONDUCTIVITY(2,15,E)
DENSITY(14,4,SW)
DUCTILITY(14,9,NW)
SOLUBILITY(1,1,S)
FLAMMABILITY(4,12,NE)
GAS(5,10,E)
HARDNESS(15,9,N)
LIQUID(10,1,SE)
MALLEABILITY(3,14,N)
PROPERTIES(4,1,SE)
MASS(15,13,N)
REACTIVITY(13,1,SW)

WEIGHT(8,9,NW)
SHAPE(13,10,S)
SMELL(8,11,W)
SOFTNESS(2,6,S)
SOLID(7,5,NW)

TEXTURE(11,13,W)
VOLUME(9,11,NE)
ODOR(12,10,NE)
PHYSICAL(4,8,NE)

Lesson 2 - Sinking and Floating

Teacher Notes

Introduction: The purpose of this lesson is for students to make and test predictions about sinking and floating and to classify objects according to whether they sink or float. In this activity students will determine whether various objects sink or float in water. Whether an object sinks or float in a liquid depends mainly on two factors: density and buoyancy. However, at this point students do not need to explain why objects sink or float. They are rather to be encouraged to observe that the same objects will sink or float every time, i.e., that there is consistency in the way the objects behave. This will help students devise their own ideas about physical properties and how they can be used to describe and categorize objects. This lesson will also provide practice categorizing a variety of objects according to observable characteristics (Science NetLinks, 2000).

Objectives for this activity:

1. Predict and test an object's ability to float or sink;
2. Develop rules for sinking and floating;

Materials needed:

1. *Floating Logs* - Worksheet
2. Mini Inquiry Worksheet – Does the size of an object affect how it sinks or floats?
3. Tub of water for each group
4. Ruler for measuring the length of objects (**Do not** give students scales to measure the mass)
5. Sink/float objects for each table group (see below):

Opener – Floating Logs:	
Same material, different size, same density	multiple sizes of wood
Activity- Mini Inquiry: *Does the size of an object affect its ability to sink or float?*:	
Same material, different size, same density	Different sizes of plastic (sinks) Different sizes of styrofoam (float)
Same size, different density, appears same material	Different sizes of white Dial bar soap (sinks) Different sizes of white Ivory bar soap (floats)
Same size, different density, different material	Density cube set
Same size, different density, similar material	Pumice (floats) Basalt (sinks)
Different size, different density, different material, same weight	Density set of similar weights (cylinders)
Different size, same material, same density	Density set of same material (cylinders)
To force qualitative thinking about density and disequilibrium	Various objects that are large that float and that are small and sink

Lesson Plan

1. Opener – Testing for conceptual understanding - *Floating Logs*. Give students the handout for Floating Logs. Ask students to compete it and to write their rule. Have students share their answers with a partner. Then using different sizes of wood that are provided and the tub of water. Have students explore their response. Then have students write and share what they have learned. Students need to understand that the heaviness of an object is not related to its ability to sink or float. Very heavy objects (ocean going vessels) float and very small objects (a dime) sink. It is the "heavy for its size" or density of an object that determines if an object sinks or floats.

Note: can do the floating logs of various sizes as a demo instead of having students do it.

2. Mini Inquiry: *Does the size of an object affect its ability to sink or float?* Students will explore the properties of a variety of objects that have been selected to force them to think about what affects an object's ability to sink or float. Students are encouraged to look at objects that are made of similar materials but are different sizes and to look at objects that weigh approximately the same yet some sink and some float. Students should be developing a quantitative (or descriptive) understanding of density in this exploration.

3. The material set was deliberately chosen to force some conceptual thinking about the relationship between size and floating and sinking. Place the materials at a material station, allowing students to chose from the station. Tell them they should be purposeful in what they are picking, in order to answer this question (ie. they should include large things that will float and small things that will sink)

Name___________________________________Date__________Core___________

Mini Inquiry: *Does the size of an object affect its ability to sink or float?*

Materials: Assorted materials provided by your teacher at the materials station.

Explore the objects you are given: Determine if the size of an object affects the object's ability to sink or float.

1. Form a hypothesis that makes a prediction based on what you know. ***Does the size of an object affect its ability to sink or float?***

2. Write down what you **plan** to do to test your hypothesis. Be thoughtful about the objects that you are testing to answer this question. Describe why you chose certain objects to test.

3. Make a **data table** to record your results. Be sure to write down what you are testing, the size of the object, and whether it sank or floated.

3. Answer the question **using data from your data table**. *Does the size of an object affect its ability to sink or float?* (*Does a smaller object of the same material behave differently than a larger object of the same material?)*

4. Explain why you think objects sink or float. Draw a model that explains why an object that is smaller sinks and one that is larger that floats.

Keys and additional teacher notes

1. Extended Teacher Notes for **Floating Logs**

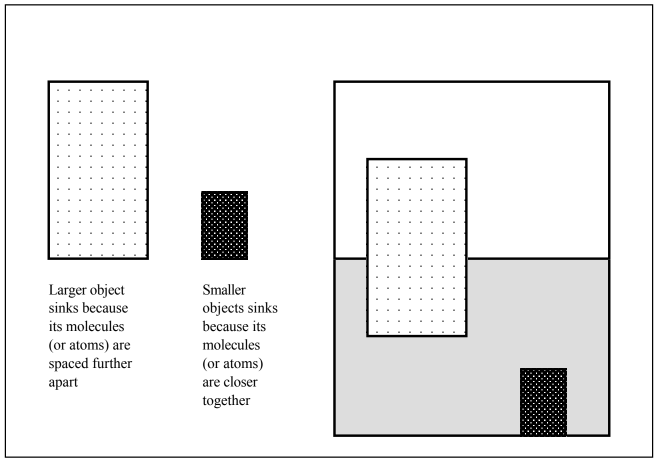
   Purpose: The purpose of the assessment probe is to elicit students' ideas about density. The probe is designed to find out if students think changing the size of an object affects its density.

   Explanation: ***The best response is B:*** Half the larger log floats above the water surface. The degree to which a solid object will float when place in water depends on the density of the material. When a second object is compared with a floating solid, a solid object with a lesser density will float higher above the water's surface, an object with the same density will float at equal levels, and an object with a greater density will be more submerged. Density is a characteristic property of matter, which means that it is independent of the amount of material. If one sample of material is very large and another sample of the same material is very small, the proportion (ratio) of the mass to volume of each sample is still the same, so the density remains the same. The first and second logs were both cut from the same tree, so they are made of the same material and have close to the same density (there might be a slight difference because the logs are not made of a homogeneous material.) Since the densities are for practical purposes the same, the two different-sized logs will float at equal levels. One-half of the first log floated above the surface, so one-half of the second (larger) log will also float above the water's surface.

   Instructional and Curricular Considerations: Middle School Students: In middle school, instructional experiences with density progress from observational (floating and sinking and heavy for its size) to a conceptual understanding of density as a characteristic property of matter. Students begin to use mathematics to quantitatively describe density. Students begin to use technical vocabulary such as mass, volume, and density. However, it is important to determine of they have a conceptual understanding of density before introducing the D = M/VB relationship.

2. **Mini Inquiry** : *Does the size of an object affect its ability to sink or float?* - The size of an object will NOT affect the object's ability to sink or float. The material determines if an object will sink or float.

3. Explain why you think objects sink or float. Draw a model that explains why an object that is smaller sinks and one that is larger that floats.


Larger object
sinks because
its molecules
(or atoms) are
spaced further
apart
Smaller
objects sinks
because its
molecules
(or atoms)
are closer
together

Mixing Materials

Teacher notes

Introduction: Students will continue to explore how objects sink or float by working with objects that have more than one type of material. Students will see that by changing the ratio a material that is less dense and the material that is more dense, that the overall density of the material will change. Students will look at this average density change as a factor of sinking and floating. They will try to create a neutrally buoyant object by adding and subtracting clay (a dense material) that covers a piece of cork (a less dense material).

Objectives for this activity:
1. Create three objects out of a clay and cork: one object will sink, one will float, and one that is neutrally buoyant.
2. Make a visual representation of 3 objects that are made of the same materials.
3. Explain how mixing the ratio of heavy for its size materials with lighter for its size materials changes how an object sinks or floats.

Materials needed:
1. *Floating High or Low*- Worksheet
2. Mini Inquiry - *How does changing the ratio of two different materials in an object affect its ability to sink or float?*
3. *Demo*
   - 3 styrofoam balls (one floats, one is neutrally buoyant, one sinks)
   - Clear jar big enough to add Styrofoam balls to for demo
   - water
4. Sink/float objects for each table group (see below):

Activity- Mini Inquiry: *How does changing the ratio of two different materials in an object affect its ability to sink or float?*			
Clay and corks to explore with	Water	Beaker	Baggies to put clay objects when lab is over to store for future use in Lesson #4

Lesson Plan
1. Students do opener. Review answers.
2. Before students begin their mini inquiry, they need to know what a neutrally buoyant object is. Demonstrate this by a discrepant event that involves using three different Styrofoam balls: one that is pure Styrofoam and floats, one that is Styrofoam with a small weight that has been added inside and is neutrally buoyant, one that is a Styrofoam ball with a larger weight and sinks in water. Weights should be embedded inside the Styrofoam balls so they are not readily visible to students.
3. Ask students: **What are they observing?** Ask for their explanations

4. Explain that an object that is neutrally buoyant neither sinks nor floats in water. (It should be in the middle of the beaker of water). It has the same density as water. Objects that are less dense than water float in water, objects that are greater in density than water sink in water.
5. Hold up a pure Styrofoam ball and a weight. Ask students which is heavy for its size (weight) and which is lighter for its size (Styrofoam)? Put both objects in the water Styrofaom will float and weight will sink.
6. Is it possible to combine these two materials to get what you observed in the discrepant event?
7. Ask students? Can combining objects that are heavy for their size and lighter for their size explain what you are observing?
8. Which object is larger in size? (Styrofoam) Which object is smaller (weight).
9. Does the size of the object affect its ability to sink or float? (No)
10. What affects its ability to sink or float? (The material of the object)
11. Challenge students that they will be creating three objects from two different materials. One will need to float in water, one will need to sink in water and one will need to be neutrally buoyant in water.
12. Students will work in groups of four.
13. Ask each group to keep these three clay objects for their next lab. Be sure that students put them in baggies and label them with their name on it. They will need them for Lab #4 and #5.

Name____________________________________**Date**___________**Core**_______

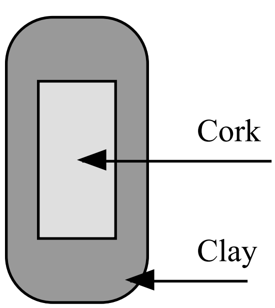
Mini Inquiry*: How does changing the ratio of two different materials in an object affect its ability to sink or float?*

Materials: Clay, corks, beaker of water

A. Observe the sinking and floating properties of pure clay and pure cork. Try different sized pieces of clay and cork. Do they behave differently? Write and draw what you observe here.

B. Which material is heavy for its size and which material is lighter for its size? Draw a diagram of a material that is heavy for its size. Draw a diagram of a material that is light for its size.

C. Using clay and cork in each object create three different objects: one that sinks in water, one that floats in water, and one that is neutrally buoyant in water (floats in the middle of the water, neither sinking or floating). Draw and describe your objects using a darker color for the clay and a lighter color for the cork. Be sure to draw the relative ratio of cork to clay in each drawing.

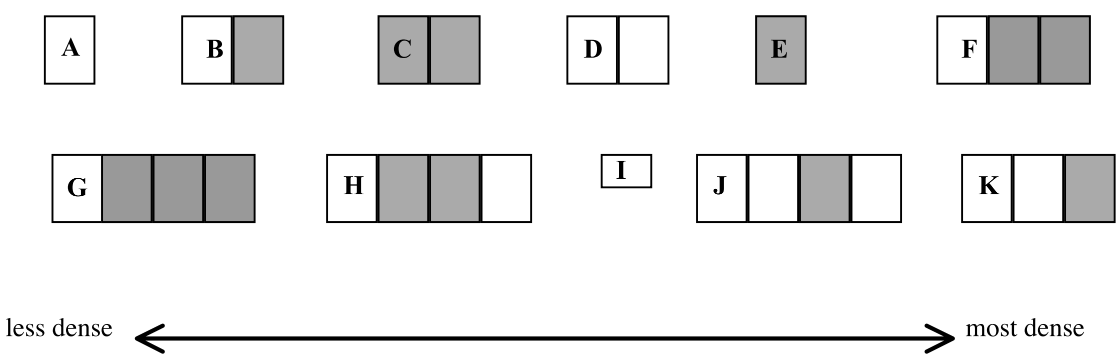


D. Explain how changing the ratio of two different materials in an object can affect its ability to sink or float. Use diagrams to help you explain your answer.

E. Explore the following using the three objects that you made: *Does changing the amount of water cause an object to float differently?* Draw and picture of what you observed and write down what you discovered.

F. Put the three clay objects that you created in a baggie and label it. After you have done, explain your rule for changing how an object floats in water.

G. Order the following objects from least dense to most dense , where ▭ = a heavy for its size material and ▭ = a light for its size material. Some objects are a combination of the two materials. Hint: Some objects may have the same density



Keys and additional teacher notes

1. Extended Teacher Notes for **Floating High and Low**

   Purpose: The purpose is to elicit students' ideas about density and buoyancy. The probe is designed to find out how students think an object can be made to sink or float differently.

   Explanation: ***The best responses are C and G.*** To make the solid ball float so that most of it is under the water, you can either use a ball of the same size made out of a denser material or attach a weight to the ball. The degree to which a solid object will float when placed in water depends on the density of the material. To be further submerged, the density of the object must be further increased. Density is defined as the ratio of the mass to the volume of an object. By using a ball of the same size made out of a denser material, the ration of the mass to volume is greater and the object will be further submerged. By taping a weight to the ball, the proportion of the total mass relative to volume is increased, so the overall density is increased. This too will result in the object being further submerged. As more matter is attached to the ball the buoyant force increases, indicated by the displacement of more water.

   Adding more water to the tank makes no difference in how a object floats. An object floats the same way regardless of how deep or shallow the water is. Adding salt to the water actually makes the object more buoyant because the salt increases the density of the water, For example, when you swim in the ocean, you float better than when you swim in freshwater because saltwater is denser than freshwater (This is will be covered in the next lesson).

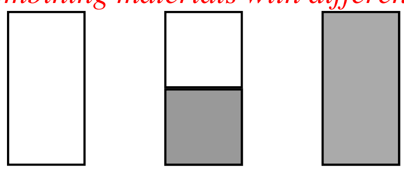
   Instructional and Curricular Considerations: In middle school, observational experiences that involve floating and sinking progresses to instructional opportunities at a conceptual level involving density. This probe is useful in determining if students can explain the significance of the characteristic property of density in relation to changing how an object floats: if an object's mass relative to its volume is increased, its density will increase. It can also be used to see if students recognize the effect of opposing forces when weight is added to a floating object in a fluid.

4. **Mini Inquiry :** *How does changing the ratio of two different materials in an object affect its ability to sink or float?- Changing the ratio of materials in an object will affect the object's ability or sink or float. A greater proportion of denser material (clay) will increase the overall density of an object. A great proportion of less dense material will decrease the overall density of an object.*

C. Using clay and cork in each object create three different objects: one that sinks in water, one that floats in water, and one that is neutrally buoyant in water (floats in the middle of the water, neither sinking or floating). Draw and describe your objects using a darker color for the clay and a lighter color for the cork.

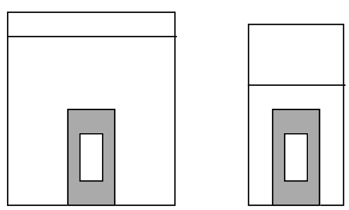
All clay (sinks) *mostly clay (sinks)* *clay w/cork (neutral)* *more clay w/cork (floats)* *all cork (floats)*

A. Explain how changing the ratio of two different materials in an object can affect its ability to sink or float. Use diagrams to help you explain your answer. *Combining materials with different densities will change the density of the object*



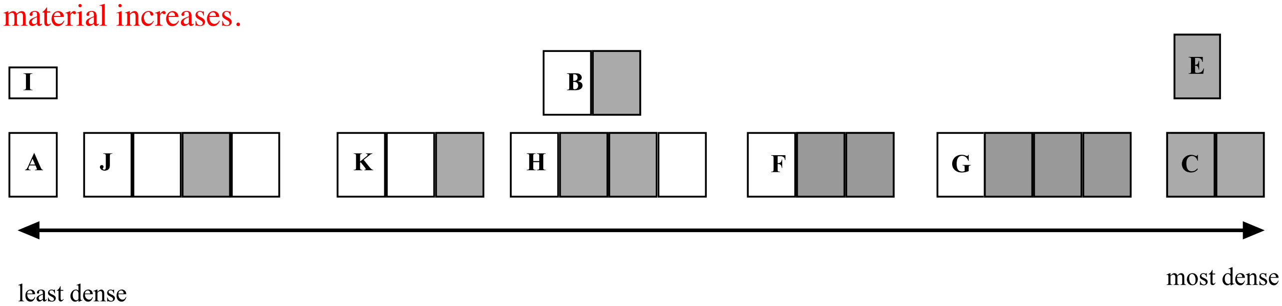
less dense floats *combination neutrally buoyant* *most dense sinks*

B. Explore the following using the three objects that you made: *Does changing the amount of water cause an object to float differently?* Draw and picture of what you observed and write down what you discovered. *The amount of water does not matter.*



C. After you have done these activities, explain your rule for changing how an object floats in water. *An objects floats or sinks dependant on the ratio of materials in it.*

G. Order the following objects from most dense to least dense , where = a heavy for its size material and = a light for its size material. Hint: Some objects may have the same density This question would be good to evaluate student conceptual understanding of ratios materials in mixed objects affecting density. You may need to review question with the class.
Note as you move from least dense to more dense the ratio of the "heavy for its size" material increases.



Lesson #4 – Scientific Inquiry Teaching Methodology

Changing the Liquid

Teacher Notes

Introduction: In the *Floating High and Low* formative assessment, one of the choices (F) was adding salt to the liquid. The addition of salt to water can change if an object sinks or floats. Objects will sink if their density is greater than the density of the liquid they are in and objects will float if their density is less than liquid they are in. Objects are neutrally buoyant if their density is the same as the liquid that they are floating in.

Objectives for this activity: Students will use the set of objects that they have been using in the previous 3 lessons and explore the sinking and floating properties of some of these objects in two different liquids: isopropyl alcohol and salt water. Alcohol has a lower density than water and salt water has a higher density than water. Some objects that sink in water will float in alcohol. Some objects that sink in water and alcohol, will float in salt water.

Materials needed:

Lab sheet for the Mini Inquiry - *How does changing the liquid an object is put into alter how an object sinks or floats?*

<table>
<tr><th colspan="4">Activity- Mini Inquiry: How does changing the liquid an object is put into alter how an object sinks or floats?</th></tr>
<tr><td>Clay and cork object students created from Mini Inquiry in Lesson #3, more clay (save for lab #5)</td><td>Salt</td><td>Alcohol</td><td>Beakers</td></tr>
<tr><td>A variety of plastic objects that are near the density of water (between 1.1 g/cm^3 – 2 g/cm^3), or an egg</td><td colspan="2">Spoon</td><td>Wax (or candle)</td></tr>
</table>

Lesson Plan:

1. Refer students to the *Floating High and Low* formative assessment. Remind them of response “F” - add salt to the water. Today, students will be exploring that response.
2. Changing the liquid by adding salt can change how an object floats in water.
3. Using plastic objects (or an egg) that are close to the density of water, students will add salt to the water to see how this affects the object from sinking and floating.
4. Students should keep track of how much salt they are adding (by spoonful is enough) and stir after each addition.
5. Once students have explored adding salt to water and changing how a plastic object floats. ask them to try the three clay/cork objects they made that are from the previous lab (#3).

6. The clay/cork object that was neutrally buoyant in water will now float in the salt water. Ask students to modify this object so that it is once again neutrally buoyant. (They will need to add more clay).
7. The final exploration is using wax and putting it into the salt water they made, pure water, and alcohol. Students will write what they observe.
8. Talk about student results and findings.
9. What is important in determining if an objects sinks or floats? *Its relative density to the liquid.*

Name____Date______________Core____

Mini Inquiry: *How does changing the liquid an object is put into alter how an object sinks or floats?*

Objective: Learn how changing the liquid that objects are put into affects whether they sink or float. There will be two explorations that will help you understand this principle today.

Materials: Three clay and cork objects from previous lab, egg, wax, salt, spoons, beaker, stirring rod, water, alcohol.

Background: Write what you already have learned about objects that sink and float. Use labeled drawings to help explain what you know.

First exploration – Salty water (density is greater than water):

1. Using the egg (or plastic object), salt, water, stirring rod, spoon and the beaker, create a salt solution where an egg (or plastic object) that sinks in pure water will float in salty water. Create a data table to keep track of how much salt you are adding and your observations.

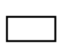
2. After you have created you salt solution– Put your group's three cork and clay objects from the previous lab into the salty water. Record your observations. What object(s) is behaving differently?

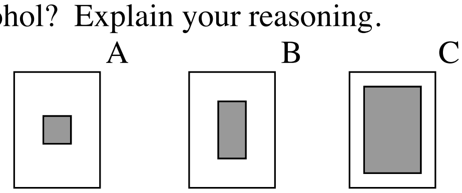
3.Take the clay/cork object that was neutrally buoyant in pure water and make it neutrally buoyant in the salty water that you have made. What are you going to have to do to accomplish this? (Add or subtract clay) Before you begin, draw and describe what you have to do and the scientific reason why you are going to do it.

4. Follow your procedure. Did it work? Explain your results. Draw both clay/cork objects by showing the ratio of clay to cork. Save your clay/cork objects in your baggie for the lab tomorrow.

Second exploration – Alcohol (density is less than water)

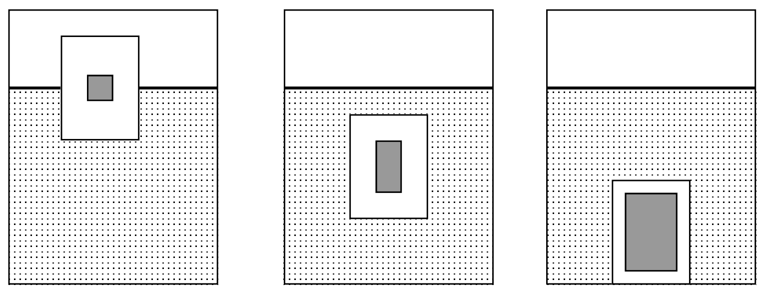
1. Using wax or a candle, compare what happens when you place it in water versus alcohol. Write what you learned about the density of the wax versus the density of the liquids. Use drawing to help explain your thinking.

2. You are given three neutrally buoyant objects below. = a material that has a high density,  = a material that has a low density. These objects each contain some of each type of material. Which object is neutrally buoyant in water? In salty water? In alcohol? Explain your reasoning.



Keys and additional teacher notes

Background: Write what you already have learned about objects that sink and float. Use labeled drawings to help explain what you know. *Objects float or sink in liquids based on the material that they are made of. This material determines density of the object. Density is a characteristic property of matter. If an object is heavy for its size and has a density that is greater than water, it will sink in water. If an object is light for its size and its density is less than water it will float in water. If an object has the same density as water it will be neutrally buoyant in water. Objects can be made of mixed materials. By changing the ratio of these materials you can change whether a mixed object will sink, float, or be neutrally buoyant in water.*



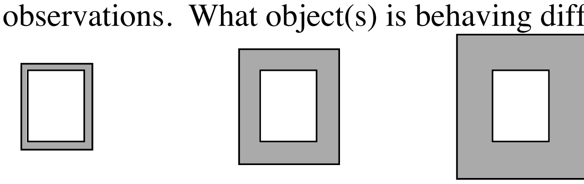
Mixed object =floats   neutrally buoyant   Mixed object = sinks

First exploration – Salty water (density is greater than water):

1. Using the egg (or plastic object), salt, water, stirring rod, spoon and the beaker, create a salt solution where an egg (or plastic object) that sinks in pure water will float in salty water. Create a data table to keep track of how much salt you are adding and your observations.

# of spoons of salt	Observations
2	Egg floated
4	Egg floated
6	Egg floated
7	Egg floated
8	Egg Neutrally buoyant

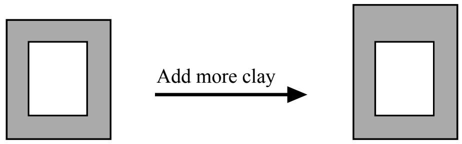
2. After you have created a salt solution that will float an object that previously sank in water – Put your group's three cork and clay objects from the previous lab in the salty water. Record your observations. What object(s) is behaving differently?



still floats   is not neutrally buoyant need to add more clay   still sinks

behaves the same   behaves differently   behaves the same

3. Take the clay/cork object that was neutrally buoyant in pure water and make it neutrally buoyant in the salty water that you have made. What are you going to have to do to accomplish this? (Add or subtract clay) Before you begin, draw and describe what you have to do and the scientific reason why you are going to do it.

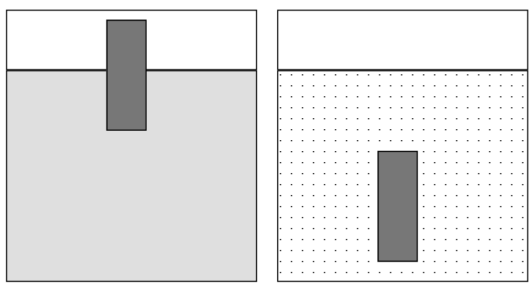


I need to add more clay because clay is more dense than cork. In order the cork and clay object to be neutrally buoyant in salt water which is denser that regular water, I need to make the average density of the object greater. I can do this by adding clay.

4. Follow your procedure. Did it work? Explain your results. Draw both clay/cork objects by showing the ratio of clay to cork. See above

Second exploration – Alcohol (density is less than water)

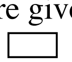
1. Using wax or a candle, compare what happens when you place it in water versus alcohol. Write what you learned about the density of the wax versus the density of the liquids. Use drawing to help explain your thinking.



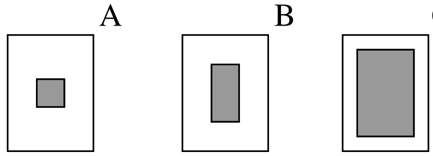
Candle floats in water
The density of the water
is greater than the density
of the candle

Candle sinks in alcohol
The density of the alcohol
is less than the density
of the candle

The density of the candle is in between the density of water and alcohol.

2. You are given three neutrally buoyant objects below.  = a material that has a high density,  = a material that has a low density. These objects each contain some of each type of material. Which object is neutrally buoyant in water? In salty water? In alcohol? Explain your reasoning.

A B C



A = Neutrally buoyant in alcohol because it has the least average density of the three objects
B = Neutrally buoyant in water because it has the middle average density

C = Neutrally buoyant in salt water because it has the highest average density of the three objects
Alcohol is the least dense liquid and the least dense object will be neutrally buoyant in it.
Salt water is the densest liquid and the most dense object will be neutrally buoyant in it.

Lesson #5 – Scientific Inquiry Teaching Methodology

Measuring Matter

Teacher Notes

Introduction: Students will review how to use a triple beam balance to measure mass. IF you have done this recently, you can skip this review. Then students will work to understand that density can not be determined by mass alone. There are objects that weigh very little, like a small marble, that are much more dense than a large log that weighs hundreds of pounds, but is less dense.

Objectives for this activity: (1). Determine the mass of an object. (2). Discover that the density of an object is not determined by mass alone.

Materials needed:

0. *Solids and Holes* worksheet
2. Flat piece of Styrofoam without holes
3. Flat piece of wood with holes and without holes
4. Tubs of water
5. One triple beam scale for each table group
6. *Reading a Triple Beam Balance* and *Using the Balance* worksheets (if needed).
7. Discover Activity Sheet – *Does the mass of an object affect its ability to float?*
8. 11 objects from Lessons # 1 and #2- for each group + pieces of Styrofoam that students can put hole into and wood that has holes and wood that does not:

Sinking clay ball	Pumice rock	Dial soap bar	Ivory soap piece
Neutral clay ball	Other rock	Small piece of wood	Dial soap piece
Floating clay ball	Ivory soap bar	Large piece of wood	

Lesson Plan:

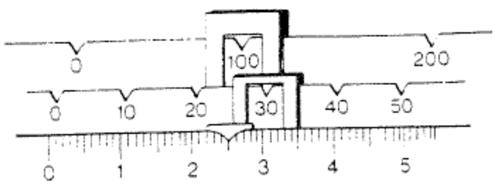
1. **Opener: Solids and Holes**
2. **Intro to using a triple beam balance (demo if needed)**
3. **Reading a Triple Beam Balance/Using the Balance Worksheet** to practice reading a balance (use only if you have not done any work with a triple beam balance this year). Pass out to students have them complete it, work a few examples together, then review answers as a class.
4. Students do the activity **– Does the mass of an object affect its ability to float?**
5. Students can brainstorm their ideas in a group.
6. You can direct this portion of the lab through questioning as students think about how to performs an experiment to test this.
    a. The point of today's lesson is to bring out the misconceptions that more density = more weight, all heavy objects sink, all light objects float, etc. Have students prove their points about heavy vs. light and sink vs. float with data

Reading a Triple Beam Balance

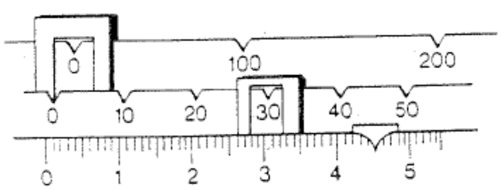
Name ______________________

To determine the mass or weight of an object using a triple beam balance, find the sum of the masses shown on all the riders.

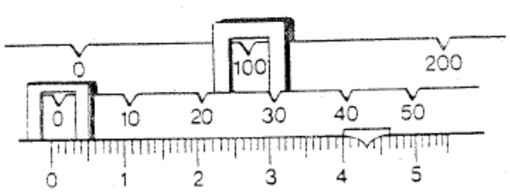
Find the mass indicated on each of the triple beam balances pictured below.



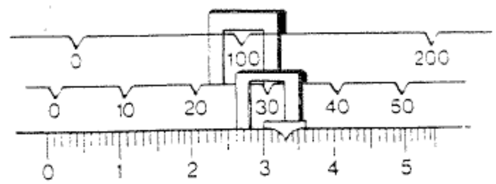
1. ______________________



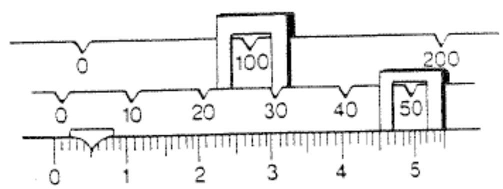
2. ______________________



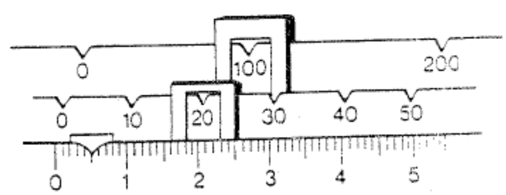
3. ______________________



4. ______________________



5. ______________________



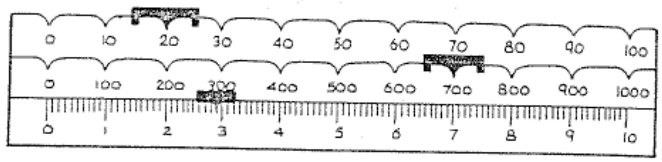
6. ______________________

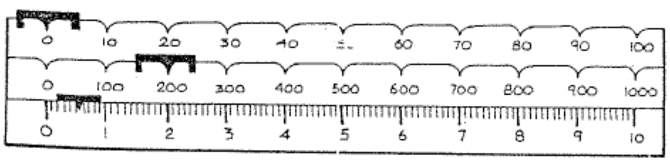
USING THE BALANCE

Name ____________________

The following balance measure mass is grams. What masses are shown on each of the following balances?

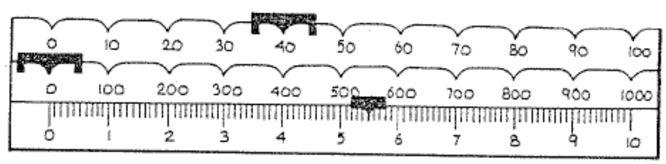
Answer: ____________________

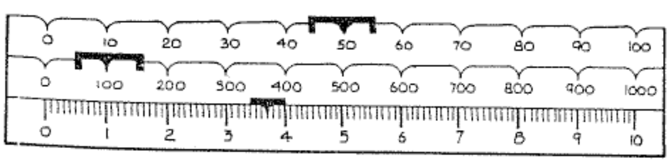




Answer: ____________________

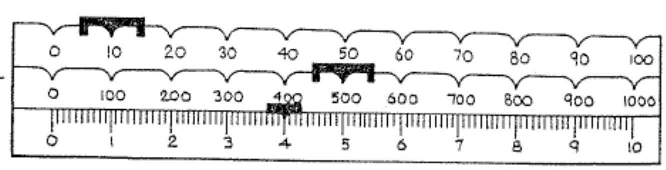
Answer: ____________________





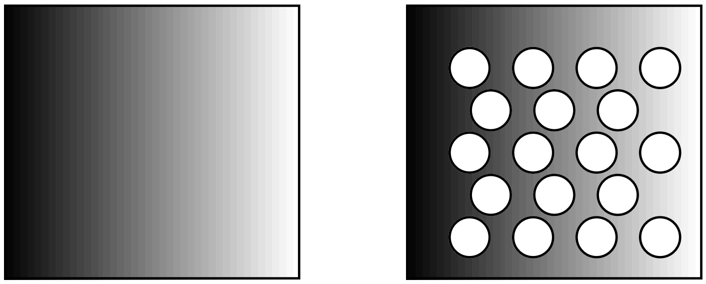
Answer: ____________________

Answer: ____________________



Name____ Date___________

Solids and Holes



Lance had a thin, solid piece of material. He placed the material in water and it floated. He took the material out and punched holes all the way through it. What do you think Lance will observe when he puts the material with the holes back in the water? Circle your prediction.

____**A.** It will sink.
____**B.** It will barely float.
____**C.** It will float the same as it did before the holes were punched in it
____**D.** It will neither sink nor float. It will bob up and down in the water.

Explain your thinking. Describe the "rule" or reasoning you used to make your prediction.

Name____ Core ___________

Does the mass of an object affect its ability to sink or float?

Work with your table group answer these questions

1. Background: Write what you already think you know about the relationship between an object's mass and its ability to float. Can you think of some very heavy objects that float? Think about the opener. Did the material of the object change? Did its mass change? Did its ability to float change?

2. Generate a hypothesis and write this here

3. You must use these materials to answer the question: Sinking clay ball, floating clay ball, neutral clay ball, pumice, basalt, large wooden ball, small wooden ball, full bar of Dial soap, full bar of Ivory Soap; scale. If you are testing additional objects, write down what you are going to test.

4. What procedures will you need to perform and measurements you will need to take in order to answer this question? Summarize them briefly here – before you begin testing.

5. Create the data table(s) to record the information you need. Use additional paper if there is not enough room here. (Hints: ideas for data table that you might find useful: Data table to record object's name and its mass, Data table that compares and objects ability to sink or float with its mass)

6. Complete this chart based on what you think density might be

Most Dense Material ⟶ *Least Dense Material*

List the objects made of given material			
Sink or Float?	***Sink***	***Neutral***	***Float***

7. Based on your investigation answer the question: **Does the mass of an object affect its ability to sink or float?** Be sure to use actual data that you obtained in your inquiry.

8. What do you think is affecting an object's ability to sink or float?

9. What do you think it means for a material to be more dense or less dense? What factors are affecting an objects density?

Teacher Key

Does the mass of an object affect its ability to sink or float?

Work with your table group answer these questions

1. Background: Write what you already think you know about the relationship between an object's mass and its ability to float. Can you think of some very heavy objecst that float? Think about the opener. Did the material of the object change? Did its mass change? Did its ability to float change? Information should include might include some of the following: large ships that are very heavy float, large trees float. When an object that sinks has holes put into it, reducing its mass, it still sinks when it is put into water. Heavy bar of soap (ivory) floated in the last lab while a tiny piece of Dial soap sank.

2. Generate a hypothesis and write this here. The mass of an object is not what determines in an object sinks or floats.

3. You must use these materials to answer the question: Sinking clay ball, floating clay ball, neutral clay ball, pumice, basalt, large wooden ball, small wooden ball, full bar of Dial soap, full bar of Ivory Soap; scale. If you are testing additional objects, write down what you are going to test. Styrofoam with and without holes, wood with and without holes.

4. What procedures will you need to perform and measurements you will need to take in order to answer this question? Students will need to weigh all objects and then rank them by mass. They should also be looking at the materials that the objects are made of. If they do not know if the object sinks or floats, then they will need to test it.

5. Create the data table(s) to record the information you need. Use additional paper if there is not enough room here. (Hints: ideas for data table that you might find useful: Data table to record object's name and its mass, Data table that compares and objects ability to sink or float with its mass)

Object	Mass (g)
Pumice	*< 5 g*
Rock	*15 - 25 g*
Floating clay ball	*< 20 g*
Neutral clay ball	*21.5 – 23.5 g*
Sinking clay ball	*39 - 40 g*
Dial Soap- bar	*113 grams*
Ivory Soap- bar	*90 grams*
Dial Soap - piece	*1.5 – 3 g*
Ivory Soap - piece	*1.5 – 3 g*
Large wooden ball	*17 – 20.5 g*
Small wooden ball	*5.5 – 7.5 g*

Heaviest → ***Lightest***

Describe Object	*Dial Soap*	*Ivory Soap*	*Sinking clay ball*	*Neutral clay ball*	*Rock*	*Floating clay ball*	*Large wooden ball*	*Small wooden ball*	*Pumice*	*Dial piece*	*Ivory Piece*
Sink, Float, or Neutral?	*Sink*	*Float*	*Sink*	*Neutral*	*Sink*	*Float*	*Float*	*Float*	*Float*	*Sink*	*Float*

6. Complete this chart

Most Dense Material → *Least Dense Material*

List the objects made of given material	*Clay (solid)* *Rock* *Dial soap*	*Clay & Cork*	*Less Clay & Cork* *Pumice* *Ivory Soap (full of air)* *Styrofoam with and without holes, wood with and without holes*
Sink or Float?	***Sink***	***Neutral***	***Float***

7. Based on your investigation answer the question: **Does the mass of an object affect its ability to sink or float?** Be sure to use actual data that you obtained in your inquiry. No. Students should be able give specific numeric data that some heavy object like blocks of wood floated and objects with less mass sank.

8. What do you think is affecting an object's ability to sink or float? The material that the object is made of affects it ability to sink and float. Things that are heavy for its size sink and things that are light for its size float.

9. What do you think it means for a material to be more dense or less dense? More dense objects are heavier for their size. Less dense objects are lighter for their size.

Lesson #6 – Scientific Inquiry Teaching Methodology

Exploring Volume

Teacher Notes

Introduction: This lab is to help students learn how to measure volume accurately. They will learn about the importance of measuring a liquid by viewing the meniscus at eye level, they will measure the volume of a drop of water and how many drops it takes to make 1 mL of water. Students will determine volume using two different methods. 1). For rectangular solids – measuring the three sides of an object and using the formula: Volume = length x height x width. 2). The water displacement method - the volume of the object is equal to the volume of water it displaces. They will use two different methods, one where they put the object in a graduated cylinder and one where they put the object in an overflow canister.

Objectives for this activity:

1. Learn how to measure volume accurately
2. Determine the volume of objects using a variety of methods.

Materials needed for each group:

1. *What Will Happen to the Weight?* Worksheet
2. Beaker, wooden block, scale for *What Will Happen to the Weight* formative assessment
3. *Reading a Graduated Cylinder/ Measuring Liquids Worksheet* (if students need the review)
4. *Exploring Volume* lab worksheet
5. Materials for the *Exploring Volume Lab* are listed below

10 mL, 100 mL graduated cylinders	Rectangular solids	Beaker
5 mL Disposable transfer pipets 24 – 26 drops/mL	Overflow can	3 identical marbles
Objects that sank in Sink/Float lab (clay ball, soap sliver, basalt, etc)	Calculator	Metric ruler

Lesson Plan:

1. **Opener:** *What Will Happen to the Weight?* – This formative assessment is meant as a follow up on the *Sinking and Floating* Labs and the *Measuring Mass* Activity. The purpose is to elicit students' ideas about weight. The probe is designed to determine whether students recognize that the gravitational force on an object and thus its weight is the same whether an object is floating in water or outside of water. Make sure that students understand that the block and the bucket of water are side by side on the scale and that the block is then put into the bucket of water while on the scale.

2. **Teacher can demonstrate this to class.**

3. Getting ready for today's lesson. Students will notice that the volume level of the water will change when an object is added to it. In fact, one of the ways that we measure the volume of irregularly shaped objects is by how much water an object that is placed in water displaces. Today, students will learn more about this.

4. **Intro** to reading at the meniscus of a graduated cylinder (only if needed)

5. You can review how to read a graduated cylinder with your students if it has been a while since you have done this. Use the worksheets *Graduated Cylinder/Measuring Liquids* to practice (only if needed)

6. **Part A:** table groups explore raising the water level and reading a graduated cylinder

7. **Part B: first** = table groups find volume using water displacement in graduated cylinder (note: depending on students' past lab experience, you may need to demo this process first)

8. **Part C: first** =table groups find volume using water displacement in an overflow can (note: again, students may need a demo of this process before attempting it in groups)

9. **Part D:** table groups use ruler and formula to find volume (note: students may need practice using a metric ruler before this lab). They will then put these objects in water and use the water displacement method to confirm that both methods will give the same results. Use the assorted plastic rectangular solids and square density cubes for this lab that can be submerged in water.

Name ________________________________ Date__________

Exploring Volume

Part A: *How many drops of water will it take to equal one milliliter? My prediction = ____ drops.*

Materials: Small graduated cylinder Medicine dropper Beaker of water

Procedure:
1. Fill a small graduated cylinder with 6mL of water. Be careful to read the water at the bottom of the meniscus.
2. Count the number of drops is takes to raise the water level from 6mL to 7mL. Record this number on the data table below.
3. Leave the 7mL water in the graduated cylinder. Count the number of drops it takes to raise the water level from 7mL to 8mL. Record this number on the data table.
4. Leave the 8mL water in the graduated cylinder. Count the number of drops it takes to raise the water level from 8mL to 9mL. Record this number on the data table.
5. Were the number of drops the same each time? If yes, record this number in the average column. If the number of drops varied, average them and record the average.

Data Table:

# of drops to raise water level from 6mL to 7mL	# of drops to raise water level from 7mL to 8mL	# of drops to raise water level from 8mL to 9mL	Average # of drops needed to raise water 1mL

Using your results calculate the average volume of a drop of water. ______mL = a drop of water

Part B: *How do you find the volume of an object using water displacement in a graduated cylinder?*

Materials: 100mL graduated cylinder 3 marbles Calculator

Procedure:
1. Add 20 mL water to a 100 mL graduated cylinder. Record this amount in the first column of the data table below.
2. Add the three marbles, one at a time, to the cylinder and measure the height of the water. Record this in the second column.
3. Find the difference between the two measurements. This is the volume of three marbles. Write the difference and the volume on the table.

3. Divide the volume of three marbles by three to find the volume of one marble. Record.

Beginning water level (mL)	Water level after adding 3 marbles (mL)	Difference (mL)	Volume of 3 marbles (mL)	Volume of 1 marble (mL)

Explore how the volume measurement of water changes as you hold the graduated cylinder at eye level and below and above eye level. How much does the volume reading change by when you do this? What data have you found that supports the technique of reading liquid volume in a graduated cylinder only at eye level?

Part C: *How do you find the volume of an object using water displacement in an overflow can?*

Materials: Overflow can Graduated cylinder
Sinking objects from Sinking and Floating lab

Procedure:
1. Fill the overflow can with water until it spills through the spout. Wait for the spout to stop dripping.
2. When the can stops dripping, carefully slide a graduated cylinder under the spout.
3. Slowly place the first object into the can without touching the water with your fingers. Water will begin coming out of the spout.
4. When the spout stops dripping, measure the amount of water in the graduated cylinder. This amount of water is the object's volume in milliliters. Record this volume on the data table below.
5. Empty the can and the cylinder and repeat steps 1-4 with the other objects.

Data Table:

Object	Volume (mL)

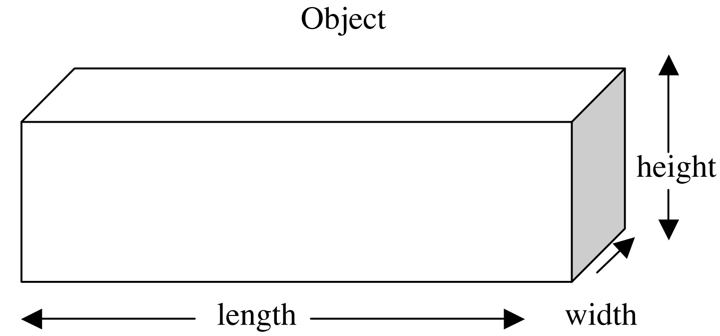
Part D: *How do you find the volume of a rectangular object using a formula?*

Materials: Ruler Calculator Rectangular objects (that can get wet)

Procedure:
1. Use a metric ruler to measure the length, width, and height of three rectangular objects in centimeters. Remember, each millimeter line

between centimeters represents 0.1cm (5.7cm = 5cm + 7mm). Record these on the data table below.

2. Multiply length x width x height on a calculator. This is the rectangular object's volume in cubic centimeters (cm^3). Record this on the data table.



Data Table:

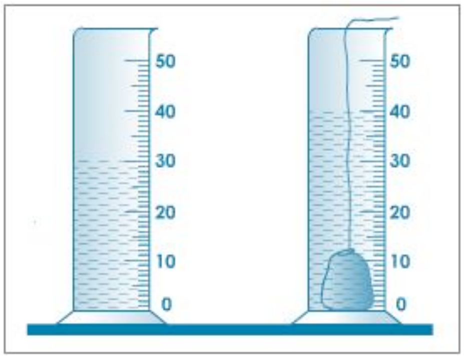
Object #	Length (cm)	Width (cm)	Height (cm)	Volume (cm^3)

Check the calculated volume of your rectangular solid by using the water displacement method.

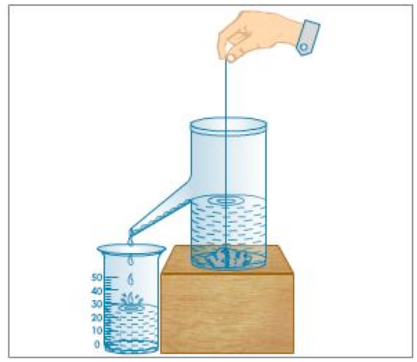
Object #	Calculated volume (from data table above)	Water displacement volume	Are they the same?	If not, explain why you think that they are different

Part E. *Answer these questions*.

1. Using the water displacement method. What is the volume of the following objects? Explain your answer.



1. graduated cylinder method



2. overflow can method

2.<u>Calculating the volume of an object with a regular shape.</u>

While walking on the beach you found a piece of rectangular driftwood. You brought it home as a souvenir of your trip to the ocean. Because you are curious about its size, you want to calculate the volume of this piece of wood. The length of the piece of wood is 29 cm. The height of the piece of wood is 22 cm and the width is 12 cm. What is the volume of this piece of wood. Show your calculations.

If you were to put the above piece of wood in water, how much water would it displace?

<u>3. Calculating the volume of an object with an irregular shape</u>

While playing outside you found a pretty basalt rock. You thought that this would be a great addition to your aquarium. If you put this rock into your aquarium, the water will overflow, so you need to calculate how much water to take out of it. To do this you obtain a 250 mL graduated cylinder and fill it with water until it reaches 150 mL. After you put the basalt rock in it, the new volume is 218 mL. What is the volume of the basalt rock and how much water do you need to take out of the aquarium? Show your calculations.

4. What did you learn about the measurement of volume today?

Teacher Notes and Keys

What Will Happen to the Weight?

Explanation: *The best answer is C. The total weight will stay the same. Some students answer the question thinking only about the block (and not the system containing both the block and the water). Students who focus only on the block are correct in thinking that the block appears to weigh less in the water (due to the upward buoyant force by the water on the block), but the total weight of the system is the same. The force by the water on the block (called buoyant force) is balanced by the fore by the block o the water. Therefore, the fact that the block is floating will have no effect on the total weight of the bucket with the water and the block.*

Exploring Volume

Part A: *How many drops of water will it take to equal one milliliter? My prediction = answers vary drops*

Data Table:

# of drops to raise water level from 6mL to 7mL	# of drops to raise water level from 7mL to 8mL	# of drops to raise water level from 8mL to 9mL	Average # of drops needed to raise water 1mL
25	25	25	25

Using your results calculate the average volume of a drop of water. .04 mL = a drop of water

Part B: *How do you find the volume of an object using water displacement in a graduated cylinder?*

Beginning water level (mL)	Water level after adding 3 marbles (mL)	Difference (mL)	Volume of 3 marbles (mL)	Volume of 1 marble (mL)
20 mL	25-27 mL	5-7 mL	5-7 mL	1.66-2.33 mL

Part C: *How do you find the volume of an object using water displacement in an overflow can?*

Data Table:

Object	Volume (mL)
Zest Soap	1.5-3
Sinking Clay Ball	23-25
Rock	5-7

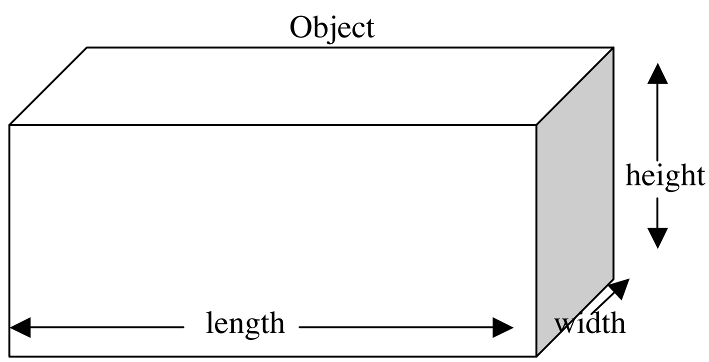
Explore how the volume measurement of water changes as you hold the graduated cylinder at eye level and below and above eye level. How much does the volume reading change by when you do this? What data have you found that supports the technique of reading liquid volume in a graduated cylinder only at eye level?

The volume can change by several mL depending on where you look from. This can really affect the accurate measurement of objects, especially if the objects are small.

Part D: *How do you find the volume of a rectangular object using a formula? Answers vary*

Object #	Length (cm)	Width (cm)	Height (cm)	Volume (cm^3)
1				
2				
3				

Data Table:



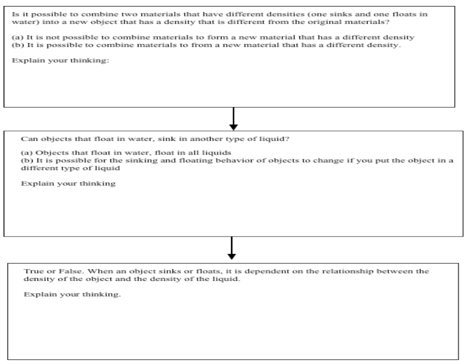
Check the calculated volume of your rectangular solid by using the water displacement method. (Answers will vary)

Object #	Calculated volume (from data table above)	Water displacement volume	Are they the same?	If not, explain why you think that they are different
1				

2				
3				

Part E. *Answer these questions*.

1. Using the water displacement method. What is the volume of the following objects? Explain your answer. In the water displacement method, the volume of water is equal to the volume of the object displaced.


Is it possible to combine two materials that have different densities (one sinks and one floats in water) into a new object that has a density that is different from the original materials?

(a) It is not possible to combine materials to form a new material that has a different density
(b) It is possible to combine materials to from a new material that has a different density.

Explain your thinking:

Can objects that float in water, sink in another type of liquid?

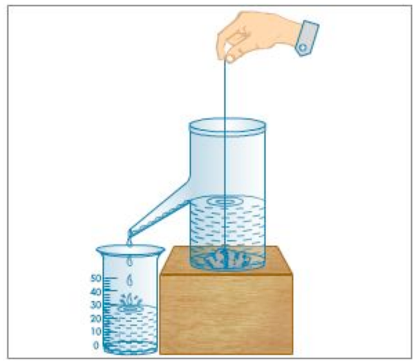
(a) Objects that float in water, float in all liquids
(b) It is possible for the sinking and floating behavior of objects to change if you put the object in a different type of liquid

Explain your thinking

True or False. When an object sinks or floats, it is dependent on the relationship between the density of the object and the density of the liquid.

Explain your thinking.

1. graduated cylinder method
40 mL – 30 mL = 10mL



2. overflow can method
30mL

2. <u>Calculating the volume of an object with a regular shape.</u>
While walking on the beach you found a piece of rectangular driftwood. You brought it home as a souvenir of your trip to the ocean. Because you are curious about its size, you want to calculate the volume of this piece of wood. The length of the piece of wood is 29 cm. The height of the piece of wood is 22 cm and the width is 12 cm. What is the volume of this piece of wood. Show your calculations.

The volume of a rectanglur solid is calculated by length x height x width.
29 cm x 22 cm x 12 cm =7656 cm^3

If you were to put the above piece of wood in water, how much water would it displace?
7656 mL

3. <u>Calculating the volume of an object with an irregular shape</u>
While playing outside you found a pretty basalt rock. You thought that this would be a great addition to your aquarium. If you put this rock into your aquarium, the water will overflow, so you need to calculate how much water to take out of it. To do this you obtain a 250 mL graduated cylinder and fill it with water until it reaches 150 mL. After you put the basalt rock in it, the new volume is 218 mL. What is the volume of the basalt rock and how much water do you need to take out of the aquarium? Show your calculations.

The volume of the basalt rock is: 218 mL – 150 mL = 68mL or 68 cm^3
You need to take out 68 mL from the aquarium

4. What did you learn about the measurement of volume today? There are many ways to measure volume. It varies by what type of object you have and whether is it is regularly shaped or irregularly shaped. 1 cm^3 = 1 mL

Lesson #7 – Scientific Inquiry Teaching Methodology

Calculating Density

Teacher Notes

Introduction: Often when density is taught, the teacher goes right to the density formula without addressing the conceptual misunderstandings that students hold about density – such as larger objects weigh more and are therefore more dense. Building a qualitative understanding of density can occur as a student explores their own world. Students have some understanding of materials that are heavy or light for their size – but translating that into a quantitative understanding is hard. The reason is that quantitative density is an abstract concept. It is not directly measurable, because it is a **ratio** between mass and volume. In this activity, students will take their qualitative understanding of density as "heavy for its size" and translate that into a number, for example – this piece of metal is more than six time as dense as this piece of wood or the density of this metal is 5.5 g/cm^3 and the density of this wood is .9 g/cm^3. As students have worked through the most common misunderstandings about density in the previous lessons, they are now ready to be given the formula and to calculate density using it

Objectives for this activity:

1. Students will gain a quantitative understanding of density
2. Students will learn and apply the density formula.

Materials needed for each student:

1. Calculator
2. *Density Reading*
3. *Calculating Density* Worksheet

Lesson Plan:

Opener:

1. **"Which is heavier, a kg of gold or a kg of feathers?"** The answer is of course, "Both are equally heavy."
2. **"If both objects are the same size, which is heavier, a bar of gold or an equal volume of feathers?"** You would say, "gold".

When we compare the heaviness of two different materials, we must refer to the same volume of each material. This leads to the concept of density. The density of a substance is defined as its mass per unit volume

Part A:

1. Students read and teacher discusses density reading.
2. **Give the formal definition for density:** Density is the mass per unit volume of an object.
3. **Discuss why density is important:** Density is important because it allows you to compare different types of matter.

4. **Discuss the formula used to calculate density:**

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}}$$

5**. What are the units for density?** g/cm3 , kg/m3

Part B:

1. Class practices together using the formula with the aluminum and copper questions
2. Table groups complete part or all of tables together (note: students will need to be given the volumes of the floating objects from the sink/float lab as they did not determine these)
3. Whole class shares answers

Parts C - F:

1. Individual students do on own first
2. Check answers with partner or table group

Do individually in class or as homework: **Calculating Density Homework**

Return to student the **Comparing Cubes** handout from lesson #1 to see if they want to change their answers from the first lesson. Discuss answers again. Have students talk about what they learned about density in their table groups.

Name ____ Date ________

Calculating Density

Part A: ***Density Background. From your reading and class discussion:***

1. Define density:

2. Why is density important?

2. Use the formula to calculate density:

If 96.5g of gold has a volume of $5cm^3$, what is the density of gold?

Step 1: Write the formula.	Density = $\frac{\text{Mass}}{\text{Volume}}$
Step 2: Substitute given numbers and units.	Density = $\frac{96.5\ g}{5\ cm^3}$
Step 3: Divide 96.5g by 5 cm^3. That equals $\frac{19.3g}{cm^3}$	or $19.3g/cm^3$
Step 4. The answer = the density of gold is 19.3 g/cm^3	

Step 5: Explain what this means in words:

Part B: Working together as a class let's practice using the density formula. Show your work!

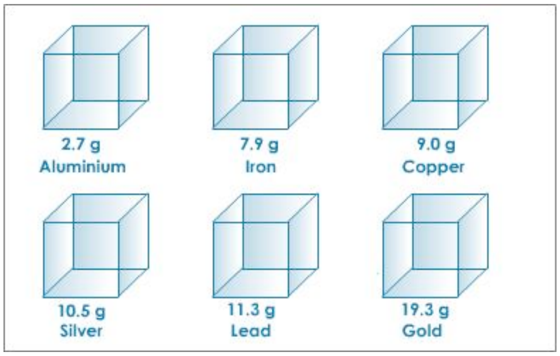
1. If 157.5g of aluminum has a volume of $35cm^3$, what is the density of the aluminum?

2. If 125.44g of copper has a volume of $14cm^3$, what is the density of the copper?

3. A solid block measures 3 cm x 3 cm x 2 cm and it has a mass of 27 grams. What is its density?

3. An irregularly shaped object displaces 35 mL of water in a graduated cylinder, The object has a mass of 42 grams. What is the density of the object?

Part C: If the volume of each of the cubes below was 1 cm^3 what is the cube's density?



Cube	Density
Aluminium	
Iron	
Copper	
Silver	
Lead	
Gold	

If one object has exactly the same volume as another object and it is heavier, will it always have a greater density? Explain your thinking.

Part D: *Calculate the densities on this data table. If the decimal repeats, round to the nearest hundredth.*

Item Name	**Mass (g)**	**Volume (mL or cm^3)**	**Density (g/mL or g/cm^3)**
Water	100 g	100 mL	1.0 g/mL
Ice	4.6 g	5.0 cm^3	
Glass	230 g	100 cm^3	
Alcohol	9.6 g	12.0 mL	
Mercury	189.7g	14mL	
Plastic	5g	5.85 cm^3	
Wood (Oak)	25g	35.2 cm^3	
Cork	1100g	5000 cm^3	

1. Does the object with the heaviest mass have the greatest density? Explain.

2. Does the object that has the greatest volume have the greatest density? Explain.

3. Can you determine if an object has a high density, if you only know the mass or if you only know the volume?

Part F: *Rank the materials on the table above in order of most to least dense*

Materials	*Density*	*Most dense*
Water	*1.0 g/mL*	
		Least dense

1. Which of the above objects would float in water?

2. If the plastic object above were put into the alcohol, would it float or sink? Explain.

3. If the cork were put in the alcohol, would it float or sink? Explain.

Calculating Density Homework

Name ____Core

Water has a density of exactly 1g/mL. This means that one milliliter (or one cubic centimeter) of water weighs exactly one gram. Any substance that has a density *less* than 1g/mL will float on water. Any substance that has a density *greater* than 1g/mL will sink.

Use the density table below to answer the questions.

Solids	**Density**	**Metals**	**Density**	**Liquids**	**Density**
Bone	2.0	Aluminum	2.7	Water	1.0
Brick	1.8	Copper	8.9	Seawater	1.3
Cork	0.2	Gold	19.3	Alcohol	0.8
Marble	2.7	Iron	7.83	Glycerine	1.25
Paraffin	0.9	Lead	11.3	Turpentine	0.9
Rubber	1.2	Silver	10.5	Mercury	13.55
Bamboo	0.3			Gasoline	0.7
Ice	0.92				

1. Name 5 substances from the table above that will **float** on water:

2. Name 5 substances from the table above that will **sink** in water:

3. What is the **least** dense substance on the table?

4. What is the **most** dense substance on the table?

5. Mercury is a liquid with a density of 13.55. Which metal on the table would sink in **mercury**?

6. You find a substance that looks like gold. Based on what we have learned about matter and density, how could you determine if it is **really** gold?

7. What is the **density** of 400g of a substance if it occupies $80cm^3$ of volume?

8. Will the substance in #7 sink or float in **seawater**?

9. **Challenge**: If a substance has a density of 2.5g/mL, and it occupies 200mL of volume, what is its mass?

Calculating Density Key

Part A: *Density Background*

Define density: *Density is the mass per unit volume of an object.*

Why is density important? *Density is important because it allows you to compare different types of matter. It is a characteristic property of matter.*

Use the formula to calculate density:

If 96.5g of gold has a volume of 5cm^3, what is the density of the gold?

Step 1: Write the formula.	Density = $\frac{\text{Mass}}{\text{Volume}}$
Step 2: Substitute given numbers and units.	Density = $\frac{96.5\text{ g}}{5\text{ cm}^3}$
Step 3: Divide 96.5g by 5 cm^3. That equals $\frac{19.3\text{g}}{\text{cm}^3}$	or 19.3g/cm^3
Step 4. The answer = the density of gold is 19.3 g/cm^3	

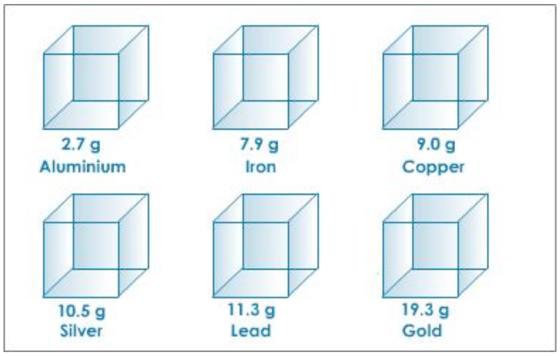
Step 5: Explain what this means in words. 19.3 grams of gold occupies 1 cm^3 of volume.

Part B: *Practice using the formula.*

1. If 157.5g of aluminum has a volume of 35cm^3, what is the density of the aluminum? *4.5g/cm^3*
2. If 125.44g of copper has a volume of 14cm^3, what is the density of the copper? *8.96 g/cm^3*
3. A solid block measures 3 cm x 3 cm x 2 cm and it has a mass of 27 grams. What is its density? 1.42 *g/cm^3*
4. An irregularly shaped object displaces 35 mL of water in a graduated cylinder, The object has a mass of 42 grams. What is the density of the object? 1.2 g/mL

Part C: *If the volume of each of the cubes below was 1 cm^3 what are the cubes' density?*

Cube	Density
Silver	10.5 g/cm^3
Lead	11.3 g/cm^3
Gold	19.3 g/cm^3
Aluminium	2.7 g/cm^3
Iron	7.9 g/cm^3
Copper	9.0 g/cm^3



If one object has exactly the same volume as another object and it is heavier, will it always have a greater density? Yes, it will. If the volume is the same, then if an object is heavier, it will always have a greater density.

Item Name	Mass (g)	Volume (mL or cm^3)	Density (g/mL or g/cm^3)
Water	100 g	100 mL	1.0 g/mL
Ice	4.6 g	5.0 cm^3	*.92 g/cm^3*
Glass	230 g	100 cm^3	*2.3 g/cm^3*
Alcohol	9.6 g	12.0 mL	*.8 g/mL*
Mercury	189.7g	14mL	*13.55 g/mL*
Plastic	5g	5.85 cm^3	*0.85 g/cm^3*
Wood (Oak)	25g	35.2 cm^3	*0.71 g/cm^3*
Cork	1100g	5000 cm^3	*.22 g/cm^3*

Part D. *Calculate the densities on this data table. If the decimal repeats, round to the nearest hundredth.*

1. Does the object with the heaviest mass have the greatest density? Explain. No. The object with the heaviest mass is the cork at 1100g. However, it has the lowest density of 0.22 g/cm3

2. Does the object that has the greatest volume have the greatest density? Explain. No. Cork also has the greatest volume and has the least density

3. Can you determine if an object has a high density, if you only know the mass or if you only know the volume? No. You need to know the ration of the mass to the volume in order to know an object's density.

Part E: *Rank the 8 items on the table above in order of least to greatest density.*

Material	*Density*	*Least dense*
Mercury	*13.55 g/mL*	
Glass	*2.3* g/cm^3	
Water	*1.0 g/mL*	
Ice	*.92* g/cm^3	
Plastic	*0.85* g/cm^3	
Alcohol	*.8 g/mL*	
Wood (Oak)	*0.71* g/cm^3	
Cork	*.22* g/cm^3	*Most dense*

1. Which of the above objects would float in water? Ice, plastic, alcohol, wood, cork
2. If the plastic object above were put into the alcohol, would it float or sink? It would sink because its denisy is higher than the alcohol
3. If the cork were put in the alcohol, would it float or sink? It would float because its density is less than the alcohol.

Calculating Density Homework Key

Water has a density of exactly 1g/mL. This means that one milliliter (or one cubic centimeter) of water weighs exactly one gram. Any substance that has a density *less* than 1g/mL will float on water. Any substance that has a density *greater* than 1g/mL will sink.

Use the density table below to answer the questions.

Solids	Density	Metals	Density	Liquids	Density
Bone	2.0	Aluminum	2.7	Water	1.0
Brick	1.8	Copper	8.9	Seawater	1.3
Cork	0.2	Gold	19.3	Alcohol	0.8
Marble	2.7	Iron	7.83	Glycerine	1.25
Paraffin	0.9	Lead	11.3	Turpentine	0.9
Rubber	1.2	Silver	10.5	Mercury	13.55
Bamboo	0.3			Gasoline	0.7
Ice	0.92				

1. Name 5 substances that will **float** on water: *Any 5 of these: Cork, Paraffin, Bamboo, Ice, Alcohol, Turpentine, Gasoline*
2. Name 5 substances that will **sink** in water: *Any 5 of these: Bone, Brick, Marble, Rubber, any of the metals, Seawater, Glycerine, Mercury*
3. What is the **least** dense substance on the table? *Cork*
4. What is the **most** dense substance on the table? *Gold*
5. Mercury is a liquid with a density of 13.55. Which metal on the table would sink in **Mercury**? *Gold*
6. You find a substance that looks like gold. Based on what we have learned about matter and density, how could you determine if it is really gold? *Find its mass and volume then calculate its density. If the density is 19.3 g/cm^3, it is gold.*
7. What is the **density** of 400g of a substance if it occupies 80cm^3 of volume? *5g/cm^3*
8. Will the substance in #7 sink or float in **seawater**? *Sink*

Challenge: If a substance has a density of 2.5g/mL, and it occupies 200mL of volume, what is its mass?

It has a mass of 500g.

$$\frac{2.5g}{mL} = \frac{x}{200mL}$$

$$500g = x$$

Density- Applying What You Have Learned

Teacher Notes

Introductions: Calculate the density of the objects that students have been using in these labs. Today's lesson will help students with their quantitative understanding of density. They will learn that the density of materials is fixed for a particular material and that materials that have different shapes or sizes that are made of the same materials will have the same density. They will calculate the density of objects and then use that information to compare materials.

Objectives for this activity:
1. Students' will be assessed on their qualitative understanding of density.
2. Students will apply what they have learned about the quantitative measurement of density by measuring the mass and volume of 10 objects and then calculating density for each object using the density formula.
3. Students will make quantitative comparisons about the density of objects.

Materials needed for each group:
1. *Density Assessment* worksheet
2. *Density Assessment* rubric
3. *Density: Applying What You Have Learned* worksheet
4. **Materials:** Place materials in a materials station for students to choose from

<table>
<tr><td rowspan="3">Objects that students have been using the past 7 labs: Focus on having students using the density cubes, the rectangular solid set, and the density cylinder sets. If they pick objects that have a variable that is held constant it will be easier to compare: same material, same mass, same volume.</td><td>Overflow cans</td><td>Beaker</td></tr>
<tr><td>Ruler</td><td>Balance</td></tr>
<tr><td colspan="2">Graduated cylinders</td></tr>
</table>

Lesson Plan:
1. Begin with *Density Assessment*. You may have done this at the beginning of the unit. Students should have shown growth. You can choose to assign this as a homework assignment instead of a pre-assessment if you wish. This assessment measures a student's qualitative understanding of density (notice -there are no numbers or data).
2. Put out materials for the lab. Encourage students to pick objects that relate to each other somehow because they will be comparing them. You may want to remind students of making groups of objects like they did for Lesson #1 – *Properties of Matter*.
3. The data table has room for 10 objects. Students can do more than this if they have time.
4. Students should make decisions about how they will want to measure the volume of the objects. Have supplies ready so that they can measure objects using rulers -

if they are rectangular solids or by water displacement – using graduated cylinders or overflow canisters.

5. When students make their graph they should try to organize the objects so they go from least dense to most dense on the histogram. They will be more likely to get the comparison information that they need for their conclusions if they do this.
6. Students may work in groups and share data about objects for this lab.

Name______________________________________Date________Core__________

Density- Applying What You Have Learned

Question*: How does the density of objects vary?*

Background: *Write a short paragraph that explains what you have learned about density.*

Materials: *Your teacher will give you a set of objects that you have been using in the sinking and floating labs. List the set of objects that you are going to calculate the density of. Choose the objects carefully so that you can make conclusions about the density of the materials.*

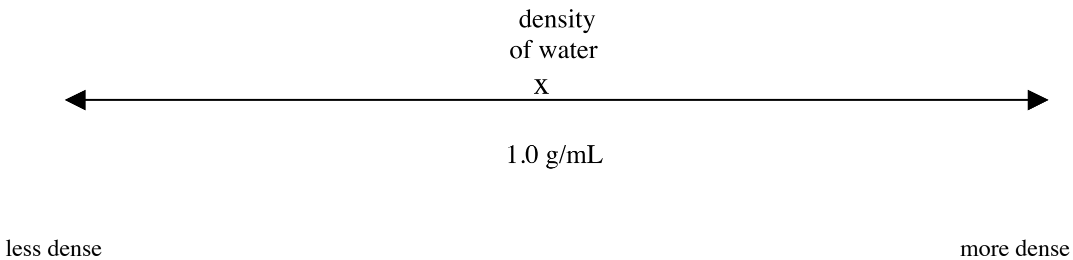
What rationale did you use to choose the objects?

Procedure

Use the density formula to calculate the densities of the objects you have chosen. You can measure the volume in any way that you have learned. Use a balance to measure the mass.

Object Name	Mass (g)	Volume (mL)	Density (g/mL)

Using the densities of the objects that you have calculated, put x's on the number line below to show each of their densities. Label the x's with each object's name (above the line) and density (below the line). Draw a line that shows where on the line objects would float in water, where objects would sink in water, and where objects are neutrally buoyant in water.



What do you observe about the relationship between an object sinking and floating and its density as compared to water?

Graph the densities of the objects you have chosen. Be sure to label both axis. Organize your density data on the graph the same way that you had it on the number line above so you can see the patterns.

Conclusion:
Compare the density of various objects. Make the comparisons quantitative. That means, use the actual measurements and calculations that you have made in the conclusion statement. **Make at least four comparison statements about the density of your objects that are similar to the ones below.**
<u>Here are some examples of comparison statements:</u>

1. "The density of Object A is 9.03 g/ cm^3 and the density of Object B is 3.1 g/ cm^3. That means that Object A is approximately three times greater than the density of Object B. This is interesting because Object B with a volume of 28 cm^3 is twice as big as Object A, which has a volume of 14 cm^3"

--or--

2. "Objects that are made of Material A, tend to be more dense than objects made of Material B. Objects made of Material A have an average density of 5 .45 g/ cm^3, where the objects made of materials B have an average density of 2.18 g/ cm^3"

What have you learned about the density of objects as you compared them using data?

Density- Applying What You Have Learned
Key

Question: *How does the density of objects vary?*
Background: *Write a short paragraph that explains what you have learned about density. Answers will vary. Students should be able to write about some of the qualitative experiences that they have had (sinking and floating) . The density formula should be here as well.*

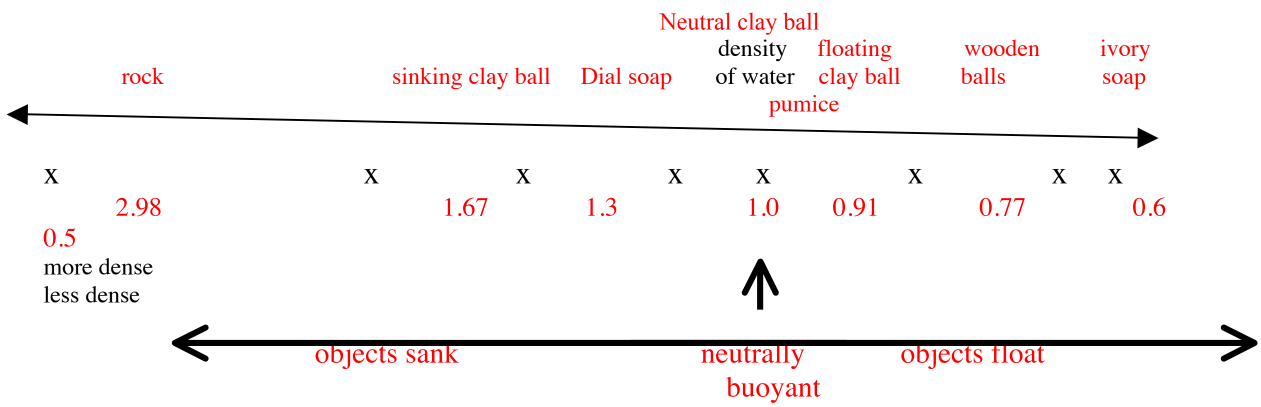
Materials: *Your teacher will give you a set of objects that you have been using in the sinking and floating labs. List the set of objects that you are going to calculate the density of. Choose the objects carefully so that you can make conclusions about the density of the materials.*
Students should choose collections of objects that go together so they can make comparisons about density. For example students should pick a set of cylinders of different materials, or the rectangular solids, or the white balls. Kids can think about how they grouped objects in Lesson #1 Properties of Matter.

What rationale did you use to choose the objects? Answers vary. But it should be a scientific reason, as opposed to , "I liked the objects"

Procedure
Use the density formula to calculate the densities of the objects you have chosen. You can measure the volume in any way that you have learned. Use a balance to measure the mass. Here are some sample densities. There are many more possible objects students could have chosen.

Object Name	Mass (g)	Volume (mL)	Density (g/mL)
Sinking clay ball	40.1 g	24 mL	1.67
Neutral clay ball	22. g	22 mL	1.0
Floating clay ball	19.3 g	21 mL	.91
Large wooden ball	18.5 g	24 mL	.77
Small wooden ball	6.2 g	8 mL	.77
Rock	17.9 g	6 mL	2.98
Pumice	2.5 g	5 mL	0.5
Ivory soap	2.4 g	4 mL	0.6
Dial soap	2.6 g	2 mL	1.3

Look at the densities of the objects from the lab that you chose. Put x's on the number line below to show each of their densities. Label the x's with each object's name (above the line) and density (below the line). Draw a line that shows where on the line object float in water, where objects sink in water, and where objects are neutrally buoyant.



What do you observe about the relationship between an object sinking and floating and its density as compared to water? If an object sinks, its density is greater than water (< 1 g/mL). If it is neutrally buoyant, then it is the same as water (=1 g/mL), if it floats, then the density is greater than water (> 1 g/mL).

Graph the densities of the objects you have chosen. Be sure to label both axis. Organize your density data on the graph the same way that you had it on the number line above so you can see the patterns. *Students should make histograms.*

Conclusion:
Compare the density of various objects. Make the comparisons quantitative. That means, use the actual measurements and calculations that you have made in the conclusion statement. **Make at least four comparison statements about the density of your objects that are similar to the ones below.**
For example, make statements like:

1. "The density of Object A is 9.03 g/ cm^3 and the density of Object B is 3.1 g/ cm^3. That means that Object A is approximately three times greater than the density of Object B. This is interesting because Object B with a volume of 28 cm^3 is twice as big as Object A, which has a volume of 14 cm^3"

--or--

2. "Objects that are made of Material A, tend to be more dense than objects made of Material B. Objects made of Material A have an average density of 5 .45 g/ cm^3, where the objects made of materials B have an average density of 2.18 g/ cm^3"

Answers vary – But should be quantitative and use data as in examples

What have you learned about the density of objects as you compared them using data?

Students should have learned that the density of an object can be exactly measured. Once it is measured it can be used to compare objects of the same and of different materials. These comparisons can be expressed in ratios.

Density of Regularly Shaped Objects (Inquiry)

Teacher Notes

Supplies Needed: computer for research
calculator

1. **Read the mystery description together.**

2. **Read over the lab** and check for understanding of how to do an inquiry lab; be careful not to give instructions on how to find the mass, volume, or density of a regularly shaped object, however.

3. **Individual, partner, or table group** research background and complete background paragraph.

4. **Table groups** work at own pace to design and complete lab.

5. When all groups finish, have a **whole class** "Science talk" about what they've learned; teacher as facilitator only.

Objective for this activity

1. Determine the density of regularly shaped objects.

Density of Regularly Shaped Objects (Inquiry)

Name ____ Core ____________

Joe Loser stole six trunks filled with ancient Egyptian and Roman works of art and antiquities from a museum in Italy . The authorities believe that Joe is storing the stolen goods on his river boat. This morning, the police boarded Joe's boat and searched it, but they failed to find the six trunks they thought would be on the boat.

Later, an informant told police that Joe had tossed the trunks into the river before they arrived. The police are now returning to the scene to try to recover the stolen items. In the table below are the contents, masses, and sizes of each trunk according to museum records.

Trunk	*Contents*	*Mass of Contents (g)*	*Mass of Empty Trunk (g)*	*Trunk Length (cm)*	*Trunk Width (cm)*	*Trunk Height (cm)*
1	Marble statues	208,650	6000	90	50	45
2	Tapestries	495,250	8750	120	120	50
3	Gold jewelry	507,500	4000	150	110	50
4	Bone carvings	330,500	7000	75	75	25
5	Wall paintings	153,400	5000	80	80	25
6	Papyrus scrolls	304,500	7500	80	75	20

If the trunk's density was greater than water, the trunk would have immediately sunk to the bottom of the river. If the trunk's density was less than water, the trunk would have floated down the river about 4km by now. If the trunk's density was close to the density of water, the trunk would have sunk a little and then floated about 2km down the river. Calculate the expected density for each trunk and then tell the police approximately where to look for each trunk in the river.

Framing the Investigation
Question(s):

Background: Research and write a paragraph on the background science that relates to this topic.

Hypothesis: Predict the answer to the above question and explain your thinking.

Designing the Investigation
Materials Needed:

Procedure: Make a plan for how you will conduct your experiment. Write the steps down in a detailed list.

Collecting and Presenting Data
Data Table: Collect your results and organize the data on a data table in the space below.

Graphing the Data: Create a graph to display the data you collected. Label the x axis and the y axis. Be sure to include a title and key.

Analyzing the Investigation

Conclusion: Write a conclusion analyzing your results. Included in your conclusion should be the following:

- What were the questions you were trying to answer by doing this lab?
- Briefly describe how you conducted this lab.
- Answer the questions you were trying to answer by doing this lab. Be sure to use results from the lab to support your conclusions and relate your data to the science concepts presented in your background.
- What errors or weaknesses were found in the design (procedures) of this lab and how were they managed? How can your design (procedures) be improved to make the results more accurate?
- Ask a follow-up question about density that you might later test.

Density of Regularly Shaped Objects Key (Inquiry)

43 points total

Joe Loser stole six trunks filled with ancient Egyptian and Roman works of art and antiquities from a museum in Italy . The authorities believe that Joe is storing the stolen goods on his river boat. This morning, the police boarded Joe's boat and searched it, but they failed to find the six trunks they thought would be on the boat.

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Trunk	Contents	Mass of Contents (g)	Mass of Empty Trunk (g)	Trunk Length (cm)	Trunk Width (cm)	Trunk Height (cm)
1	Marble statues	208,650	6000	90	50	45
2	Tapestries	495,250	8750	120	120	50
3	Gold jewelry	507,500	4000	150	110	50
4	Bone carvings	330,500	7000	75	75	25
5	Wall paintings	153,400	5000	80	80	25
6	Papyrus scrolls	304,500	7500	80	75	20

If the trunk's density was greater than water, the trunk would have immediately sunk to the bottom of the river. If the trunk's density was less than water, the trunk would have floated down the river about 4km by now. If the trunk's density was close to the density of water, the trunk would have sunk a little and then floated about 2km down the river. Calculate the expected density for each trunk and then tell the police approximately where to look for each trunk in the river.

Framing the Investigation
Question(s): **2 points**
What is the density of each trunk? Where should the police look for each trunk?

Background: Research and write a paragraph on the background science that relates to this topic.
5 points:
•Volume = length x width x height
•Mass ÷ Volume = Density
•Density < 1 = Floats
•Density > 1 = Sinks
•Density ≈ 1 = Neutral

Designing the Investigation
Materials Needed: 1 point
Calculator

Procedure: Make a plan for how you will conduct your experiment. Write the steps down in a detailed list. **5 points total (example below; procedures will vary)**

1. For each trunk, add the mass of contents to the mass of empty trunk. Record this as the total mass on the data table.
2. For each trunk, multiply the trunk length x trunk width x trunk height. Record this trunk volume on the data table.
3. For each trunk, divide the total mass by the trunk volume. Record this trunk density on the data table.
4. Look at the trunk density. If the number is less than 1, write floats on the data table. If it is more than 1, write sinks. If it is about 1, write neutral.
5. Look back at the description of the mystery on page 1. Figure out where the trunk would be now if it sinks, floats, or is neutral. Record the location of each trunk on the data table.

Collecting and Presenting Data
Data Table: Collect your results and organize the data on a data table in the space below. **10 points total (Below is an example; data tables will vary)**

Trunk	*Contents*	*Total Mass (g) [contents mass + empty trunk mass]*	*Trunk Volume (cm^3) [length x width x height]*	*Trunk Density (g/cm^3) [total mass divided by volume]*	*Sinks, Floats, or Neutral*	*Location of Trunk*
1	**Marble statues**	**214,650**	**202,500**	**1.06**	**Neutral**	**2 km away**
2	**Tapestries**	**504,000**	**720,000**	**0.7**	**Floats**	**4 km away**
3	**Gold jewelry**	**511,500**	**825,000**	**0.62**	**Floats**	**4 km away**
4	**Bone carvings**	**337,500**	**140,625**	**2.4**	**Sinks**	**Under boat**
5	**Wall paintings**	**158,400**	**160,000**	**0.99**	**Neutral**	**2 km away**
6	**Papyrus scrolls**	**312,000**	**120,000**	**2.6**	**Sinks**	**Under boat**

Graphing the Data: Create a graph to display the data you collected. Label the x axis and the y axis. Be sure to include a title and key. **10 points total**

Analyzing the Investigation

Conclusion: Write a conclusion analyzing your results. Included in your conclusion should be the following: **10 points total**

- -What were the questions you were trying to answer by doing this lab? **1 point**
- -Briefly describe how you conducted this lab. **2 points**
- -Answer the questions you were trying to answer by doing this lab. Be sure to use results from the lab to support your conclusions and relate your data to the science concepts presented in your background. **4 points**
- -What errors or weaknesses were found in the design (procedures) of this lab and how were they managed? How can your design (procedures) be improved to make the results more accurate? **2 points**
- -Ask a follow-up question about density that you might later test. **1 point**

Density of Irregularly Shaped Objects (Inquiry)

Teacher Notes

For this inquiry lab, each group decides what supplies they will need. All groups will need to be given access to a computer for research and several irregularly shaped objects. The following list is a suggestion to have on hand, but keep in mind that students may or may not use them:

- objects with different masses (rocks, for example)
- graduated cylinders
- beakers
- overflow cans
- triple beam scales
- calculators
- metric rulers

Since this is their second inquiry experience, they should not need any further direction. When everyone is finished, have a whole class “Science talk” about what they’ve learned; teacher as facilitator only.

Objective for this activity

1. Determine the density of irregularly shaped objects.

Density of Irregularly Shaped Objects (Inquiry)

Name____ Core ______

Juliette Schwimmer was found dead in her home, and investigators have ruled it a homicide. The victim died from blunt force trauma to the forehead. Investigators have determined that because of the depth of the wound, the object that hit her forehead most likely had a density greater than 2.5g/mL but less than 3.5g/mL and was likely thrown with some type of slingshot. Several objects are found near the body. You have been asked by the investigators to determine which of the objects most likely caused the wound.

Framing the Investigation

Question:

Background: Research and write a paragraph on the background science that relates to this topic.

Hypothesis: Predict the answer to the above question and explain your thinking.

Designing the Investigation

Use the materials available in the classroom to explore the above question.

Materials Needed:

Procedure: Make a plan for how you will conduct your experiment. Write the steps down in a detailed list.

Collecting and Presenting Data

Data Table: Collect your results and organize the data on a data table in the space below.

Graphing the Data: Create a graph to display the data you collected. Label the x axis and the y axis. Be sure to include a title and key.

Analyzing the Investigation

Conclusion: Write a conclusion analyzing your results. Included in your conclusion should be the following:

- -What was the question you were trying to answer by doing this lab?
- -Briefly describe how you conducted this lab.
- -Answer the question you were trying to answer by doing this lab. Be sure to use results from the lab to support your conclusions and relate your data to the science concepts presented in your background.
- -What errors or weaknesses were found in the design (procedures) of this lab and how were they managed? How can your design (procedures) be improved to make the results more accurate?
- -Ask a follow-up question about density that you might later test.

Density of Irregularly Shaped Objects Key(Inquiry)

43 points total

Juliette Schwimmer was found dead in her home, and investigators have ruled it a homicide. The victim died from blunt force trauma to the forehead. Investigators have determined that because of the depth of the wound, the object that hit her forehead most likely had a density greater than 2.5g/mL but less than 3.5g/mL and was likely thrown with some type of slingshot. Several objects are found near the body. You have been asked by the investigators to determine which of the objects most likely caused the wound.

Framing the Investigation

Question: 1 point

Background: Research and write a paragraph on the background science that relates to this topic.

3 points

•Use water displacement to find the volume.
•Use a scale to find the mass.
•Divide mass by volume to calculate density.

Hypothesis: Predict the answer to the above question and explain your thinking. **1 point**

Designing the Investigation

Use the materials available in the classroom to explore the above question.

Materials Needed: 3 points

overflow can
graduated cylinder or beaker
triple beam scale
calculator

Procedure: Make a plan for how you will conduct your experiment. Write the steps down in a detailed list. **5 points**

•Find the mass using a scale and record it on the data table.
•Use the overflow can (water displacement) to find the volume and record it on the data table.
•Divide the mass by the volume to find the density and record it on the data table.
•Repeat these steps for all objects.
•Identify the possible weapons by finding the objects with densities between 2.5 and 4.0 g/mL.

Collecting and Presenting Data

Data Table: Collect your results and organize the data on a data table in the space below. **10 points**

Object Description	Mass (g)	Volume (mL)	Density (g/mL)
Wart Hog Toy	52.7	100	0.53
Pulley	79.8	15	5.32
Faucet		49	
Doorstop	25.4	8	3.175
Bolt	160.0	20	8.0
Pink jewel		105	
Rock	85.1	98	.70
Fishing weight	170.5	16	10.65

Graphing the Data: Create a graph to display the data you collected. Label the x axis and the y axis. Be sure to include a title and key. **10 points**

Analyzing the Investigation

Conclusion: Write a conclusion analyzing your results. Included in your conclusion should be the following: **10 points total**

-What were the questions you were trying to answer by doing this lab? **1 point**

-Briefly describe how you conducted this lab. **2 points**

-Answer the questions you were trying to answer by doing this lab. Be sure to use results from the lab to support your conclusions and relate your data to the science concepts presented in your background. **4 points**

-What errors or weaknesses were found in the design (procedures) of this lab and how were they managed? How can your design (procedures) be improved to make the results more accurate? **2 points**

-Ask a follow-up question about density that you might later test. **1 point**

Density of Liquids (Inquiry)

Teacher Notes

For this inquiry lab, each group decides what supplies they will need. All groups will need to be given access to a computer for research and samples of the 5 liquids with different densities: rubbing alcohol, water, corn syrup, glycerin, and mineral oil.

The following list is a suggestion to have on hand, but keep in mind that students may or may not use them:

graduated cylinders
beakers
paper cups
test tubes
test tube holders
medicine droppers
pipettes
overflow cans
triple beam scales
calculators

Since this is their third inquiry experience, **they should not need any further direction**. You should, however, remind them that when finding the density of a liquid, it's important *not* to include the density of the container holding the liquid. When everyone is finished, have a whole class "Science talk" about what they've learned; teacher as facilitator only.

Objective for this activity

1. Determine the density of various liquids.

Density of Liquids (Inquiry)

Name ____ Core _______________

Friday morning, a neighbor found John Smith unconscious on his living room floor. The neighbor called 911 and an ambulance took John to Mercy Hospital. John had traces of a clear, odorless liquid in and around his mouth. He is currently in a coma. The cause of his illness is unknown.

Dr. Homes, a brilliant diagnostician who loves the challenges of a medical mystery, is assigned to the case. He believes that identifying the liquid may provide a vital clue that can be used to save John's life. The liquid is tested in the hospital lab. It is found to be colorless and clear. It also has a density of 1.25g/mL.

Dr. Homes sends his team to John's house to bring back samples of all possible liquids. They return with five liquids. Your teacher has samples of each of the liquids. Your task is to discover the identity of the liquid found in and around John Smith's mouth.

(Hint: when finding the density of a liquid, it's important not to include the density of the container holding the liquid.)

Framing the Investigation
Question:

Background: Research and write a paragraph on the background science that relates to this topic.

Hypothesis: Predict the answer to the above question and explain your thinking.

Designing the Investigation

Use the materials available in the classroom to explore the above question.
Materials Needed:

Procedure: Make a plan for how you will conduct your experiment. Write the steps down in a detailed list.

Collecting and Presenting Data

Data Table: Collect your results and organize the data on a data table in the space below.

Graphing the Data: Create a graph to display the data you collected. If you would rather have a blank sheet of paper for your graph, use one. Don't forget to label.

Analyzing the Investigation

Conclusion: Write a conclusion analyzing your results. Included in your conclusion should be the following:

-What was the question you were trying to answer by doing this lab?

-Briefly describe how you conducted this lab.

-Answer the question you were trying to answer by doing this lab. Be sure to use results from the lab to support your conclusions and relate your data to the science concepts presented in your background.

-What errors or weaknesses were found in the design (procedures) of this lab and how were they managed? How can your design (procedures) be improved to make the results more accurate?

-Ask a follow-up question about density that you might later test.

Density of Liquids Key (Inquiry)

Name ____ Core ____________

Friday morning, a neighbor found John Smith unconscious on his living room floor. The neighbor called 911 and an ambulance took John to Mercy Hospital. John had traces of a clear, odorless liquid in and around his mouth. He is currently in a coma. The cause of his illness is unknown.

Dr. Homes, a brilliant diagnostician who loves the challenges of a medical mystery, is assigned to the case. He believes that identifying the liquid may provide a vital clue that can be used to save John's life. The liquid is tested in the hospital lab. It is found to be colorless and clear. It also has a density of 1.25g/mL.

Dr. Homes sends his team to John's house to bring back samples of all possible liquids. They return with five liquids. Your teacher has samples of each of the liquids. Your task is to discover the identity of the liquid found in and around John Smith's mouth.

(Hint: when finding the density of a liquid, it's important not to include the density of the container holding the liquid.)

Framing the Investigation
Question: **1 point**

Background: Research and write a paragraph on the background science that relates to this topic.
2 points

•To find the mass of a liquid, you must find the mass of the liquid and its container and then subtract the mass of the container.
•To find the density of a liquid, divide the mass by the volume.

Hypothesis: Predict the answer to the above question and explain your thinking. **1 point**

Designing the Investigation
Use the materials available in the classroom to explore the above question.
Materials Needed: 2 points
graduated cylinder, liquids, scale, liquids

Procedure: Make a plan for how you will conduct your experiment. Write the steps down in a detailed list. **6 points**

•Find the mass of the container.
•Find the mass of the container and the first liquid.

•Subtract the mass of the container to find the mass of the liquid. Record this mass on the data table.
•Record the volume (how much liquid is in the container) on the data table.
•Calculate the density by dividing the mass by the volume. Record this on the data table.
•Repeat above steps with the other liquids.

Collecting and Presenting Data

Data Table: Collect your results and organize the data on a data table in the space below. **10 points**

Liquid	Mass of empty cylinder (g)	Total Mass of cylinder + liquid (g)	Mass of liquid (g)	Volume of liquid (mL)	Density (g/mL)
Rubbing Alcohol	7.9	16.7	8.8	10	0.88
Water	7.9	17.9	10	10	1.0
Corn Syrup	8	22	14	10	1.4
Glycerin	7.9	20.5	12.4	10	1.24
Mineral Oil	8	16.9	8.9	10	0.89

Graphing the Data: Create a graph to display the data you collected. If you would rather have a blank sheet of paper for your graph, use one. Don't forget to label. **10 points**

Analyzing the Investigation

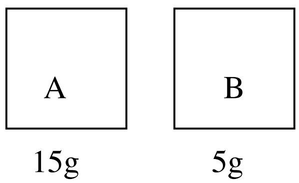
Conclusion: Write a conclusion analyzing your results. Included in your conclusion should be the following: **10 points total**

- What were the questions you were trying to answer by doing this lab? **1 point**
- Briefly describe how you conducted this lab. **2 points**
- Answer the questions you were trying to answer by doing this lab. Be sure to use results from the lab to support your conclusions and relate your data to the science concepts presented in your background. **4 points**
- What errors or weaknesses were found in the design (procedures) of this lab and how were they managed? How can your design (procedures) be improved to make the results more accurate? **2 points**
- Ask a follow-up question about density that you might later test. **1 point**

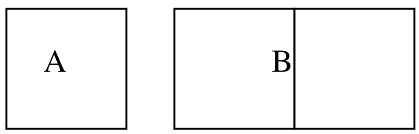
Density Final Review
(Do this orally, as a class, with students taking notes the day before the final assessment.)

Size = Volume
Weight = Mass

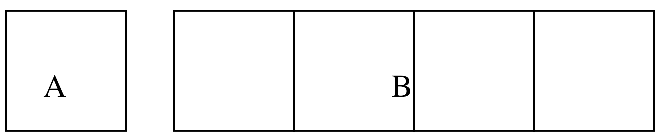
<u>Part A: Size & Density</u> (A is one material, B is a different material…doesn't matter what you call them. One cube of A weighs 15 grams and one cube of B weighs 5 grams)



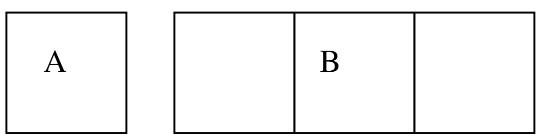
•objects are same size
•objects have different weights
•Which object has more density?



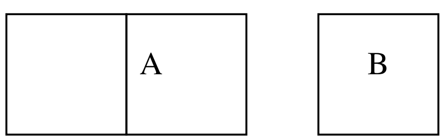
•Which is heavier?
•Has the density of B changed?



•Which is heavier?
•Has the density of B changed?



•Which is heavier?
•Has the density of B changed?



•Which is heavier?
•Has the density of A changed?

1. The weight changed in each example above. What else changed? What did not change?

<u>Part B: Material & Density</u>

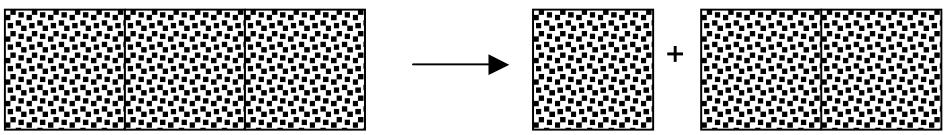
One square represents cork, another represents clay, and a third rectangle represents gold.

1. Assume that the volumes are exactly the same. Which is the densest? Which weighs the most? (Think back to your density lesson to answer this question).

2. Which material weighs the least? Which is the least dense?

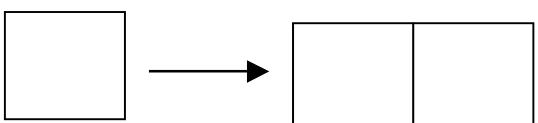
cork gold clay

One piece of clay Clay cut into 2 pieces



A B C

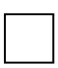
3. Which has the most density: A, B, or C? Explain.



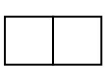
D E

4. Which has the most density: D or E? Explain.

<u>Part C: Visual Calculations of Density</u>

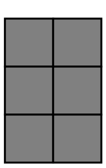
 This picture represents 1 cube unit. One cube unit = $1cm^3$

Material A

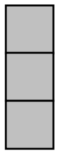
 2 cube units = 6 grams → What is the density? Answer | 3g | 3g | = 3g/cube unit

or $3g/cm^3$

Material B

 6 cube units = 24 grams → 1. What is the density of one cube?

Material C

 = 3 cube units = 12 grams

2. What is the density of the object?

3. Is the density of one cube of material C the same as the density of three cubes of material C? Explain?

4. Is the weight of one cube of material C the same as the weight of three cubes of material C? Explain.

5. Is the volume of one cube of material C the same as the volume of three cubes of material C? Explain.

6. Which of the above materials was the densest?

<u>Part D: Unit Rate = Density Per Cube Unit</u>

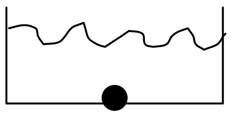
1. Draw an object that is 4 cube units and weighs 16 grams. Use the drawing to calculate the **unit rate** (density per cube unit). Will this object sink or float in water?

2. Draw an object that is 8 cube units and weighs 4 grams. Use the drawing to calculate the **unit rate**. Will this object sink or float in water?

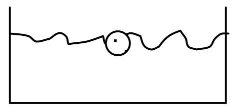
3. Draw an object that is 6 cube units and weighs 6 grams. Use the drawing to calculate the **unit rate**. Will this object sink or float in water?

<u>Part E: Density & Weight</u>

1. Object A weighs 20 grams and displaces 10 mL of water.
   Object B weighs 20 grams and displaces 20 mL of water.
   Which weighs more, A or B? Which is more dense, A or B? Explain.



this piece of clay sinks
this piece weighs 10 grams



this pumice floats in water
this piece weighs 2.5 grams

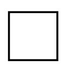
2. If you pinch off a small piece of this clay, will it sink or float?

3. If you had a very large piece of pumice, will it sink or float?

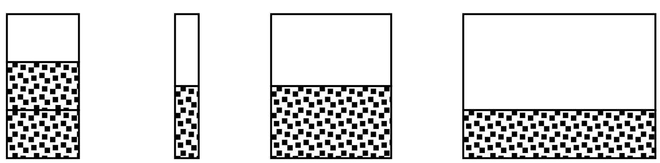
4. Explain your answers.

Part F: Density of mixed objects – Mixing two substances together that have different densities.

 clay

 cork

1. Recall from your studies, which is the densest? Clay or cork?



A B C D

Objects A, B, C, and D are a mixture of clay and cork.

2. Which of the above objects have the same density?

3. Which of the above object has the greatest density?

4. Which of the above object has the least density?

5. How do you know? Explain your answers.

__**Part G: Simple density calculations.**__ ***Use the density formula to calculate the following densities. If the decimal repeats, round to the nearest hundredth.***

1. mass = 14g
volume = 15mL

2. mass = 14g
volume = 13mL

density = _____g/mL

density = _____g/mL

3. mass = 7.5g
volume = 6.5mL
density = _____g/mL

4. mass = 7.5g
volume = 8.2cm^3
density = ______g/cm^3

5. mass = 8g
volume = 2.5cm^3
density = _____g/cm^3

6. mass = 2.5g
volume = 8cm^3
density = ______g/cm^3

7. mass = 12g
volume = 6mL
density = _____g/mL

8. mass = 24g
volume = 8mL
density = _____g/mL

9. mass = 8g
volume = 2cm^3
density = ___________

10. mass = 40g
volume = 5mL
density = ____________

11. mass = 3g
volume = 3mL
density = ___________

12. mass = 10g
volume = 7.2cm^3
density = ____________

Part H: Density Word Problems – ***Putting it all together.***

1. The initial readings of the water level in a beaker is150 mL. After placing an object in the beaker the level rises to 220 mL. The object weighs 35 grams Calculate the density of the object; show your calculations. Will this object sink or float in water?

2. Calculate the density of an object that weighs 450 grams and has a rectangular shape with the following dimensions: height = 7 cm, width = 5 cm, and length = 10 cm. Show your calculations. Will this object sink or float in mercury if mercury's density is 13.55 g/mL?

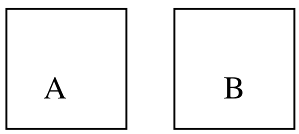
3. Calculate the density of a liquid. It has a volume of 25 mL and weighs 15 grams. If you were to pour this liquid into a graduated cylinder that had water in it, would this liquid sink below the water or float on top of the water? Would cork float or sink in this liquid if cork's density is .22g/cm^3 ?

Density Final Review - Key

(You can this orally, as a class, with students taking notes the day before the final assessment or you can hand this out to students and do together.)

Size = Volume
Weight = Mass

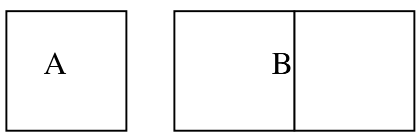
<u>Part A: Size & Density</u> (A is one material, B is a different material…doesn't matter what you call them. One cube of A weighs 15 grams and one cube of B weighs 5 grams)



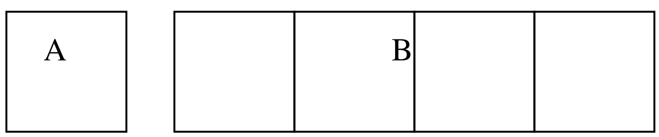
- objects are same size
- objects have different weights
- Which object has more density?

A is the most dense. It has the same volume as B, but it weighs three times more.

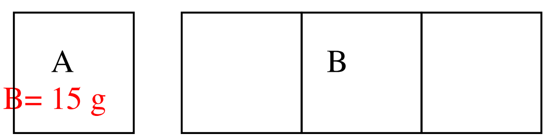
15g 5g



- Which is heavier? A is heavier. A = 15 g, B= 10 g
- Has the density of B changed? No.



- Which is heavier? B is heavier. A = 15 g, B= 20 g
- Has the density of B changed? No



- Which is heavier? Neither. A = 15 g, B= 15 g
- Has the density of B changed? No

- Which is heavier? A is heavier. A = 30 g, B = 5 grams
- Has the density of A changed? No

1. The weight changed in each example above. What else changed? What did not change?

The volume changed in each example. The density of the objects A and B did not change.

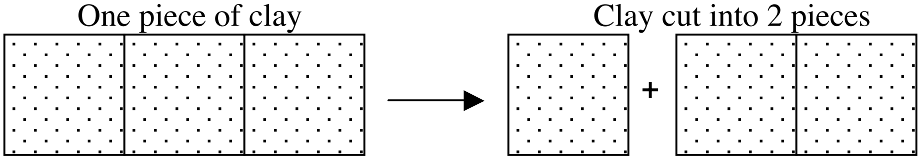
Part B: Material & Density

One square represents cork, another represents clay, and a third rectangle represents gold.

1. Assume that the volumes are exactly the same. Which is the densest? Which weighs the most? (Think back to your density lesson to answer this question). Gold is the densest and it weighs the most.
2. Which material weighs the least? Which is the least dense? Cork is the least dense and weighs the least.

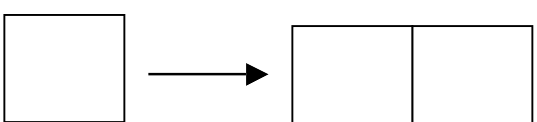
cork gold clay

One piece of clay Clay cut into 2 pieces



A B C

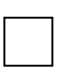
3. Which has the most density: A, B, or C? Explain. A, B, and C all have the same density. Changing the object into two pieces does not change its density. Density is a characteristic property of matter. If the matter stays the same, then the density stays the same.



D E

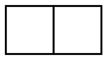
4. Which has the most density: D or E? Explain. Both are the density. Having a piece of cork that is twice as big does not change the density. The mass increases in proportion to the volume.

Part C: Visual Calculations of Density



This picture represents 1 cube unit. One cube unit = $1cm^3$

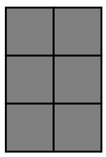
Material A



2 cube units = 6 grams ⟶ What is the density? Answer | 3g | 3g | = 3g/cube unit

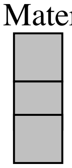
or $3g/cm^3$

Material B



6 cube units = 36 grams ⟶ 1. What is the density of one cube of material B? 6 g/cm^3

Material C



= 3 cube units = 12 grams ⟶ 2. What is the density of material C?

4 g/cm^3

3. Is the density of one cube of material C the same as the density of three cubes of material C? Explain. Yes. One cube's density = 4 g/cm^3, all cubes density together = 4 g/cm^3

4. Is the weight of one cube of material C the same as the weight of three cubes of material C? Explain. No. Three cubes of material C weighs 12 grams, one cube weighs 4 grams.

5. Is the volume of one cube the same as the volume of three cubes? Explain. No. Three cubes has the volume of 3 cm^3, one cube has the volume of 1 cm^3

6. Which of the above materials was the densest? Material B was the densest at 6 g/cm^3

Part D: Unit Rate = Density Per Cube Unit

1. Draw an object that is 4 cube units and weighs 16 grams. Use the drawing to calculate the **unit rate** (density per cube unit). Will this object sink or float in water? It will sink.

4g	4g	4g	4g

= 16 grams total. The unit rate or density is 16 g/ 4 cube units =4 g/cm^3

2. Draw an object that is 8 cube units and weighs 4 grams. Use the drawing to calculate the **unit rate**. Will this object sink or float in water? It will float.

.5 g	.5 g	.5 g	.5 g

.5 g	.5 g	.5 g	.5 g

= 8 grams total. The unit rate or density is 4 g/8 cube units =0.5 g/cm^3

3. Draw an object that is 6 cube units and weighs 6 grams. Use the drawing to calculate the **unit rate**. Will this object sink or float in water? Neither. It is neutral buoyant. It has the same density as water.

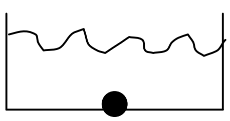
1 g	1 g	1 g
1 g	1 g	1 g

= 6 grams total. The unit rate or density is 4 g / 8 cube units = 1 g/cm^3

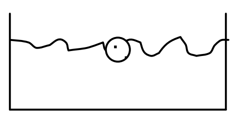
Part E: Density & Weight

1. Object A weighs 20 grams and displaces 10 mL of water.
   Object B weighs 20 grams and displaces 20 mL of water.
   Which weighs more, A or B? B Which is more dense, A or B? A Explain.

Object A displaced 10 mL of water, so its volume is 10 cm^3. The density of Object A is 20 g/10 cm^3 and that equals 2 g/ cm^3. Object B displaces 20 mL of water, so its volume is 20 cm^3. The density of Object B = 20 g/ 20 cm3 = 1 g/cm^3.



this piece of clay sinks
this piece weighs 10 grams



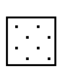
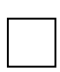
this pumice floats in water
this piece weighs 2.5 grams

2. If you pinch off a small piece of this clay, will it sink or float? It will still sink. Changing the size of an object does not change its density.

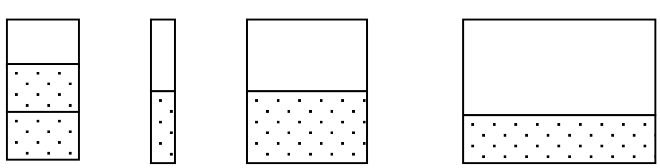
3. If you had a very large piece of pumice, will it sink or float? It will still float. Changing the size of an object does not change its density.

4. Explain your answers. If the material stays the same, then changing the size of an object does not change its density.

Part F: Density of mixed objects – Mixing two substances together that have different densities.

 clay  cork

1. Recall from your studies, which is the most dense? Clay or cork? Clay is the most dense.



A B C D

Objects A, B, C, and D are a mixture of clay and cork.

2. Which of the above objects have the same density? B and C. The proportion of clay to cork is the same in these objects

3. Which of the above object has the greatest density? A. It has the greatest proportion of clay.

4. Which of the above object has the least density? D. It has the least proportion of clay.

5. How do you know? Explain your answers. The ratio of the amount of low density to high density materials in an object determines its density. If there is a greater proportion of higher density materials, the object will have a greater density.

<u>Part G: Simple density calculations.</u> ***Use the formula to calculate the following densities. If the decimal repeats, round to the nearest hundredth.***

1. mass = 14g
   volume = 15mL
   density = 0.93g/mL

2. mass = 14g
   volume = 13mL
   density = 1.07g/mL

3. mass = 7.5g
   volume = 6.5mL
   density = 1.15g/mL

4. mass = 7.5g
   volume = 8.2cm^3
   density = 0.91g/cm^3

5. mass = 8g
   volume = 2.5cm^3
   density = 3.2g/cm^3

6. mass = 2.5g
   volume = 8cm^3
   density = 0.31g/cm^3

7. mass = 12g
   volume = 6mL
   density = 2g/mL

8. mass = 24g
   volume = 8mL
   density = 3g/mL

9. mass = 8g
   volume = 2cm^3
   density = 4g/cm^3

10. mass = 40g
    volume = 5mL
    density = 8g/mL

11. mass = 3g
    volume = 3mL
    density = 1g/mL

12. mass = 10g
    volume = 7.2cm^3
    density = 1.39g/cm^3

<u>Part H: Density Word Problems -</u> ***<u>Putting it all together.</u>***

1. The initial readings of the water level in a beaker is150 mL. After placing an object in the beaker the level rises to 220 mL. The object weighs 35 grams. Calculate the density of the object; show your calculations. Will this object sink or float in water?

220 mL – 150 mL = 70 mL. 70 mL/ 35 g = 2 g/mL It will sink because its density is greater than water (1 g/mL)

2. Calculate the density of an object that weighs 450 grams and has a rectangular shape with the following dimensions: height = 7 cm, width = 5 cm, and length = 10 cm. Show your calculations. Will this object sink or float in mercury if mercury's density is 13.55 g/mL?

7 cm x 5 cm x 10 cm = 350 cm^3 450 g/ 350 cm^3 = 1.29 g/ cm^3 It will float in mercury because it has a lower density than mercury.

3. Calculate the density of a liquid. It has a volume of 25 mL and weighs 15 grams. If you were to pour this liquid into a graduated cylinder that had water in it, would this liquid sink below the water or float on top of the water? Would cork float or sink in this liquid if cork's density is .22g/cm^3 ?

15 g/25 mL = 0.6 g/mL

This liquid would float on top of the water. The density is less than the density of water (1 g/mL). The cork would float in this liquid because the cork's density (o.22 g/cm^3) is less than the liquid (0.

APPENDIX P

COMPARISON DENSITY LESSONS, TEACHER NOTES, AND KEYS

Lesson #1 – Traditional Teaching Methodology

Properties of Matter
Teacher Notes

Introduction: The goal of this lesson is to familiarize students with the properties of matter. They will learn that everything that they touch, taste, and see is made of matter and that matter has characteristic properties.

Objectives for this lesson:
1. Students will define key terms that relate to the properties of matter.
2. Students will learn that properties of matter can be physical properties or chemical properties
3. Students will understand how properties of matter can help describe objects

Materials Needed:
1. Graphic Organizer on Characteristic Properties of Matter
5. *Properties of Matter* Lab Sheet
6. *Properties of Matter Word Search* Worksheet
7. Sets of objects (see below). Each table/lab group should have one set of materials in a basket that is on their desk.
8. Here is a suggested object list

Various sizes, shapes, colors of wood	2 Sizes of Marbles	Cork	Stones
Various types of balls, approx the same size (golf balls, ping pong balls, Styrofoam balls, wood)	Al Foil	Bolt and nut	Brass rad
Various sizes, shapes, colors of plastic	Acrylic beads	Paper clip	Rubber band
Fishing weights	Rocks	Pom-pom ball	Yarn

Lesson Plan

5. **Background**: PROPERTIES OF MATTER- (Adapted from Cribb and Duane, 2010). Teacher Dialogue: say to students as an introduction.
   1. **If you had an unknown substance in front of you, how would you describe it? How would your descriptions help you identify it?** You could describe its size, its shape, whether it is soft or hard, smooth or rough. These questions ask you to describe this object, but what they really are "what are its characteristics?" Every object has characteristics that help identify it. Some characteristics may differ between objects, but objects share the same qualities. (For example, all objects have mass, weight volume, and density, but they may differ in texture, shape, and size.)

m. **Ask students to define the word “matter.”** (It is optional for you to review some of the popular uses of the word) Popular uses, “What is the matter with you?”, “Matter of fact”, “It is only a matter of time”, “To make matters worse…” How could this use of the word matter relate to science?
n. **Pass out -** Graphic Organizer on Characteristic Properties of Matter. Student will record definitions on this sheet.
o. **Define matter:** *Anything that has mass and takes up space.* Matter takes up space and has a certain size. It is anything that has mass and volume. It is something that you could see, smell, feel, or even taste. It is something that you can hold in your hand. Matter itself consists of various atoms and molecules, can be pure or impure, seen or not seen, living or non-living. Plants, animals, rocks, water, salt, gold, air, oxygen are all examples of matter. They all consist of atoms and molecules and they all take up space.
p. **Ask students to list things that are made up of matter.** Write their answers on the board.
q. **Are there similarities between these objects? Differences? Describe**
r. **All objects have different characteristics or properties that can be used to identify them.** These characteristics of matter describe the object – or define the object. Characteristics of matter can be either physical properties or chemical properties.
s. **Physical properties**. Physical characteristics are properties that describe how the object looks, feels, tastes, etc. They are descriptions of what it is. Physical characteristics of matter include its mass, weight, volume, and density. It also specifically describes its odor, shape, texture, and hardness. In addition, physical properties describe whether the object is a solid, a liquid, or a gas – its phase of matter at room temperature.
    1. **Mass-** the amount of matter in an object. The mass of an object does not change from place to place.
    2. **Weight -** The weight of an object is determined by the force of the pull of gravity on the mass of the object. Because weight is based on the force of gravity, an object's weight may change from place to place. If you weigh 120 lbs on Earth, your weight will be 20 lbs on the moon, since the Earth’s gravitational force is 6 times stronger than that of the moon.
    3. **Volume-** Volume describes how much space matter occupies.
    4. **Density-** Density is the mass per unit volume of an object and it allows you to compare different types of matter.

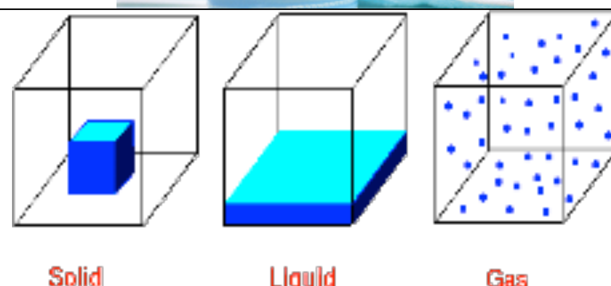
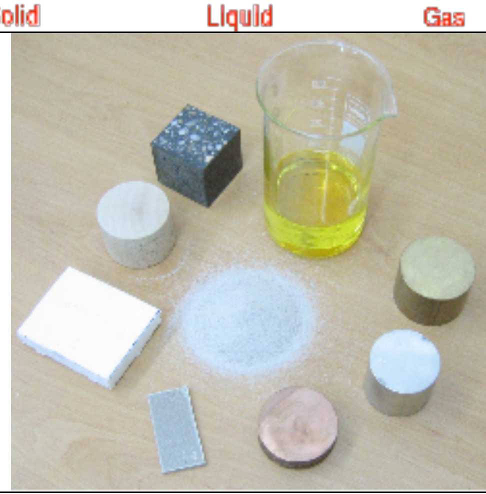
7. **Chemical properties.** Chemical properties describe how a substance can change into other new substances. Another way of phrasing that, chemical properties describe how reactive the substance is with other substances, and sometimes even tell what specific substances with which it reacts. An example of a chemical properties is flammability or the ability to burn, or that acids and bases will react together (baking soda and vinegar will react together to form bubbles of carbon dioxide)
8. **Characteristic properties of matter –**these are the specific properties of an object that cannot be changed without changing the nature of the substance.

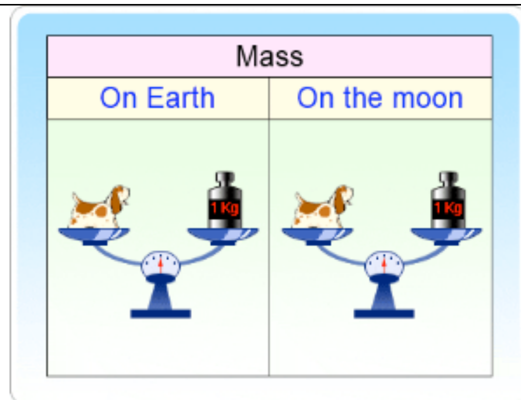
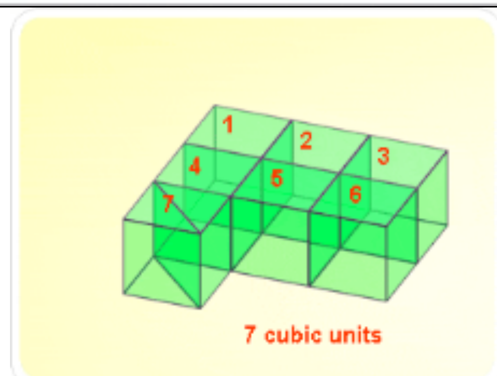
Examples are: Density, melting point, boiling point, conductivity, and heat capacity. (Some physical properties of matter can be changed without changing the substance. i.e. weight, mass, color, texture – these are not characterisitic properties)

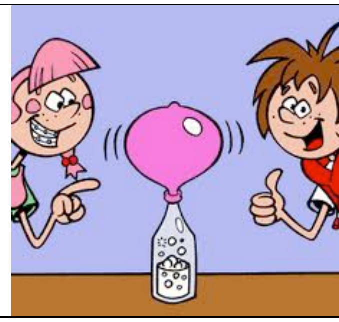
9. **Optional –** Properties of Matter video clip:
    a. Go to Discovery Education (http://my.discoveryeducation.com/)
    b. Password; holvecksu
    c. eh335
    d. Under My Content is *Physical Science Series: Properties of Matter* Video
    e. Length of video is 18:01 minutes, but there are video clips you can use if you wish.
10. **Practice -Now list some of the ways in which to describe matter.** Use a specific object in your classroom. What is its color? Shape? Texture? Smell? Stress that these qualities are used in science to describe all matter, and that the video they are about to see will explore many facts about matter. **What is a characteristic property of this object?** Its density, boiling point, etc.
11. "Today you are going to practice your observational skills and describe the properties of a set of objects. You are then going to group objects by different properties."
12. Each table group gets a collection of 20 or more objects. Each group should get an identical set of objects.
    a. Part A: first = individual; second =work with partner
    b. Part B: first = individual; second = share with table group; third = share as whole class
    c. Part C: first = table group sorts 2 or 3 different times; second = table groups share out with whole class; suggested you have them show their groupings on the overhead or document camera.
13. Wordsearch- This is an optional vocabulary exercise. Students can complete it as a homework.

Name__________________________________Date______Core____

Properties of Matter- Definitions

Vocabulary Term	Definition	Picture/Visual Aid
Matter		
Characteristic properties of matter		
Physical properties		

Mass		
Weight		
Volume		
Density		**Density of Coke**  What is the difference? Both cans are in water.

Chemical Property		

Name____Date______ Core_______

Properties of Matter

Part A: *Describe 10 items in your basket of objects. Use at least three descriptive words or phrases for each object. Try to use different words in each description. Think about what properties are unique to each object. Determine if the object is heavy for its size by comparing it to other objects. Once you have described your objects, trade your descriptions with your partner and see if they can guess which 10 objects you described.*

My object descriptions	Object is heavy for its size (yes or no)	Partner's Guess	Check here if guess was correct
1.			
2.			
3.			
4.			
5.			
6.			
7.			
8.			
9.			
10.			

Part B: *Look at all of the objects in the basket.*

1. What properties do some objects have in common?

2. Which objects were easiest to describe? Which were hardest? Why?

3. Which objects appear to be heavy for their size?

4. Which objects appear to be light for their size?

5. Name two objects in the basket that appear to have the same characteristic properties. Explain your reason.

6. Name two objects that appear to have different characteristic properties. Explain your reason.

Part C: *Sort objects according to properties.*

1. Using all of the objects in the basket (not just the 10 you described), divide the objects into groups so that each object in a group shares a similar property. List the properties that you sorted your objects by here.

2. Use the same objects. Divide them into different groups using different properties. List those properties here.

3. If you have time, try to divide your objects into different groups again. List the properties that you used to sort them here.

Part D: *Answer these questions*

1. T/F If two objects have the same size but different weights, the heavier object is made of a heavier kind of material. Explain your answer.

2. T/F If two objects have the same weight but different sizes, then the smaller object is made of a heavier kind of material. Explain your answer.

3. T/F If two objects are made of the same material, equal-sized pieces would have the same weight. Explain your answer.

Name____

Properties of Matter Word Search

```
S C D P P Y O Q C L L J R P Y
O D I I R J T O D A I E Q T S
L F Y T L O L I C Z A Q I D S
U O T Z S O P I L C N L U D E
B K I H R I S E T I I G E I N
I S L M G Y R I R B T N G E D
L O I O H I V E A T S C M A R
I F B P W I E M T I I U U O A
T T A M T X M W T C L E D D H
Y N E Y G A S Y Z O A O S K S
Y E L L L E M S V U B R H D S
Y S L F C H E M I C A L A I A
A S A R E R U T X E T J P H M
H T M S S E N H G U O R E B C
N C O N D U C T I V I T Y B Y
```

Mass	Chemical	Softness
Weight	Properties	Hardness
Volume	Characteristic	Conductivity
Density	Color	Reactivity
Odor	Roughness	Smell
Shape	Malleability	Solid
Texture	Ductility	Liquid
Hardness	Flammability	Gas
Physical	Solubility	

Write the definitions for four words on the back of this sheet. Pick words where you are unsure of the meaning.

Teacher Key:
2. Properties of Matter – Answers to Questions

Part B

5. What properties do some objects have in common? *Answers vary*
6. Which objects were easiest to describe? Which were hardest? Why? *Answers vary*
7. Which objects appear to be heavy for their size? *The metal objects*
8. Which objects appear to be light for their size? *Ping pong ball, feather*
9. Name two objects in the basket that have the same characteristic properties. *Any two objects made of the same materials*.
10. Name two objects that have different characteristic properties. *Any two objects made of different materials.*

Part D: *Answer these questions*

4. T/F If two objects have the same size but different weights, the heavier object is made of a heavier kind of material. Explain you reasoning *True. You could weigh the two objects that are the same size. The heavier object should have a greater weight.*
6. T/F If two objects have the same weight but different sizes, then the smaller object is made of a heavier kind of material. Explain you reasoning. *True. Find an object that is of the same material as the smaller object, but is also the same size as the larger object. Then weigh them. The object that is of the heavier material will weigh more.*
7. .T/F If two objects are made of the same material, equal-sized pieces would have the same weight. Explain you reasoning *True. Weigh two objects that are the same size and the same material. They should weigh the same.*

Teacher Key: Wordfind Solution

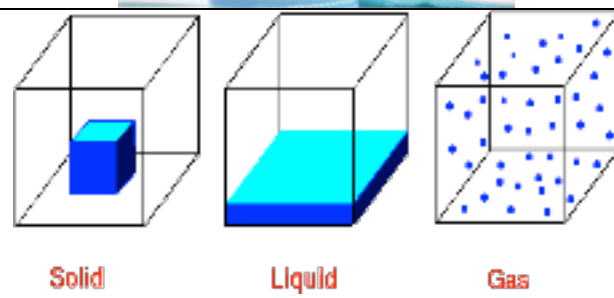
```
S C D P + Y + + C L L + R + Y
O + I I R + T O + A I E + T S
L + Y T L O L I C + A Q I + S
U + T + S O P I L C + L U D E
B + I H R I S E T I I + E I N
I S L + G Y R I R B T N + E D
L O I + H I V E A T S C M + R
I F B P + I E M T I I U U O A
T T A + T + M W T C L E D D H
Y N E Y G A S Y + O A O S + S
+ E L L L E M S V + + R H + S
+ S L F C H E M I C A L A + A
+ S A + E R U T X E T + P H M
+ + M S S E N H G U O R E + C
+ C O N D U C T I V I T Y + +
```

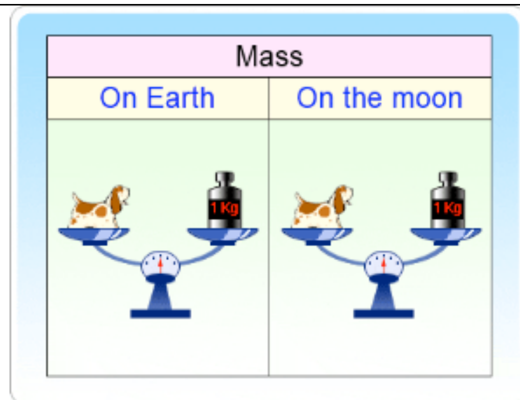
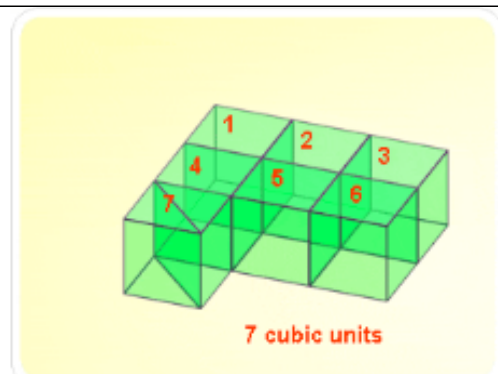
```
(Over,Down,Direction)
CHARACTERISTIC(15,14,NW)          PROPERTIES(4,1,SE)
```

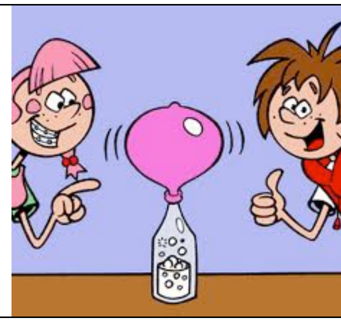
CHEMICAL(5,12,E)
COLOR(9,1,SW)
CONDUCTIVITY(2,15,E)
DENSITY(14,4,SW)
DUCTILITY(14,9,NW)
FLAMMABILITY(4,12,NE)
GAS(5,10,E)
HARDNESS(15,9,N)
LIQUID(10,1,SE)
MALLEABILITY(3,14,N)
MASS(15,13,N)
ODOR(12,10,NE)
PHYSICAL(4,8,NE)
REACTIVITY(13,1,SW)
ROUGHNESS(12,14,W)
SHAPE(13,10,S)
SMELL(8,11,W)
SOFTNESS(2,6,S)
SOLID(7,5,NW)
SOLUBILITY(1,1,S)
TEXTURE(11,13,W)
VOLUME(9,11,NE)
WEIGHT(8,9,NW)

Teacher Key: **Vocabulary**

Characteristic Properties of Matter- Definitions

Vocabulary Term	Definition	Picture/Visual Aid
Matter	Anything that has mass and takes up space.	
Characteristic properties of matter	Characteristics of matter describe the object – or define the object. Characteristics of matter can be either physical properties or chemical properties	
Physical properties	Physical characteristics are properties that describe how the object looks, feels, tastes, it color, odor, shape, etc. They are descriptions of what an object looks like.	

Mass	The amount of matter in an object. The mass of an object does not change from place to place.	
weight	The weight of an object is determined by the force of the pull of gravity on the mass of the object. Because weight is based on the force of gravity, an object's weight may change from place to place.	
Volume	Volume describes how much space matter occupies.	
Density	Density is the mass per unit volume of an object and it allows you to compare different types of matter.	**Density of Coke**  What is the difference? Both cans are in water.

Chemical Property	Chemical properties describe how a substance can change into other new substances.	

Lesson #2 – Traditional Teaching Methodology

Lesson 2-Sinking and Floating

Teacher Notes

Introduction: The purpose of this lesson is for students to make and test predictions about sinking and floating and to classify objects according to whether they sink or float. In this activity students will determine whether various objects sink or float in water. Whether an object sinks or float in a liquid depends mainly on two factors: density and buoyancy. However, at this point students do not need to explain why objects sink or float. They are rather to be encouraged to observe that the same objects will sink or float every time, i.e., that there is consistency in the way the objects behave. This will help students devise their own ideas about physical properties and how they can be used to describe and categorize objects. This lesson will also provide practice categorizing a variety of objects according to observable characteristics (Science NetLinks, 2000).

Objectives for this activity:

1. Students will predict and test an object's ability to float or sink;
2. Students will develop rules for sinking and floating;
3. Students will make a visual representation of 3 objects that sink, float, and are neutral.

Supplies needed: tub of water for each group
extra clay balls to cut at end of each class
9 sink/float objects for each table group:

same material, different size, same density	Small piece of wood (floats) Larger piece of wood (floats)
same size, different density, appears same material	small ball of clay (sinks) sm ball of clay small cork hidden inside (neutral) sm ball of clay larger cork hidden inside (floats)
same size, different density, appears same material	small sliver of white **Dial** soap (sinks) small sliver of white **Ivory** bar soap (floats)
same size, different density, similar material	pumice (floats) basalt (sinks)

Note: it is not easy to cut slivers of soap to be the same size. Don't try to prep this lab at the last minute!

Lesson Plan

1. **Part A: first** = individual makes list of things that sink and things that float.
   second = share list as whole class; suggested **not** to discuss **why** things sink or float at this point.
2. **Part B:first** = individuals describe, predict, and give reason for predictions.
   second = table groups conduct test and change reasons
   Notes: •Be sure students do not leave soap in water for any length of time or use different pieces of soap for each class period.
   •Caution students that the clay objects should not be changed or altered in any way. One slight change (pulling off a tiny piece of clay, for example) can change results.
3. **Part C: first** = individual creates rules
   second = share in table groups
   third = share as whole class; suggested to have a "science talk" at this point: have students share their rules for sinking and floating, explain their thinking, debate with each other; teacher is facilitator of discussion only.
   Note: when the question about what might be inside the clay comes up (after part B is completed), have extra clay balls (all 3 types) to cut open for class so they can see the insides.
4. **Part D: first** = individual draws picture (possibly homework)
   second = share in table groups
   third = share as whole class

Optional Demo (dramatic visual of how much air there is in Ivory soap)

If you do this, do it **after** they have discovered that Ivory soap floats.

Directions: Place a bar of Ivory soap in a large, clear, glass bowl. Microwave it on high for 2 minutes. If microwave is powerful, it may take less time. Monitor so it doesn't puff up too high. The bar of soap will quickly puff up and fill the bowl. It looks a lot like whipped cream! If you wait too long after taking it out of the microwave, it will sink back down so show it quickly. You can put the same soap back in the microwave over and over again, and it will continue to puff up, although it's not as dramatic as when students see a full bar of soap transform.

Here's an explanation for and a little history about why Ivory soap floats: Ivory soap is one of the few brands of bar soap that floats in water. If it floats in water, it must mean that it's less dense than water. When you break the bar of soap into several pieces, no large pockets of air can be seen. Ivory soap floats because it has air pumped into it during the manufacturing process. The air-filled soap was actually discovered by accident in 1890 by an employee at Proctor and Gamble. While mixing up a batch of soap, the employee forgot to turn off his mixing machine before taking his lunch break. This caused so much air to be whipped into the soap that the bars floated in water. The response by the public was so favorable that Proctor and Gamble continued to whip air into the soap and capitalized on the mistake by marketing their new creation as The Soap that Floats!

Why does the soap expand in the microwave? This is actually very similar to what happens when popcorn pops. Here's the secret: All soap contains water, both in the form of water vapor inside trapped air bubbles (particularly important in the case of Ivory) and water that is caught up in the matrix of the soap itself. The expanding effect is caused by the heating of the water that is inside the soap. The water vaporizes, forming bubbles, and the heat also causes trapped air to expand. Likewise, the heat causes the soap itself to soften and become pliable. This effect is actually a demonstration of Charles' Law. When the soap is heated, the molecules of air in the soap move faster causing them to move far away from each other. This causes the soap to puff up and expand to an enormous size. Charles' Law states that as the temperature of a gas increases so does its volume. Other brands of soap without whipped air tend to heat up and melt in the microwave.

Sinking and Floating

Name____Core _____

Part A: *Think about things you have seen sink and things you have seen float. List as many as you can on the chart below.*

Things that sink	Things that float

Part B: *Observe the nine objects in the container. On the data table on the back of this page, describe each object, predict whether it will sink or float in water, and give a reason for your prediction. Next, test your prediction by placing each object in water. Tell whether each object sinks or floats, and change the reason it sinks or floats if you have a new idea.*

Part B: *Data Table*

Describe What is the object?	***Predict*** Will it sink or float?	***Give Reason*** Why will it sink or float?	***Test*** Put the object in water. Does it sink or float?	***Change Reason*** Do you have a new reason to explain why it sinks or floats? If yes, what is it?

Part C: *Based on your observations, create rules for things that sink and things that float.*

Rules for things that sink	Rules for things that float

Part D: *Using a dark color to represent clay and a light color to represent cork, draw the 3 clay objects in the space below. Below each drawing, label with a description of what is inside the object and whether it would sink, float, or be neutral.*

Questions

1. Does size affect whether an object will sink or float? Explain.

2. Does the material an object is made out of affect whether it sinks or floats? Explain
3. How many of your predictions were correct?

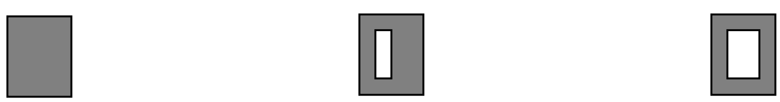
4. Did your predictions get better, worse, or stay the same? Explain

Sinking and Floating Key

Part C: *Based on your observations, create rules for things that sink and things that float. Possible answers given below.*

Rules for things that sink	Rules for things that float
Heavy objects Objects with more stuff in them Objects that are more compacted	Light objects Objects with less stuff in them Objects that are less compacted

Part D: *Using a dark color to represent clay and a light color to represent cork, draw the 3 clay objects in the space below. Below each drawing, label with a description of what is inside the object and whether it would sink, float, or be neutral.*



clay (sinks) | clay w/cork (neutral) | more clay w/cork (floats)

Questions

1. Does size affect whether an object will sink or float? Explain. **No. Small things can sink (marble) and large things can float (styrofoam ball)**

2. Does the material an object is made out of affect whether it sinks or floats? Explain. **Yes. Objects made out of heavy for its size materials wil sink and objects made out of light for its size materials will float.**

3. How many of your predictions were correct? **Answers vary**

4. Did your predictions get better, worse, or stay the same? Explain. **Answers vary**

Lesson #3 - Traditional Teaching Methodology

Mixing Materials

Teacher Notes

Introduction: Students will continue to explore how objects sink or float by working with objects that have more than one type of material. Students will see that by changing the ratio a material that is less dense and the material that is more dense, that the overall density of the material will change. Students will look at this average density change as a factor of sinking and floating. They will try to create a neutrally buoyant object by adding and subtracting clay (a dense material) that covers a piece of cork (a less dense material).

Objectives for this activity:

1. Define ratio, buoyant force, neutral buoyancy. Apply those definitions to solving a few problems.
2. Observe a neutrally buoyant object.
3. Observe how Diet Coke and Classic Coke have different floating and sinking behaviors.
4. Change these objects by mixing materials so that they are neutrally buoyant
5. Explain how mixing the ratio of heavy for its size materials with lighter for its size materials changes how an object sinks or floats.

Materials needed:

1. *Vocabulary and Problems on Buoyancy* worksheet
2. *Mixing Materials* Lab
3. For Demo:
    a. Set of Styrofoam Balls (one that sinks, one that floats, and one that is neutrally buoyant)
    b. Large vessel that you can float Styrofoam balls in
4. For Lab- Materials listed below:

Cans of Diet Coke and Classic Coke	Large clear vessel that will hold can of floating coke in water	clay	1000 ml beakers in tubs (in case water overflows)
Styrofoam pieces	Duct Tape	weights	

Lesson Plan:

14. View Buoyancy video clip (5:38 minutes). I strongly urge you to do this, but if logistics are such that it would not work, lesson is OK without it. This will tie Buoyancy and Density together. (I could not download this video – it was disabled. You can get to it this way:
    a. Go to Discovery Education (http://my.discoveryeducation.com/)
    b. Password; holvecksu
    c. eh335

d. Under My Content is Explaining Buoyancy Video

15. Have students complete *Vocabulary and Problems on Buoyancy* worksheet. This is a teacher directed activity.

16. Demonstrate neutral buoyancy using three different Styrofoam balls: one that is pure Styrofoam and floats, one that is Styrofoam with a small weight that has been added inside and is neutrally buoyant, one that is a Styrofoam ball with a larger weight and sinks in water. Weights should be embedded inside the Styrofoam balls so they are not readily visible to students (these are provided to the teacher)

17. Ask students: **What are they observing?** Ask for their explanations

18. Explain that an object that is neutrally buoyant neither sinks nor floats in water. (It should be in the middle of the beaker of water). *It has the same density as water. Objects that are less dense than water float in water, objects that are greater in density than water sink in water. The force of gravity and buoyancy are balanced in a neutrally buoyant object.*

19. Hold up a pure Styrofoam ball and a weight. Ask students which is heavy for its size (weight) and which is lighter for its size (Styrofoam)? Put both objects in the water Styrofoam will float and weight will sink.

20. Is it possible to combine these two materials to get what you observed in the discrepant event?

21. Ask students? Can combining objects that are heavy for their size and lighter for their size explain what you are observing?

22. Which object is larger in size? (Styrofoam) Which object is smaller *(weight)*.

23. Does the size of the object affect its ability to sink or float*? (No)*

24. What affects its ability to sink or float? *(The material of the object)*

25. Soda Can Demo

<table>
<tr><td rowspan="9">Density of Coke


What is the difference?
Both cans are in water.</td><td>1. Put a can of Diet Coke in water and a can of Classic Coke in water.</td></tr>
<tr><td>2. Ask students what they are observing?</td></tr>
<tr><td>3. Ask them why they think there is a difference between the two soda cans. They have different densities. Both cans have the same volume of 355 mL , but one weighs more.</td></tr>
<tr><td>4. Which can weighs more? Classic Coke
<table>
<tr><th colspan="2">Comparison of:</th></tr>
<tr><td>Classic Coke</td><td>Diet Coke</td></tr>
<tr><td>355 mL</td><td>355 mL</td></tr>
<tr><td>Water = 355 g</td><td>Water = 355 g</td></tr>
<tr><td>Sugar = 39 g</td><td>Sugar = 0 g</td></tr>
<tr><td>Nutra Sweet = 0 g</td><td>Nutra Sweet = 0.1g</td></tr>
<tr><td>Tot. Wgt. = 394 g</td><td>Tot. Wgt. = 355.1 g</td></tr>
</table></td></tr>
<tr><td>5. What could you do to make the Classic Coke float and the Diet Coke sink? By mixing materials.</td></tr>
<tr><td>6. Show students your clay, weights, corks, and Styrofoam.</td></tr>
<tr><td>7. What could they use to cause the Classic Coke to sink? The weights and clay. Do this for them.</td></tr>
<tr><td>8. What could they do to make the Diet Coke Float? Add Styrofoam and/or corks.</td></tr>
<tr><td>9. Could either object be made to be neutrally buoyant? Yes, by adding the correct mixture of materials.</td></tr>
</table>

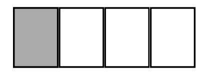
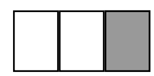
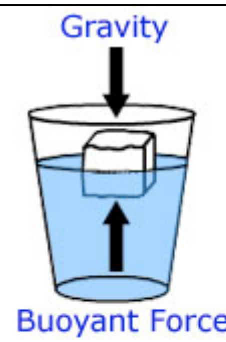
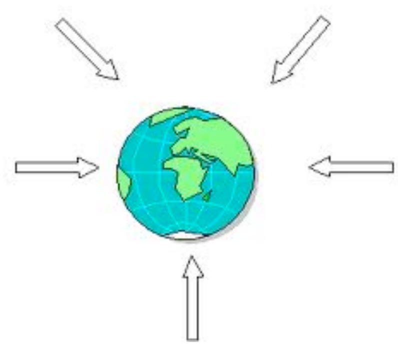
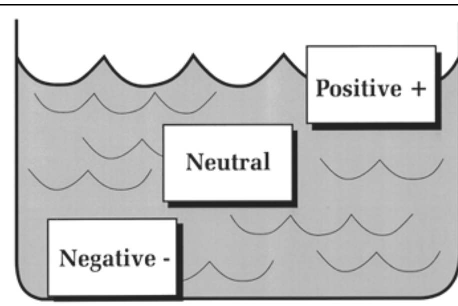
For each table group, give students supplies to try and make the Diet Coke and the Classic Coke neutrally buoyant (Clay, weights, duct tape, Styrofoam) –or do this in front of class as demo.

Add modeling clay to the Diet Coke
to make it neutrally buoyant

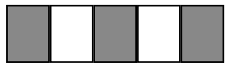
Add styrofoam to the Classic Coke
to make it neutrally buoyant

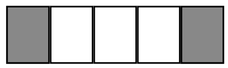
Name____Date________Core____________

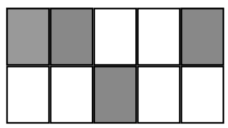
Vocabulary and Problems on Buoyancy

Vocabulary Term	Definition	Picture/Visual Aid
Ratio		Ratio of dark to light squares 1:3 or 1/3  2:2 or 2/2  1:2 or 1/2 
Buoyant Force		
Gravity	.	
Neutral buoyancy		

1. Determine the ratio of light to dark squares in the following objects:

A. 

B. 

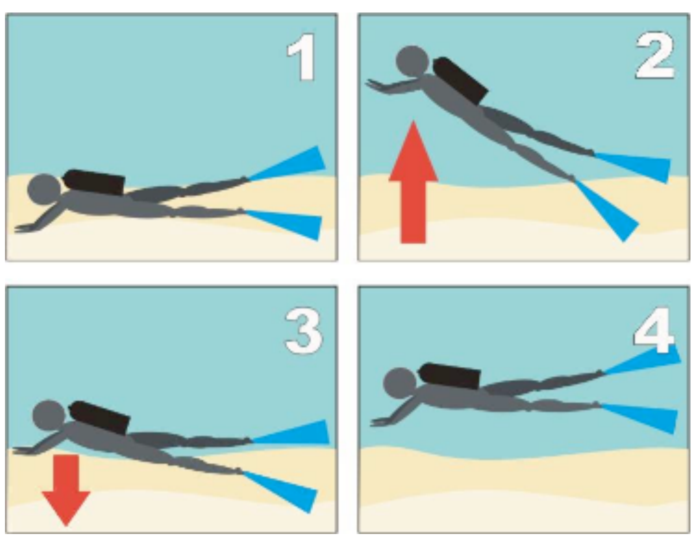
C. 

2. Jeannine has a bag with 3 videocassettes, 4 marbles, 7 books, and 1 orange.

a) What is the ratio of books to marbles?

b) What is the ratio of videocassettes to the total number of items in the bag?

3. Explain these four pictures in terms of buoyancy and gravity.



Name____Date____________Core___

Mixing Materials Activity

Objective: Make a can of Diet Coke and a can of Classic Coke neutrally buoyant by adding other materials.

Materials: Diet Coke, Classic Coke, Styrofoam, clay, weights, duct tape

Procedure:

1. Before you begin, discuss with your group how changing the ratio of two different materials in an object can affect its ability to sink or float. Use a diagram to help you explain your answer.

2. Create two neutrally buoyant objects using the materials given. Draw a picture of what you did and label it.

3. Which object seemed to be more difficult to make neutrally buoyant. Why?

4. What is your rule for changing how an object floats in water?

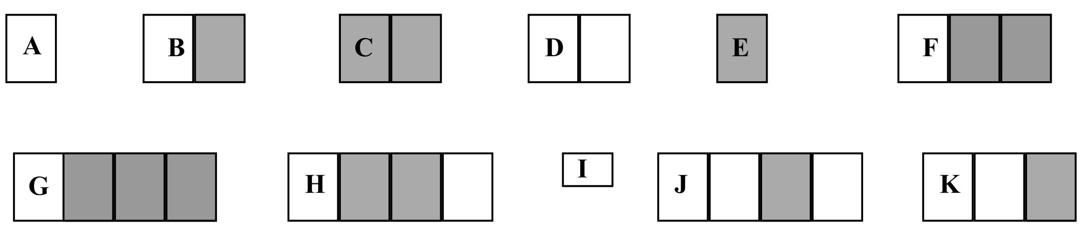
5. Before you made the cans of Coke neutrally buoyant, which object had the greatest density? How did you know this?

6. Before you made the cans of Coke neutrally buoyant, which object had the lowest density? How did you know this?

7. To make the objects neutrally buoyant you made a mixture of low and high density materials. By doing this you changed the density of the object.

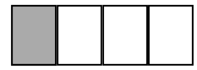
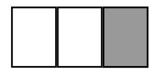
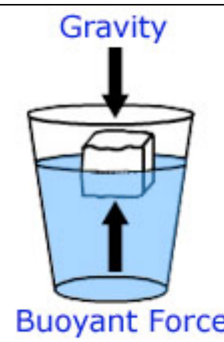
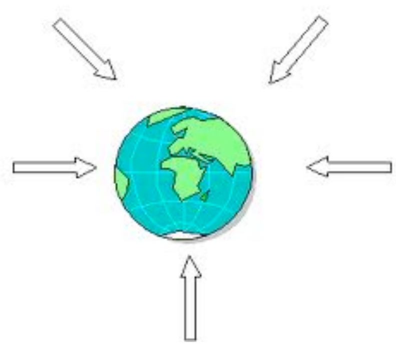
Order the following objects from least dense to most dense, where = a heavy for its size material and = a light for its size material. Some objects are a combination of the two materials.

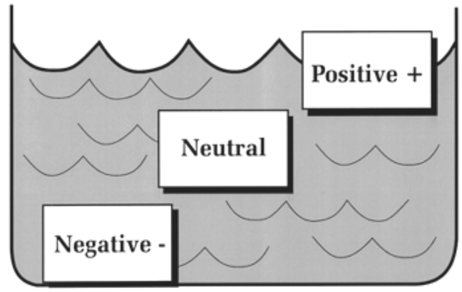
Hint: Some objects may have the same density if the ratio of heavy to light materials is the same.



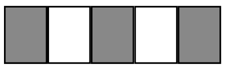
Teacher Keys

Vocabulary and Problems on Buoyancy

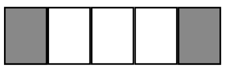
Vocabulary Term	Definition	Picture/Visual Aid
Ratio	When two (or more) numbers are compared by division. Ratios are generally written as a:b or a/b. The ratio "a:b" is read "a is to b." The number that comes after the "to" goes second or at the bottom of the fraction. If you want to write the ratio of 8 and 12. You can write it as 8:12 or as a fraction 8/12 and you say the ratio is *eight to twelve*	Ratio of dark to light squares 1:3 or 1/3  2:2 or 2/2  1:2 or 1/2 
Buoyant Force	When an object is placed in a fluid, the fluid exerts an upward force we call the buoyant force. An object that is floating in water displaces the same amount of water that it weighs. Buoyant force is in the opposite direction as gravity. In the illustration **gravity** is pulling the ice cube down and **buoyant force** is pushing it up. Buoyant force is what allows very large, heavy ships to float.	
Gravity	Gravity is the force that pulls objects towards the centre of the Earth. Gravity gives weight to objects with mass and causes them to fall to the ground when dropped.	

Neutral buoyancy	This happens if an object has the same density as the medium it is in. If the object is floating it has a positive buoyancy, if the object is sinking it has a negative buoyancy. When an object has a positive buoyancy, then the force of buoyancy is greater than the force of gravity. When an object has a negative buoyancy then the force of gravity is greater than the force of buoyancy.	

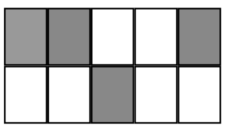
1. Determine the ratio of light to dark squares in the following objects:



2:3 or 2/3

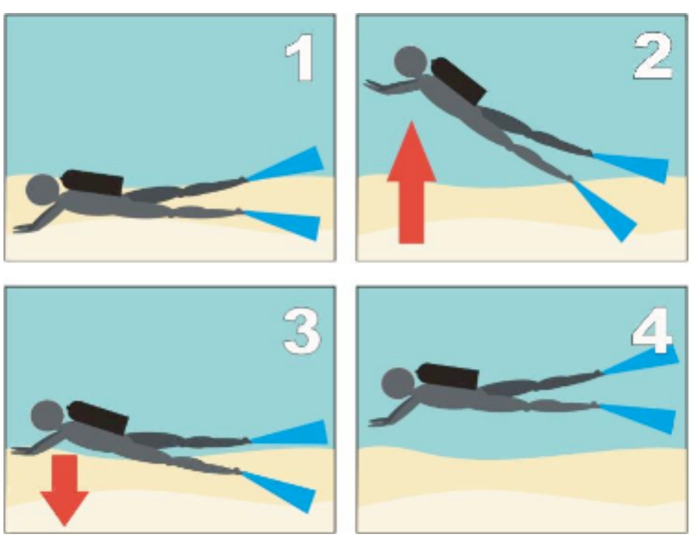


3:2 or 3/2



6:4 or 6/4

2. Jeannine has a bag with 3 videocassettes, 4 marbles, 7 books, and 1 orange.
a) What is the ratio of books to marbles?*Expressed as a fraction, with the numerator equal to the first quantity and the denominator equal to the second, the answer would be 7/4. Two other ways of writing the ratio are 7 to 4, and 7:4.*
b) What is the ratio of videocassettes to the total number of items in the bag?*There are 3 videocassettes, and 3 + 4 + 7 + 1 = 15 items total. The answer can be expressed as 3/15, 3 to 15, or 3:15.*
3. Explain these four pictures in terms of buoyancy and density

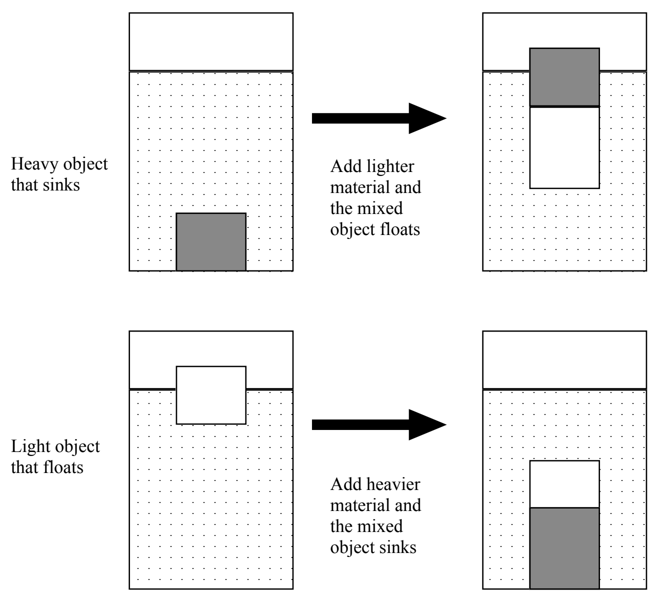


1 = negative buoyancy. The diver sank to the bottom. His density is greater that water. The gravity of Earth pulled him to the bottom of the ocean floor.
2 = positive buoyancy. The diver is rising to the top. His density is less than water. The force of buoyancy is greater than the force of gravity.
3 = negative buoyancy. The diver is sinking to the bottom. His density is greater that water. The force of gravity is greater than the force of buoyancy.
4 = neutrally buoyant. The diver is the same density as the water and as a result, he is floating. The force of gravity is equal to the force of buoyancy.

Mixing Materials Activity

Objective: Make a can of Diet Coke and a can of Classic Coke neutrally buoyant by adding other materials.
Materials: Diet Coke, Classic Coke, Styrofoam, clay, weights, duct tape
Procedure:
1. Before you begin, discuss with your group how changing the ratio of two different materials in an object can affect its ability to sink or float. Use a diagram to help you explain your answer.

If you add a light material to a sinking object material, it can float. If you add enough heavy material to a floating object, it can sink.



2. Create two neutrally buoyant objects using the materials given. Draw a picture of what you did and label it.

Add modeling clay to the Diet Coke to make it neutrally buoyant

Add styrofoam to the Classic Coke to make it neutrally buoyant

3. Which object seemed to be more difficult to make neutrally buoyant. Why? *The Diet Coke should have been easier as it is already very close to the density of water, but answers may vary.*

4. What is your rule for changing how an object floats in water? *Mixing materials that have different densities will change how an object sinks and floats.*

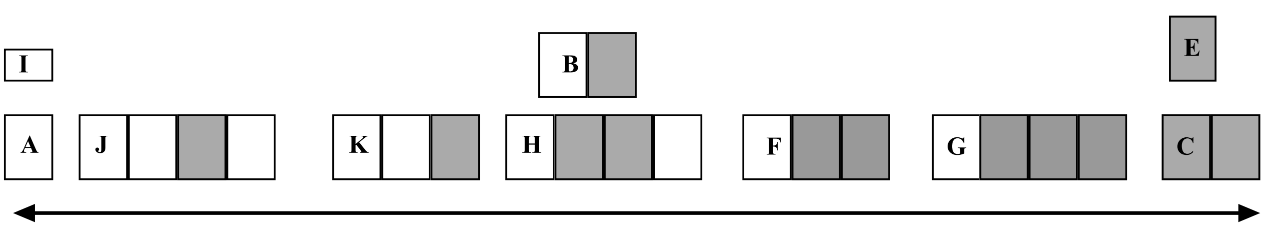
5. Before you made the cans of Coke neutrally buoyant, which object had the greatest density? *The Classic Coke.* How did you know this? *Because it sank in water*

6. Before you made the cans of Coke neutrally buoyant, which object had the lowest density? *The Diet Coke* How did you know this? *Because it floated.*

7. To make the objects neutrally buoyant you made a mixture of low and high density materials. By doing this you changed the density of the object.

Order the following objects from least dense to most dense, where ▢ = a heavy for its size material and ▢ = a light for its size material. Some objects are a combination of the two materials. Hint:

Some objects may have the same density if the ratio of heavy to light materials is the same.



least dense

most dense

Lesson #4 – Traditional Teaching Methodology

Changing the Liquid

Teacher Notes

Introduction: Objects will sink if their density is greater than the density of the liquid they are in and objects will float if their density is less than liquid they are in. Students will explore this basic property of density through readings and an experiment.

Objectives: Students will read a passage on ice that does not float and learn that its crystalline structure is the reason that the ice sinks. Students will explore the sinking and floating properties of objects in three different liquids: isopropyl alcohol, water, and salt water. Alcohol has a lower density than water and salt water has a higher density than water. Some objects that sink in water will float in alcohol. Some objects that sink in water and alcohol, will float in salt water.

Materials Needed:

1. *This Ice Sinks* Worksheet
2. Materials for activity

Beaker	Salt
A variety of plastic objects that are near the density of water (between 1.1 g/cm^3 – 2 g/cm^3), or an egg	Spoon
Wax (or candle)	Alcohol

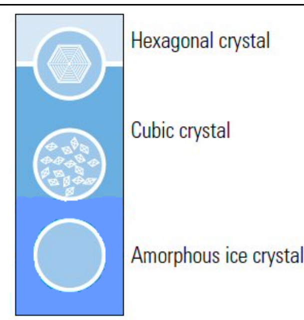
Lesson Plan:

1. **Opening Question: Why so you think that it is easier to float in salt water than it is in fresh water?** Salt water is heavier or more dense than fresh water. Therefore objects that are denser can float in it. An object that can float in fresh water will float higher in salt water.
2. Solid objects that are denser than the liquid that they float in sink. Solid objects that are less dense than the liquid that they are put in float.
3. Students do reading and vocabulary exercise – *This Ice Sinks*.
4. Students do Activity – *Floating Eggs in Salt Water and Floating Objects in Alcohol*

Name____Core _________Date_______

This Ice Sinks

Reading Passage	**Notes on Big Ideas**
INNSBRUCK, Austria—What happens when an ice cube is dropped into a glass of water? It floats, right? Not if it's a special type of ice called very high density amorphous ice (VHDA). Normal water ice floats because it is less dense than liquid water. VHDA ice sinks because it is 25 percent denser than regular ice. VHDA ice is made under high pressure and low temperatures. Normal ice is crystalline ice. Its molecules line up in a well defined, repeating structure. Altogether, 13 types of crystalline water ice are known to exist. The ice in most home refrigerators is hexagonal ice, with molecules stacked in six-sided symmetry. VHDA is the newest known type of amorphous ice. In amorphous ice, the water molecules do not fall into a regular pattern. Instead, the molecules are all jumbled. Glass is another type of amorphous material.	How is amorphous ice different than a regular ice cube? What does VHDA stand for? How is VHDA ice made? Why does normal ice float? What is another kind of amorphous material? Do you think that glass will sink or float in water?

Vocabulary Term	**Definition**	**Picture/Visual Aid**
Amorphous ice		

Crystalline ice		

Citation: “This Ice Sinks.” *Current Science* Feb. 28, 2003. Facts For Learning. Facts On File News Services. http://factsforlearning.2facts.com

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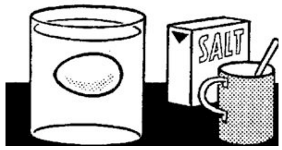


FLOATING EGGS IN SALT WATER

Background

Density is a measure of how much matter takes up a certain amount of space or volume. The more matter you can pack into a certain space, the denser it is. Since density is defined as how much matter takes up a certain amount of volume, we can take ordinary water, add salt to it, and make it denser. Yes, the volume increases a little bit when we add the salt but the mass increases by a much bigger factor. This is because rather than just floating around and taking up space, the salt dissolves into ions which are attracted to the water molecules and bind very tightly to them, packing more matter into the space. Salt water has more "stuff "in it and is much denser than ordinary water.

So how can we prove that the saltwater is denser than ordinary water? By understanding that the higher the density of a fluid, the easier it is for things to float in it. You can think of the salt water as having more particles with which to hold up the floating object.

Materials: Egg, beaker, salt, spoon

Procedure:

1. Fill a beakers with water
2. Place an egg into the beaker
3. Note what happens.
4. Take out the egg.
5. Put a teaspoon of salt in the water and stir to dissolve it.
6. Put your egg in the beaker. Is it floating yet?
7. Repeat steps 2 - 6 until your egg is neutrally buoyant.
8. Add more salt until your egg is floating.
9. Save your salty water for the next experiment.

Data: Amount of water in your beaker. ________________mL

Amount of salt added to water	Egg sinking, neutrally buoyant, or sinking?	Other Observations (What does the water look like, is the volume of water changing?)

How can the concept of an egg floating in saltwater but sinking in freshwater apply to people who are swimming in salt water versus freshwater? Use words and pictures to answer.

Floating Objects in Alcohol

Some objects will float in fresh water and then the same object will sink in alcohol. Explain in terms of density, why you think this might happen.

Materials: candle or wax, alcohol

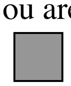
<u>Try it out!</u>

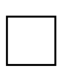
4. Using wax or a candle, compare what happens when you place it in water versus alcohol. Write what you learned about the density of the wax versus the density of the liquids. Use drawing to help explain your thinking.

5. Predict what will happen when you place the piece of wax in the salt water from the egg experiment.

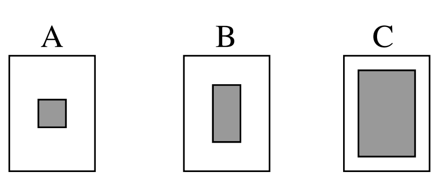
6. Write down what you actually observed. Use a drawing and words.

7. You are given three neutrally buoyant objects below.

 = a material that has a high density

 = a material that has a low density.

These objects each contain some of each type of material. Which object is neutrally buoyant in water? In salty water? In alcohol? Explain your reasoning.



Teacher Notes

This Ice Sinks

Reading Passage	Notes on Big Ideas
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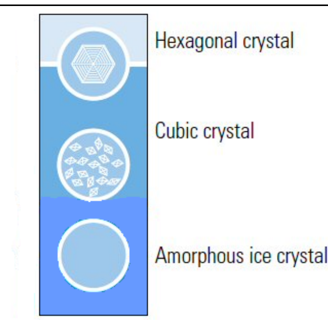
Vocabulary Term	Definition	Picture/Visual Aid
Amorphous ice	Does not have a clearly defined shape or form. Ice molecules are jumbled and have no clear pattern. This kind of ice is very dense and will sink in water.	

Crystalline ice	Having the structure and form of a crystal. Molecules line up in a well-defined repeating structure. This kind of ice is less dense than water and will float.	

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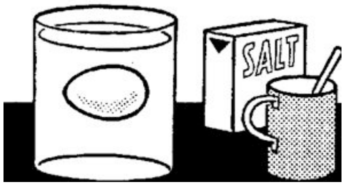


FLOATING EGGS IN SALT WATER

Background

Density is a measure of how much matter takes up a certain amount of space or volume. The more matter you can pack into a certain space, the denser it is. Since density is defined as how much matter takes up a certain amount of volume, we can take ordinary water, add salt to it, and make it denser. Yes, the volume increases a little bit when we add the salt but the mass increases by a much bigger factor. This is because rather than just floating around and taking up space, the salt dissolves into ions which are attracted to the water molecules and bind very tightly to them, packing more matter into the space. Salt water has more "stuff "in it and is much denser than ordinary water.

So how can we prove that the saltwater is denser than ordinary water? By understanding that the higher the density of a fluid, the easier it is for things to float in it. You can think of the salt water as having more particles with which to hold up the floating object.

Materials: Egg, beaker, salt, spoon

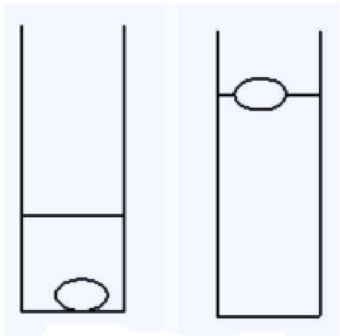
Procedure:

1. Fill a beakers with water
2. Place an egg into the beaker
3. Note what happens.
4. Take out the egg.
5. Put a teaspoon of salt in the water an stir to dissolve it.
6. Put your egg in the beaker. Is it floating yet?
7. Repeat steps 2 - 6 until your egg is neutrally buoyant.
8. Add more salt until your egg is floating.
9. Save your salty water for the next experiment.

Data: Amount of water in your beaker. ________________mL

Amount of salt added to water	Egg sinking, neutrally buoyant, or sinking?	Other Observations (What does the water look like, is the volume of water changing?)

How can the concept of an egg floating in saltwater but sinking in freshwater apply to people who are swimming in salt water versus freshwater? Use words and pictures to answer.



Egg sinking in fresh water like a person, because the egg is more dense than the water

Egg floating in salt water like a person, because the egg is less dense than the water

This same principle applies to people swimming in oceans or salt water lakes. The average person will sink in ordinary water but can float like a boat in saltwater. The Dead Sea is 33% salt by mass. People find it very odd how "floaty" they are when they

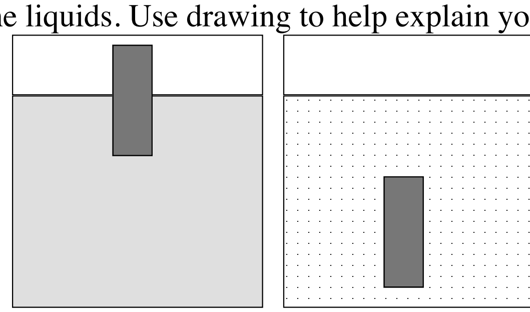
Floating Objects in Alcohol

Some objects will float in fresh water and then the same object will sink in alcohol. Explain in terms of density, why you think this might happen. *The density of the object is not changing, the density of the liquids is different causing the change in the sinking and floating behavior of the object. Alcohol must have a lower density than water if objects are sinking in it that normally float in water.*

Materials: candle or wax, alcohol

<u>Try it out!</u>

1. Using wax or a candle, compare what happens when you place it in water versus alcohol. Write what you learned about the density of the wax versus the density of the liquids. Use drawing to help explain your thinking.



Candle floats in water
The density of the water is greater than the density of the candle

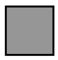
Candle sinks in alcohol
The density of the alcohol is less than the density of the candle

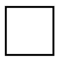
The density of the candle is in between the density of water and alcohol.

2. Predict what will happen when you place the piece of wax in the salt water from the egg experiment. *It will float*.

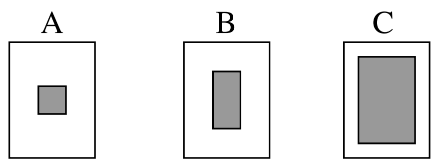
3. Write down what you actually observed. *It floated very high in the water.*

4. You are given three neutrally buoyant objects below.

 = a material that has a high density

 = a material that has a low density.

These objects each contain some of each type of material. Which object is neutrally buoyant in water? In salty water? In alcohol? Explain your reasoning.



A = Neutrally buoyant in alcohol because it has the least average density of the three objects
B = Neutrally buoyant in water because it has the middle average density
C = Neutrally buoyant in salt water because it has the highest average density of the three objects

Alcohol is the least dense liquid and the least dense object will be neutrally buoyant in it. Salt water is the densest liquid and the most dense object will be neutrally buoyant in it.

Lesson #5 - Traditional Teaching Methodology

Measuring Matter
Teacher Notes

Introduction: Objectives for this activity (1). Determine the mass of an object. (2). Discover that the density of an object is not determined by mass alone. Note that students will begin this lesson with a reading selection while the inquiry will begin the lesson with a conceptual understanding based formative assessment. The activity is the same for both.

Materials Needed

1. Reading selection – *Measuring Matter* (taken from: Science Explorer: Chemical Building Blocks, pp. 16-17).
2. One triple beam scale for each table group
3. Reading a Triple Beam Balance and Using the Balance worksheets (if needed)
4. Discover Activity Sheet - Which has More Mass?
5. 11 objects from Lesson #2- for each group:

Sinking clay ball	Pumice rock	Dial soap bar	Ivory soap piece
Neutral clay ball	Basalt rock	Small piece of wood	Dial soap piece
Floating clay ball	Ivory soap bar	Large piece of wood	

Lesson Plan

1. **Opener:** Have students read **Measuring Matter** Students should be able to answer the following questions after they read:
   a. **How are weight and mass different?** (weight is the measure of the force of gravity on an object, mass is the measurement of the amount of mass in an object)
   b. **Does weight or mass change with location?** *(Weight. An object will weigh less on the moon. Mass does not change with location. An object has the same mass on the moon and on Earth)*
   c. **What is the SI unit of mass?** *(grams)*
   d. **How do you convert mass in grams to the equivalent mass in kilograms?** *(divide by 1000)*
2. **Intro to using a triple beam balance** (demo if needed)
7. **Reading a Triple Beam Balance/Using the Balance Worksheet** to practice reading a balance (use only if you have not done any work with a triple beam balance this year). Pass out to students have them complete it, work a few examples together, then review answers as a class.
8. Students do the activity **– Which Has More Mass?**
9. **Part A:** Individuals make predictions
10. **Part B**: table groups find masses
11. **Part C**: Individual completes. Checks answers with group
12. **Part D:**
    a. **first** = table groups complete table

b. **second** =share as a class to check answers

13. **Part E:** table groups complete table
14. **Part F:**
    a. **first =** individuals answer question; b. **second** = share Part D and E as a class;

Which Has More Mass?

Materials: Objects: Sinking clay ball, floating clay ball, neutral clay ball, pumice, basalt, large wooden ball, small wooden ball, full bar of Dial soap, full bar of Ivory Soap; scale

Part A: *Predict which object is the lightest, which is the second lightest, and so on. Record your prediction in the following table.*

Object - prediction	
	Lightest
	↓
	Heaviest

Part B: *Use the scale to find the mass of each object and complete the data table below.*

Object	Mass (g)

Part C: How did your predictions compare with your results? Are bigger objects always heavier than smaller objects? Why or why not?

Part D: Sort the objects by actual mass on the table below. Record whether each object sinks or floats in water. (Look at the data table from the Sinking and Floating lab if needed)

Lightest → *Heaviest*

Describe Object											
Sink, Float, or Neutral?											

Part E: *Observe the objects. What material is each object made of? Sort the objects by type of material on the table below.*

Most Dense Material → *Least*
Dense Material

List the objects made of given material			
Sink or Float?	***Sink***	***Neutral***	***Float***

Part F: *What do you think it means for a material to be more dense or less dense?*

Teacher Key

Which Has More Mass?

Materials: Objects: Sinking clay ball, floating clay ball, neutral clay ball, pumice, basalt, large wooden ball, small wooden ball, full bar of Dial soap, full bar of Ivory Soap; scale

Part A: *Predict which object is the lightest, which is the second lightest, and so on. Record your prediction in the following table.*

Object - prediction	
Answers vary	**Lightest**
	Heaviest

Part B: *Use the scale to find the mass of each object and complete the data table below.*

Object	Mass (g)
Pumice	*< 5 g*
Rock	*15 - 25 g*
Floating clay ball	*< 20 g*
Neutral clay ball	*21.5 – 23.5 g*
Sinking clay ball	*39 - 40 g*
Dial Soap- bar	*113 grams*
Ivory Soap- bar	*90 grams*
Dial Soap - piece	*1.5 – 3 g*
Ivory Soap - piece	*1.5 – 3 g*
Large wooden ball	*17 – 20.5 g*
Small wooden ball	*5.5 – 7.5 g*

Part C: *How did your predictions compare with your results? Are bigger objects always heavier than smaller objects? Why or why not?* Answers will vary. Larger objects do not always weigh more than smaller objects. A large Styrofoam ball can weigh less than a smaller rock.

Part D: *Sort the objects by actual mass on the table below. Record whether each object sinks or floats in water. (Look at the data table from the Sinking and Floating lab if needed)*

Heaviest → *Lightest*

Describe Object	*Dial Soap*	*Ivory Soap*	*Sinking clay ball*	*Neutral clay ball*	*Rock*	*Floating clay ball*	*Large wooden ball*	*Small wooden ball*	*Pumice*	*Dial piece*	*Ivory Piece*
Sink, Float, or	*Sink*	*Float*	*Sink*	*Neutral*	*Sink*	*Float*	*Float*	*Float*	*Float*	*Sink*	*Float*

Part E: *Observe the objects. What material is each object made of? Sort the objects by type of material on the table below.*

Most Dense Material → *Least*

Dense Material

List the objects made of given material	*Clay (solid)* *Rock* *Zest soap*	*Clay & Cork*	*Less Clay & Cork* *Wood* *Pumice* *Ivory Soap (full of air)*
Sink or Float?	***Sink***	***Neutral***	***Float***

Part F: *What do you think it means for a material to be more dense or less dense?*
Answers vary

Lesson #6 - Traditional Teaching Methodology

Exploring Volume

Teacher Notes

Introduction: Students will read about volume. They will then practice determining the volume of objects using a variety of methods.

Objectives for this Activity:

1. Students will learn what methods are used to measure regular solids, irregular solids, and liquids
2. Students will use the water displacement method to measure the volume of irregularly shaped objects.

Materials needed for each group:

100 mL graduated cylinder	3 objects that will fit into graduated cylinder (Three different sizes of screws)	Beaker to catch water in when students remove objects.
metric ruler	calculator	Reading and activity sheets

Lesson Plan

a. **Opener:** Read pg. 299 Volume: CPO Physical Science and pg. 18 on volume in Science Explorer. Have students write down what information is new to them that they did not know or remember. Then ask them to write the answers to the following questions.
   a. **What is volume?** Volume is the amount of space an object takes up.
   b. **Why do the units of volume vary?** It varies dependant on if what you are measuring is a liquid (mL or L) or a solid (cm^3 or m^3)
   c. **What piece of lab equipment is used to measure a liquid?** A graduated cylinder
   d. **What is a meniscus?** It the curve that water makes in a graduated cylinder due to the surface tension of water.
   e. **How do you calculate the volume of a rectangle?** Volume = length x width x height.
   f. **How do you calculate the volume of an object that is not a rectangle, but has an irregular shape?** You use the water displacement method. You put the object in water and submerge it. The water level will rise by the amount of water that is equal to the volume of the object in milliliters.

2. Give students these worksheets and then review, only if you have not covered how to use and read a graduated cylinder before: a). **Intro** to reading at the meniscus of a graduated cylinder B). Reading a Graduated Cylinder/Measuring Liquids Worksheet
3. Have students complete- **Calculating volume worksheet.** Hopefully there will be enough time for students to practice taking the volume of an irregulary shaped object.

Name____ Core _____________

Exploring Volume- Reading

1. Before you begin reading about volume, write down what you already know about volume.

2. Read about volume on the sheets that are provided. And then answer the following questions.

    a. **Why do the units of volume vary?**

    b. **What is volume?**

    c. **What piece of lab equipment is used to measure a liquid?**

    d. **What is a meniscus?**

    e. Why is it important to read the volume of water at eye level?

    f. How do you calculate the volume of a rectangle?

    g. How do you calculate the volume of an object that is not a rectangle, but has an irregular shape?

    h. What is one mL equal to?

Name____________________________________Date______________

Calculating Volume

Practice calculating volume by completing the following problems. Answer the questions in the space provided

1. Calculating the volume of an object with a regular shape.

While walking on the beach you found a piece of rectangular driftwood. You brought it home as a souvenir of your trip to the ocean. Because you are curious about its size, you want to calculate the volume of this piece of wood. The length of the piece of wood is 29 cm. The height of the piece of wood is 22 cm and the width is 12 cm. What is the volume of this piece of wood. Show your calculations.

If you were to put the above piece of wood in water, how much water would it displace?

4. Calculating the volume of an object with an irregular shape

While playing outside you found a pretty basalt rock. You thought that this would be a great addition to your aquarium. If you put this rock into your aquarium, the water will overflow, so you need to calculate how much water to take out of it. To do this you obtain a 250 mL graduated cylinder and fill it with water until it reaches 150 mL. After you put the basalt rock in it, the new volume is 218 mL. What is the volume of the basalt rock and how much water do you need to take out of the aquarium? Show your calculations.

3. Applying what you learned.

A. Measuring the volume of a rectangular solid.

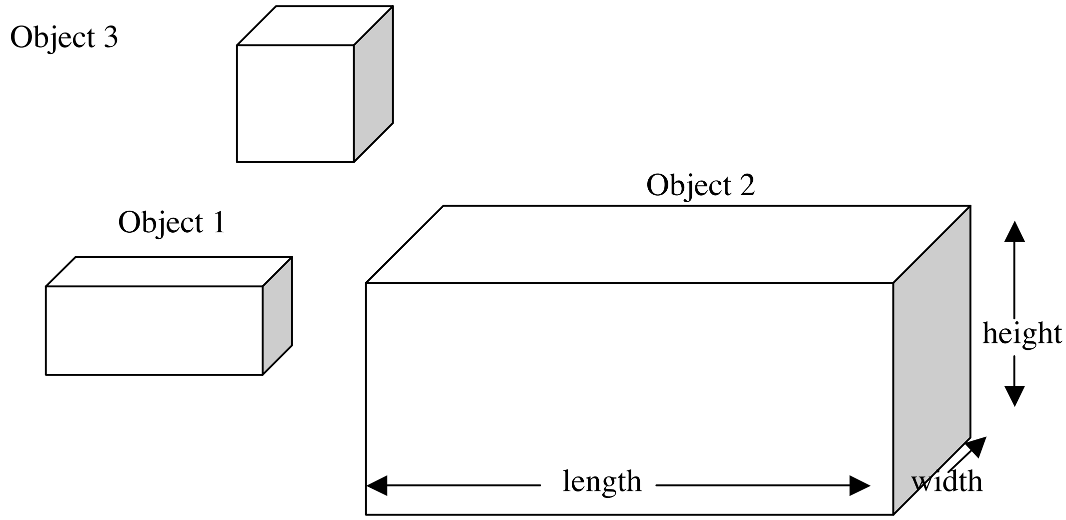
a. Use a metric ruler to measure the length, width, and height of the first rectangular object below in centimeters. Remember, each millimeter line between centimeters represents 0.1cm (5.7cm = 5cm + 7mm). Record these in the data table below.

b. Multiply length x width x height on a calculator. This is the rectangular object's volume in cubic centimeters (cm^3). Record this on the data table.

c. Use steps one and two to calculate the volume of the other rectangular objects.

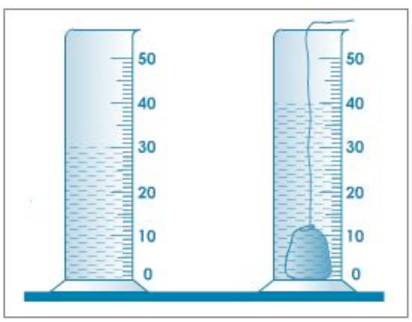
Data Table

Object #	Length (cm)	Width (cm)	Height (cm)	Volume (cm^3)

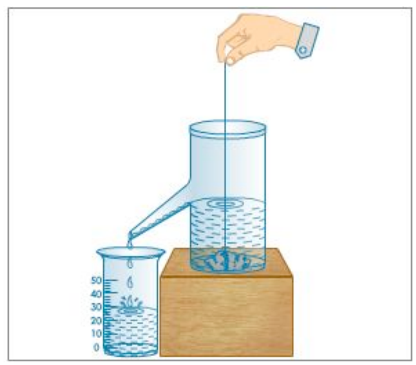


B. Measuring the volume of an irregularly shaped object.

a. What is the volume of the objects below? Explain your answer.



1. graduated cylinder method



2. overflow can method

C. Measure the volume of three objects that have an irregular shape using a graduated cylinder and the water displacement method.

Object	Volume of water before adding object	Volume of water after adding object	Volume of object

D. Explore with your eyes how the volume measurement of water changes as you hold the graduated cylinder at eye level and below and above eye level. How much does the volume reading change by when you do this? What data have you found that supports the technique of reading liquid volume in a graduated cylinder only at eye level?

E. Explain two ways to find the volume of a plastic cube.

Exploring Volume

Key

Exploring Volume Reading

1. Before you begin reading about volume, write down what you already know about volume. Answers vary
2. Read about volume on the sheets that are provided. And then answer the following questions.

2. **What is volume?** The amount of space that matter occupies
3. **Why do the units of volume vary?** Because the amount of volume varies. Smaller liquid volumes are measured in mL and larger in L. Smaller solid volumes are measured in cm^3 and larger solid volumes are measured in m^3
4. **What piece of lab equipment is used to measure a liquid?** A graduated cylinder is best. It has markings that show volume.
5. **What is a meniscus?** Where the surface of a liquid forms a curve due to surface tension. The curve is called a meniscus.
6. **Why is it important to read the volume of water at eye level?** It is more accurate
7. **How do you calculate the volume of a rectangle?** Measure the three dimensions of the rectangle and then use this formula: Volume = Length x height x width
8. **How do you calculate the volume of an object that is not a rectangle, but has an irregular shape?** You use the water displacement method. You submerge the object in a known amount of water and see how much water it displaces. The amount that is displaced is equal to the volume of the object that was submerged.
9. **What is one mL equal to?** **One cm^3 = 1 mL = 1 gram (for water)**

Calculating Volume

Practice calculating volume by completing the following problems. Answer the questions in the space provided

10. Calculating the volume of an object with a regular shape.
While walking on the beach you found a piece of rectangular driftwood. You brought it home as a souvenir of your trip to the ocean. Because you are curious about its size, you want to calculate the volume of this piece of wood. The length of the piece of wood is 29 cm. The height of the piece of wood is 22 cm and the width is 12 cm. What is the volume of this piece of wood? Show your calculations.

The volume of a rectangular solid is calculated by length x height x width.
29 cm x 22 cm x 12 cm =7656 cm^3

If you were to put the above piece of wood in water, how much water would it displace? 7656 mL

11. Calculating the volume of an object with an irregular shape

While playing outside you found a pretty basalt rock. You thought that this would be a great addition to your aquarium. If you put this rock into your aquarium, the water will overflow, so you need to calculate how much water to take out of it. To do this you obtain a 250 mL graduated cylinder and fill it with water until it reaches 150 mL. After you put the basalt rock in it, the new volume is 218 mL. What is the volume of the basalt rock and how much water do you need to take out of the aquarium? Show your calculations.

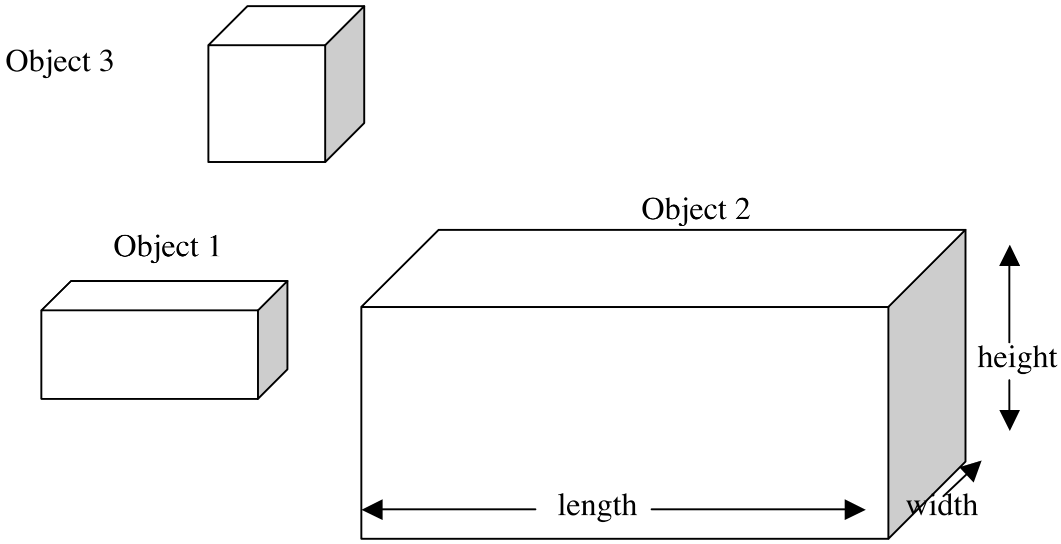
The volume of the basalt rock is: 218 mL – 150 mL = 68mL or 68 cm^3
You need to take out 68 mL from the aquarium

12. Applying what you learned.
    A. Measuring the volume of a rectangular solid.

        a. Use a metric ruler to measure the length, width, and height of the first rectangular object below in centimeters. Remember, each millimeter line between centimeters represents 0.1cm (5.7cm = 5cm + 7mm). Record these in the data table below.
        b. Multiply length x width x height on a calculator. This is the rectangular object's volume in cubic centimeters (cm^3). Record this on the data table.
        c. Use steps one and two to calculate the volume of the other rectangular objects.

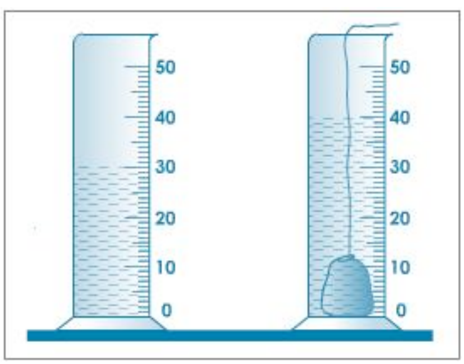
Data Table

Object #	Length (cm)	Width (cm)	Height (cm)	Volume (cm^3)
1	2.9	0.6	1.2	2.088
2	7.0	1.5	3.1	32.55
3	1.5	.7	1.5	1.575

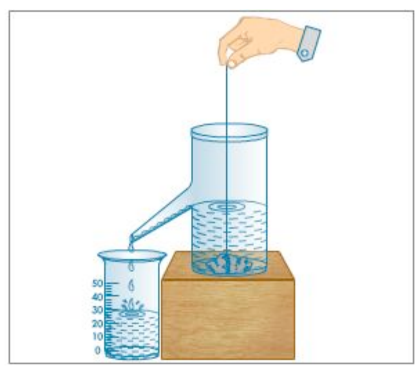


B. Measuring the volume of an irregularly shaped object.

a. What is the volume of the object below? Explain your answer. In the water displacement method, the volume of water is equal to the volume of the object displaced.



1. graduated cylinder method
40 mL – 30 mL = 10mL



2. overflow can method
30mL

C. Measure the volume of three objects that have an irregular shape using a graduated cylinder and the water displacement method.

Object	Volume of water before adding object	Volume of water after adding object	Volume of object
Medium screw	50 mL	52 mL	2 mL
Large nail	50 mL	55 mL	5 mL
rock	50 mL	60 mL	10 mL

D. Explore how the volume measurement of water changes as you hold the graduated cylinder at eye level and below and above eye level. How much does the volume reading change by when you do this? What data have you found that supports the technique of reading liquid volume in a graduated cylinder only at eye level?

The volume can change by several mL depending on where you look. This can really affect the accurate measurement of objects, especially if the objects are small.

E. Explain two ways to find the volume of a plastic cube.

Measure L x W x H = volume, use the water displacement method.

Lesson #7 - Traditional Teaching Methodology

Calculating Density

Teacher Notes

Introduction: Often when density is taught, the teacher goes right to the density formula without addressing the conceptual misunderstandings that students hold about density – such as larger objects weigh more and are therefore more dense. Building a qualitative understanding of density can occur as a student explores their own world. Students have some understanding of materials that are heavy or light for their size – but translating that into a quantitative understanding is hard. The reason is that quantitative density is an abstract concept. It is not directly measurable, because it is a **ratio** between mass and volume. In this activity, students will take their qualitative understanding of density as "heavy for its size" and translate that into a number, for example – this piece of metal is more than six time as dense as this piece of wood or the density of this metal is 5.5 g/cm^3 and the density of this wood is .9 g/cm^3. As students have worked through the most common misunderstandings about density in the previous lessons, they are now ready to be given the formula and to calculate density using it

Objectives for this activity:

3. Students will gain a quantitative understanding of density
4. Students will learn and apply the density formula.

Materials needed for each student:

4. Calculator
5. *Density Reading*
6. *Calculating Density* Worksheet

Lesson Plan:

Opener

1. **"Which is heavier, a kg of gold or a kg of feathers?"** The answer is of course, "Both are equally heavy."

2. **"If both objects are the same size, which is heavier, a bar of gold or an equal volume of feathers?"** You would say, "gold".

When we compare the heaviness of two different materials, we must refer to the same volume of each material. This leads to the concept of density. The density of a substance is defined as its mass per unit volume

Part A:

1. Students read and teacher discusses density reading.
2. **Give the formal definition for density:** Density is the mass per unit volume of an object.
3. **Discuss why density is important:** Density is important because it allows you to compare different types of matter.
4. **Discuss the formula used to calculate density:**

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}}$$

5**. What are the units for density?** g/cm3 , kg/m3

Part B:

1. Class practices together using the formula with the aluminum and copper questions
2. Table groups complete part or all of tables together (note: students will need to be given the volumes of the floating objects from the sink/float lab as they did not determine these)
3. Whole class shares answers

Part C-F:

1. individual students do on own first
2. check answers with partner or table group

Do individually in class or as homework: **Calculating Density Homework**

Name ____ Date

Calculating Density

Part A: ***Density Background. From your reading and class discussion:***

1. Define density:

2. Why is density important?

5. Use the formula to calculate density:

If 96.5g of gold has a volume of $5cm^3$, what is the density of gold?

Step 1: Write the formula.	Density = $\frac{\text{Mass}}{\text{Volume}}$
Step 2: Substitute given numbers and units.	Density = $\frac{96.5\text{ g}}{5\text{ cm}^3}$
Step 3: Divide 96.5g by 5 cm^3. That equals $\frac{19.3\text{g}}{\text{cm}^3}$	or 19.3g/cm^3
Step 4. The answer = the density of gold is 19.3 g/cm^3	

Step 5: Explain what this means in words:

Part B: Working together as a class let's practice using the density formula. Show your work!

1. If 157.5g of aluminum has a volume of $35cm^3$, what is the density of the aluminum?

2. If 125.44g of copper has a volume of $14cm^3$, what is the density of the copper?

3. A solid block measures 3 cm x 3 cm x 2 cm and it has a mass of 27 grams. What is its density?

6. An irregularly shaped object displaces 35 mL of water in a graduated cylinder, The object has a mass of 42 grams. What is the density of the object?

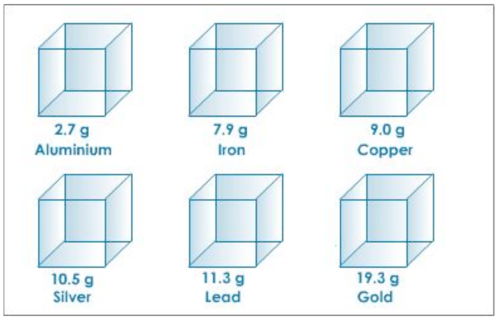
Part C. *Use the density formula to calculate the densities of the objects from the Sinking and Floating Lab.*

Object Name	Mass (g)	Volume (mL)	Density (g/mL)
Sinking clay ball	40.1 g	24 mL	
Neutral clay ball	22 g	22 mL	
Floating clay ball	19.3 g	21 mL	
Large wooden ball	18.5 g	24 mL	
Small wooden ball	6.2 g	8 mL	
Rock	17.9 g	6 mL	
Pumice	2.5 g	5 mL	
Ivory soap piece	2.4 g	4 mL	
Dial soap piece	2.6 g	2 mL	

1. Look at the densities of the objects from the Sinking and Floating lab above. Put x's on the number line below to show each of their densities. Label the x's with each object's name (above the line) and density (below the line). Draw a line that shows where on the line object float in water, where objects sink in water, and where objects are neutrally buoyant.

2. What do you observe about the relationship between an object sinking and floating and its density as compared to water?

Part D: If the volume of each of the cubes below was 1 cm^3 what is the cube's density?



Cube	Density
Aluminium	
Iron	
Copper	
Silver	
Lead	
Gold	

If one object has exactly the same volume as another object and it is heavier, will it always have a greater density?

Part E: *Calculate the densities on this data table. If the decimal repeats, round to the nearest hundredth.*

Item Name	**Mass (g)**	**Volume (mL or cm^3)**	**Density (g/mL or g/cm^3)**
Water	100 g	100 mL	1.0 g/mL
Ice	4.6 g	5.0 cm^3	
Glass	230 g	100 cm^3	
Alcohol	9.6 g	12.0 mL	
Mercury	189.7g	14mL	
Plastic	5g	5.85 cm^3	
Wood (Oak)	25g	35.2 cm^3	
Cork	1100g	5000 cm^3	

1. Does the object with the heaviest mass have the greatest density? Explain.

2. Does the object that has the greatest volume have the greatest density? Explain.

3. Can you determine if an object has a high density, if you only know the mass or if you only know the volume?

Part F: *Rank the materials on the table above in order of most to least dense*

Materials	*Density*	*Most dense*
Water	*1.0 g/mL*	
		Least dense

1. Which of the above objects would float in water?

2. If the plastic object above were put into the alcohol, would it float or sink? Explain.

3. If the cork were put in the alcohol, would it float or sink? Explain.

Calculating Density Homework

Name ____Core______

Water has a density of exactly 1g/mL. This means that one milliliter (or one cubic centimeter) of water weighs exactly one gram. Any substance that has a density *less* than 1g/mL will float on water. Any substance that has a density *greater* than 1g/mL will sink.

Use the density table below to answer the questions.

Solids	Density	Metals	Density	Liquids	Density
Bone	2.0	Aluminum	2.7	Water	1.0
Brick	1.8	Copper	8.9	Seawater	1.3
Cork	0.2	Gold	19.3	Alcohol	0.8
Marble	2.7	Iron	7.83	Glycerin	1.25
Paraffin	0.9	Lead	11.3	Turpentine	0.9
Rubber	1.2	Silver	10.5	Mercury	13.55
Bamboo	0.3			Gasoline	0.7
Ice	0.92				

1. Name 5 substances from the table above that will **float** on water:

2. Name 5 substances from the table above that will **sink** in water:

3. What is the **least** dense substance on the table?

4. What is the **densest** substance on the table?

5. Mercury is a liquid with a density of 13.55. Which metal on the table would sink in **mercury**?

6. You find a substance that looks like gold. Based on what we have learned about matter and density, how could you determine if it is **really** gold?

7. What is the **density** of 400g of a substance if it occupies 80cm^3 of volume?

8. Will the substance in #7 sink or float in **seawater**?

9. **Challenge**: If a substance has a density of 2.5g/mL, and it occupies 200mL of volume, what is its mass?

Calculating Density Key

Name ____ Core _______

Part A: ***Density Background***
Define density: *Density is the mass per unit volume of an object.*

Why is density important? *Density is important because it allows you to compare different types of matter. It is a characteristic property of matter.*

Use the formula to calculate density:
If 96.5g of gold has a volume of 5cm^3, what is the density of the gold?

Step 1: Write the formula.	Density = $\frac{\text{Mass}}{\text{Volume}}$
Step 2: Substitute given numbers and units.	Density = $\frac{96.5\text{ g}}{5\text{ cm}^3}$
Step 3: Divide 96.5g by 5 cm^3. That equals <u>19.3g</u> cm^3	or 19.3g/cm^3
Step 4. The answer = the density of gold is 19.3 g/cm^3	

Step 5: Explain what this means in words. 19.3 grams of gold occupies 1 cm^3 of volume.

Part B: *Practice using the formula.*
1. If 157.5g of aluminum has a volume of 35cm^3, what is the density of the aluminum? *4.5g/cm^3*
2. If 125.44g of copper has a volume of 14cm^3, what is the density of the copper? *8.96 g/cm^3*
3. A solid block measures 3 cm x 3 cm x 2 cm and it has a mass of 27 grams. What is its density? 1.42 *g/cm^3*
4. An irregularly shaped object displaces 35 mL of water in a graduated cylinder, The object has a mass of 42 grams. What is the density of the object? 1.2 g/mL

Part C: *Use the density formula to calculate the densities of the objects from the Sinking and Floating Lab. Use the formula to calculate the densities of the objects from the Sinking and Floating lab.*

Object Name	Mass (g)	Volume (mL)	Density (g/mL)
Sinking clay ball	40.1 g	24 mL	1.67
Neutral clay ball	22. g	22 mL	1.0

Floating clay ball	19.3 g	21 mL	.91
Large wooden ball	18.5 g	24 mL	.77
Small wooden ball	6.2 g	8 mL	.77
Rock	17.9 g	6 mL	2.98
Pumice	2.5 g	5 mL	0.5
Ivory soap	2.4 g	4 mL	0.6
Dial soap	2.6 g	2 mL	1.3

1. Look at the densities of the objects from the Sinking and Floating lab above. Put x's on the number line below to show each of their densities. Label the x's with each object's name (above the line) and density (below the line). Draw a line that shows where on the line object float in water, where objects sink in water, and where objects are neutrally buoyant.

Neutral

clay ball

density of water

floating clay ball

wooden balls

ivory soap

rock

sinking clay ball

Dial soap

pumice

x x x x x x x x

2.98 1.67 1.3 1.0 0.91 0.77 0.6

0.5

more dense

less dense

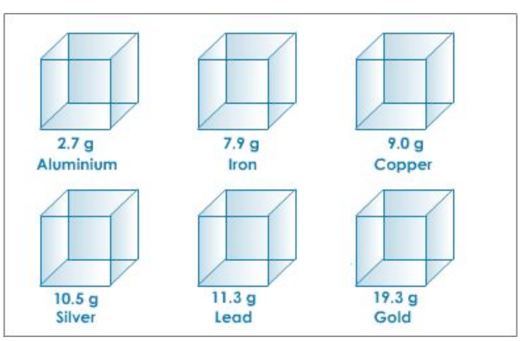
objects sank

neutrally bouyant

objects float

2. What do you observe about the relationship between an object sinking and floating and its density as compared to water? If an object sinks, its density is greater than water (< 1 g/mL). If it is neutrally buoyant, then it is the same as water (=1 g/mL), if it floats, then the density is greater than water (> 1 g/mL).

Part D: *If the volume of each of the cubes below was 1 cm^3 what are the cubes' density?*



Cube	Density
Aluminum	2.7 g/cm^3
Iron	7.9 g/cm^3
Copper	9.0 g/cm^3
Silver	10.5 g/cm^3
Lead	11.3 g/cm^3
Gold	19.3 g/cm^3

If one object has exactly the same volume as another object and it is heavier, will it always have a greater density? Yes, it will. If the volume is the same, then if an object is heavier, it will always have a greater density.

Item Name	Mass (g)	Volume (mL or cm^3)	Density (g/mL or g/cm^3)
Water	100 g	100 mL	1.0 g/mL
Ice	4.6 g	5.0 cm^3	*.92 g/cm^3*
Glass	230 g	100 cm^3	2.3 g/cm^3
Alcohol	9.6 g	12.0 mL	*.8 g/mL*
Mercury	189.7g	14mL	*13.55 g/mL*
Plastic	5g	5.85 cm^3	*0.85 g/cm^3*
Wood (Oak)	25g	35.2 cm^3	*0.71 g/cm^3*
Cork	1100g	5000 cm^3	*.22 g/cm^3*

Part E. *Calculate the densities on this data table. If the decimal repeats, round to the nearest hundredth.*

1. Does the object with the heaviest mass have the greatest density? Explain. No. The object with the heaviest mass is the cork at 1100g. However, it has the lowest density of 0.22 g/cm^3
2. Does the object that has the greatest volume have the greatest density? Explain. No. Cork also has the greatest volume and has the least density
3. Can you determine if an object has a high density, if you only know the mass or if you only know the volume? No. You need to know the ration of the mass to the volume in order to know an object's density.

Part F: *Rank the 8 items on the table above in order of least to greatest density.*

Material	*Density*	*Least dense*
Mercury	*13.55 g/mL*	
Glass	2.3 *g/cm^3*	
Water	*1.0 g/mL*	
Ice	*.92 g/cm^3*	
Plastic	*0.85 g/cm^3*	
Alcohol	*.8 g/mL*	
Wood (Oak)	*0.71 g/cm^3*	
Cork	*.22 g/cm^3*	*Most dense*

4. Which of the above objects would float in water? Ice, plastic, alcohol, wood, cork
5. If the plastic object above were put into the alcohol, would it float or sink? It would sink because its density is higher than the alcohol
6. If the cork were put in the alcohol, would it float or sink? It would float because its density is less than the alcohol.

Calculating Density Homework Key

Water has a density of exactly 1g/mL. This means that one milliliter (or one cubic centimeter) of water weighs exactly one gram. Any substance that has a density *less* than 1g/mL will float on water. Any substance that has a density *greater* than 1g/mL will sink.

Use the density table below to answer the questions.

Solids	**Density**	**Metals**	**Density**	**Liquids**	**Density**
Bone	2.0	Aluminum	2.7	Water	1.0
Brick	1.8	Copper	8.9	Seawater	1.3
Cork	0.2	Gold	19.3	Alcohol	0.8
Marble	2.7	Iron	7.83	Glycerin	1.25
Paraffin	0.9	Lead	11.3	Turpentine	0.9
Rubber	1.2	Silver	10.5	Mercury	13.55
Bamboo	0.3			Gasoline	0.7
Ice	0.92				

1. Name 5 substances that will **float** on water: *Any 5 of these: Cork, Paraffin, Bamboo, Ice, Alcohol, Turpentine, Gasoline*
2. Name 5 substances that will **sink** in water: *Any 5 of these: Bone, Brick, Marble, Rubber, any of the metals, Seawater, Glycerin, Mercury*
3. What is the **least** dense substance on the table? *Cork*
4. What is the **densest** substance on the table? *Gold*
5. Mercury is a liquid with a density of 13.55. Which metal on the table would sink in **Mercury**? *Gold*
6. You find a substance that looks like gold. Based on what we have learned about matter and density, how could you determine if it is really gold? *Find its mass and volume then calculate its density. If the density is 19.3 g/cm^3, it is gold.*
7. What is the **density** of 400g of a substance if it occupies 80cm^3 of volume? *5g/cm^3*
8. Will the substance in #7 sink or float in **seawater**? *Sink*

9. Challenge: If a substance has a density of 2.5g/mL, and it occupies 200mL of volume, what is its mass?

It has a mass of 500g.

$$\frac{2.5g}{mL} = \frac{x}{200mL}$$

$$500g = x$$

Density- Applying What You Have Learned

Teacher Notes

Introductions: Calculate the density of the objects that students have been using in these labs. Today's lesson will help students with their quantitative understanding of density. They will learn that the density of materials is fixed for a particular material and that materials that have different shapes or sizes that are made of the same materials will have the same density. They will calculate the density of objects and then use that information to compare materials.

Objectives for this activity:

4. Students' will be assessed on their qualitative understanding of density.
5. Students will apply what they have learned about the quantitative measurement of density by measuring the mass and volume of 10 objects and then calculating density for each object using the density formula.
6. Students will make quantitative comparisons about the density of objects.

Materials needed for each group:

5. *Density Assessment* worksheet
6. *Density Assessment* rubric
7. *Density: Applying What You Have Learned* worksheet
8. **Materials:** Place materials in a materials station for students to choose from

Density cube set, Density cylinder set (equal mass) Can also use other density cylinders I have given you and the rectangular plastic solids	Overflow cans	Beaker
	Ruler	Balance
		Graduated cylinders

Lesson Plan:

7. Begin with *Density Assessment*. You may have done this at the beginning of the unit. Students should have shown growth. You can choose to assign this as a homework assignment instead of a pre-assessment if you wish. This assessment measures a student's qualitative understanding of density (notice -there are no numbers or data).
8. Put out materials for the lab. Encourage students to pick objects that relate to each other somehow because they will be comparing them. This means that they should compare materials that have a variable in common: 2 objects made of same materials, 2 objects with same mass, 2 objects with same volume (etc)
9. The data table has room for 10 objects. Students should begin with the density cubes. Students can do more than this if they have time.
10. Students should make decisions about how they will want to measure the volume of the objects. Have supplies ready so that they can measure objects using rulers -

if they are rectangular solids They will use graduated cylinders for water displacement if they use the density cylinders.

11. When students make their graph they should try to organize the objects so they go from least dense to most dense on the histogram. They will be more likely to get the comparison information that they need for their conclusions if they do this.
12. Students may work in groups and share data about objects for this lab.

Name____Date________Core__________

Density- Applying What You Have Learned

Question: *How does the density of objects vary?*

Background: *Write a short paragraph that explains what you have learned about density.*

Materials: *Density cube set, density cylinder set, ruler, graduated cylinder, balance.*
Procedure:

1. Weigh the ten objects you have chosen.
2. For the density cubes, use a ruler to calculate the volume using the L x H x W formula
3. For the density cylinders, use the graduated cylinder and find the volume using water displacement
4. Use the density formula to calculate the densities of the objects you have chosen.

Object name and material	Mass (g)	Volume cm^3	Density (g/ cm^3)

Data Table

1. Using the densities of the objects that you have calculated, put x’s on the number line below to show each of their densities. Label the x’s with each object’s name (above the line) and density (below the line). Draw a line that shows where on the line objects would float in water, where objects would sink in water, and where objects are neutrally buoyant in water.

2. What do you observe about the relationship between an object sinking and floating and its density as compared to water?

3. Graph the densities of the objects you have chosen. Be sure to label both axis. Organize your density data on the graph the same way that you had it on the number line above so you can see the patterns.

Conclusion:
Compare the density of various objects. Make the comparisons quantitative. That means, use the actual measurements and calculations that you have made in the conclusion statement. **Make at least four comparison statements about the density of your objects that are similar to the ones below.**

Make at least four comparison statements.
Here are some examples of comparison statements:

1. "The density of Object A is 9.03 g/ cm^3 and the density of Object B is 3.1 g/ cm^3. That means that Object A is approximately three times greater than the density of Object B. This is interesting because Object B with a volume of 28 cm^3 is twice as big as Object A, which has a volume of 14 cm^3"

--or--

2. “Objects that are made of Material A, tend to be more dense than objects made of Material B. Objects made of Material A have an average density of 5 .45 g/ cm^{3}, where the objects made of materials B have an average density of 2.18 g/ cm^{3}”

1.

2.

3.

4.

What have you learned about the density of objects as you compared them using data?

Density- Applying What You Have Learned

Key

Question: *How does the density of objects vary?*
Background: *Write a short paragraph that explains what you have learned about density. Answers will vary. Students should be able to write about some of the qualitative experiences that they have had (sinking and floating) . The density formula should be here as well.*

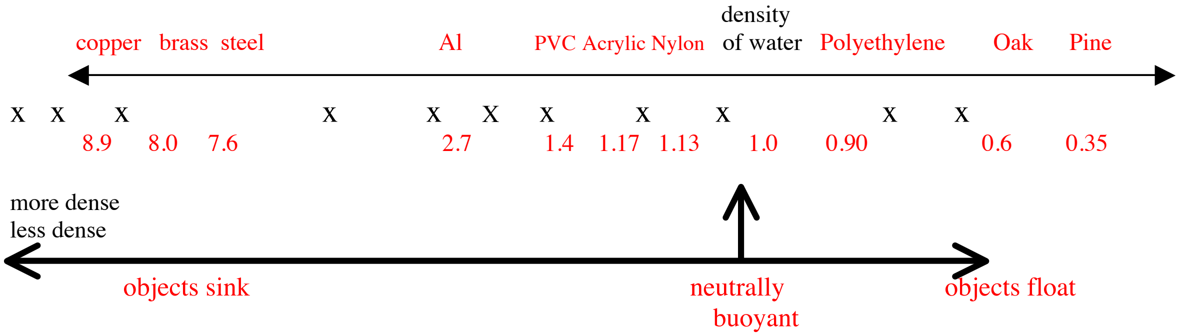
Materials: *Be sure that students are using density set materials so they have good comparisons.*

Procedure

1. Weigh the ten objects you have chosen.
2. For the density cubes, use a ruler to calculate the volume using the L x H x W formula
3. For the density cylinders, use the graduated cylinder and find the volume using water displacement
4. Use the density formula to calculate the densities of the objects you have chosen. *Here are some sample densities. There are many more possible objects students could have chosen.*

Object Name and material	Mass (g)	Volume (mL)	Density (g/mL)
Brass Cube	60 g	7.5 cm^3	8.0 g/ cm^3
Steel Cube	57 g	7.5 cm^3	7.6 g/ cm^3
Acrylic Cube	8.85 g	7.5 cm^3	1.17 g/ cm^3
Pine Cube	3.75 g	7.5 cm^3	0.35 – 0.60 g/ cm^3
Nylon Cube	8.475g	7.5 cm^3	1.13 g/ cm^3
Oak Cube	6.75 g	7.5 cm^3	0.60 – 0.90 g/ cm^3
Polyethylene cylinder	15 g	16.7 cm^3	.90 g/ cm^3
PVC cylinder	15 g	10.7 cm^3	1.4 g/ cm^3
Al cylinder	15 g	5.5 cm^3	2.7 g/ cm^3
Copper cylinder	15 g	1.6 cm^3	8.9 g/cm^3

Look at the densities of the objects from the lab that you chose. Put x's on the number line below to show each of their densities. Label the x's with each object's name (above the line) and density (below the line). Draw a line that shows where on the line object float in water, where objects sink in water, and where objects are neutrally buoyant.



What do you observe about the relationship between an object sinking and floating and its density as compared to water? If an object sinks, its density is greater than water (< 1 g/mL). If it is neutrally buoyant, then it is the same as water (=1 g/mL), if it floats, then the density is greater than water (> 1 g/mL).

Graph the densities of the objects you have chosen. Be sure to label both axis. Organize your density data on the graph the same way that you had it on the number line above so you can see the patterns.*Students should make histograms*.

Conclusion:

Compare the density of various objects. Make the comparisons quantitative. That means, use the actual measurements and calculations that you have made in the conclusion statement. **Make at least four comparison statements.**

Answers vary – But should be quantitative and use data as in examples

What have you learned about the density of objects as you compared them using data?

Students should have learned that the density of an object can be exactly measured. Once it is measured it can be used to compare objects of the same and of different materials. These comparisons can be expressed in ratios.

Density of Regularly Shaped Objects (Step-by-step)

Teacher Notes

Supplies needed for each group: calculators

1. **Whole class:** Read mystery description.

2. **Individual**: Complete background section together.

3. **Table groups:** Use Data Table 1 to complete Data Table 2. Check answers with other table group members before recording.

4. **Whole class:** demo how to make a bar graph
   Individual: bar graph showing results

5. **Individual:** answer conclusion questions

6. **Whole class:** "Science talk" about the conclusion questions; correct misconceptions when needed.

Objective for this activity

1. Determine the density of regularly shaped objects.

Density of Regularly Shaped Objects (Step-by-step)

Name ____ Core

Joe Loser stole six trunks filled with ancient Egyptian and Roman works of art and antiquities from a museum in Italy . The authorities believe that Joe is storing the stolen goods on his river boat. This morning, the police boarded Joe's boat and searched it, but they failed to find the six trunks they thought would be on the boat.

Later, an informant told police that Joe had tossed the trunks into the river before they arrived. The police are now returning to the scene to try to recover the stolen items. In the table on the next page are the contents, masses, and sizes of each trunk according to museum records.

If the trunk's density was greater than water, the trunk would have immediately sunk to the bottom of the river. If the trunk's density was less than water, the trunk would have floated down the river about 4km by now. If the trunk's density was close to the density of water, the trunk would have sunk a little and then floated about 2km down the river by now. Calculate the expected density for each trunk and then tell the police approximately where to look for each trunk in the river.

Question: Where should the police look for each trunk?

Background: Write three sentences telling what you know about finding the density of rectangles and how you know whether an object will sink, float, or remain neutral in water.

Materials: Calculator

Procedure:

1. Use a calculator and the information in Data Table 1 to complete Data Table 2.
2. For each trunk, add the mass of contents to the mass of empty trunk. Record this total mass on Data Table 2.
3. For each trunk, multiply the trunk length x trunk width x trunk height. Round to the nearest hundredth if the decimal repeats. Record this trunk volume on Data Table 2.
4. For each trunk, divide the total mass by the trunk volume. Record this trunk density on Data Table 2.
4. Look at the trunk density. If the number is less than 1, write floats on Data Table 2. If it is more than 1, write sinks. If it is about 1, write neutral.
5. Look back at the description of the mystery on page 1. Figure out where the trunk would be now if it sinks, floats, or is neutral. Record this for each trunk on Data Table 2.
6. Check all calculations.

Data Table 1:

Trunk	***Contents***	***Mass of Contents (g)***	***Mass of Empty Trunk (g)***	***Trunk Length (cm)***	***Trunk Width (cm)***	***Trunk Height (cm)***
1	Marble statues	208,650	6000	90	50	45
2	Tapestries	495,250	8750	120	120	50
3	Gold jewelry	507,500	4000	150	110	50
4	Bone carvings	330,500	7000	75	75	25
5	Wall paintings	153,400	5000	80	80	25
6	Papyrus scrolls	304,500	7500	80	75	20

Data Table 2:

Trunk	*Contents*	*Total Mass (g) [contents mass + empty trunk mass]*	*Trunk Volume (cm3) [length x width x height]*	*Trunk Density (g/cm3) [total mass divided by volume]*	*Sinks, Floats, or Neutral*	*Location of Trunk*
1	**Marble statues**					
2	**Tapestries**					
3	**Gold jewelry**					
4	**Bone carvings**					
5	**Wall paintings**					
6	**Papyrus scrolls**					

Graph: Create a bar graph showing the density of each trunk. Label the x axis and the y axis. Be sure to include a title and key.

Conclusion: Using what you have learned so far about density, answer the following questions. Be sure to study the data tables and graph from this lab.

1. Describe how to find the <u>density</u> of a regularly shaped (rectangular) object.

2. Rank the six trunks from this lab according to their density by writing <u>their contents</u> next to each number.

Most dense	1.
	2.
	3.
	4.
	5.
Least dense	6.

3. Look at your data tables from this lab. Do objects with the greatest mass have the greatest density? Do objects with the least mass have the least density? Answer <u>both</u> of these questions and <u>prove</u> your answers with <u>examples</u> from the data tables for this lab.

4. Look at your data tables from this lab. Do objects with the greatest volume have the greatest density? Do objects with the least volume have the least density? Answer <u>both</u> of these questions and <u>prove</u> your answers with <u>examples</u> from the data tables for this lab.

5. What would be interesting to find out about density next? Put your idea in the form of a testable, inquiry question.

Density of Regularly Shaped Objects Key (Step-by-step)

28 points total

Joe Loser stole six trunks filled with ancient Egyptian and Roman works of art and antiquities from a museum in Italy . The authorities believe that Joe is storing the stolen goods on his river boat. This morning, the police boarded Joe's boat and searched it, but they failed to find the six trunks they thought would be on the boat.

Later, an informant told police that Joe had tossed the trunks into the river before they arrived. The police are now returning to the scene to try to recover the stolen items. In the table on the next page are the contents, masses, and sizes of each trunk according to museum records.

If the trunk's density was greater than water, the trunk would have immediately sunk to the bottom of the river. If the trunk's density was less than water, the trunk would have floated down the river about 4km by now. If the trunk's density was close to the density of water, the trunk would have sunk a little and then floated about 2km down the river by now. Calculate the expected density for each trunk and then tell the police approximately where to look for each trunk in the river.

Question: Where should the police look for each trunk?

Background: Write three sentences telling what you know about finding the density of rectangles and how you know whether an object will sink, float, or remain neutral in water.

3 pts:

•Volume = length x width x height

•Mass ÷ Volume = Density

•Density < 1 = Floats, Density > 1 = Sinks, Density ≈ 1 = Neutral

Materials: Calculator

Procedure:

1. Use a calculator and the information in Data Table 1 to complete Data Table 2.
2. For each trunk, add the mass of contents to the mass of empty trunk. Record this total mass on Data Table 2.
3. For each trunk, multiply the trunk length x trunk width x trunk height. Round to the nearest hundredth if the decimal repeats. Record this trunk volume on Data Table 2.
4. For each trunk, divide the total mass by the trunk volume. Record this trunk density on Data Table 2.
4. Look at the trunk density. If the number is less than 1, write floats on Data Table 2. If it is more than 1, write sinks. If it is about 1, write neutral.
5. Look back at the description of the mystery on page 1. Figure out where the trunk would be now if it sinks, floats, or is neutral. Record this for each trunk on Data Table 2.
6. Check all calculations.

Data Table 1:

Trunk	***Contents***	***Mass of Contents (g)***	***Mass of Empty Trunk (g)***	***Trunk Length (cm)***	***Trunk Width (cm)***	***Trunk Height (cm)***
1	Marble statues	208,650	6000	90	50	45
2	Tapestries	495,250	8750	120	120	50
3	Gold jewelry	507,500	4000	150	110	50
4	Bone carvings	330,500	7000	75	75	25
5	Wall paintings	153,400	5000	80	80	25
6	Papyrus scrolls	304,500	7500	80	75	20

Data Table 2: 6 points: 1 per row

Trunk	*Contents*	*Total Mass (g)* *[contents mass + empty trunk mass]*	*Trunk Volume (cm3)* *[length x width x height]*	*Trunk Density (g/cm3)* *[total mass divided by volume]*	*Sinks, Floats, or Neutral*	*Location of Trunk*
1	**Marble statues**	**214,650**	**202,500**	**1.06**	**Neutral**	**2 km away**
2	**Tapestries**	**504,000**	**720,000**	**0.7**	**Floats**	**4 km away**
3	**Gold jewelry**	**511,500**	**825,000**	**0.62**	**Floats**	**4 km away**
4	**Bone carvings**	**337,500**	**140,625**	**2.4**	**Sinks**	**Under boat**
5	**Wall paintings**	**158,400**	**160,000**	**0.99**	**Neutral**	**2 km away**
6	**Papyrus scrolls**	**312,000**	**120,000**	**2.6**	**Sinks**	**Under boat**

Graph: Create a bar graph showing the density of each trunk. Label the x axis and the y axis. Be sure to include a title and key. **8 points**

Conclusion: Using what you have learned so far about density, answer the following questions. Be sure to study the data tables and graph from this lab.

1. Describe how to find the density of a regularly shaped (rectangular) object. **1 point**

   Find the volume by multiplying length x width x height. Then find the mass. Finally divide mass by volume to determine density.

2. Rank the six trunks from this lab according to their density by writing their contents next to each number. **1 point**

Most dense	1. Papyrus scrolls (#6)
	2. Bone carvings (#4)
	3. Marble statues (#1)
	4. Wall paintings (#5)
	5. Tapestries (#2)
Least dense	6. Gold jewelry (#3)

3. Look at your data tables from this lab. Do objects with the greatest mass have the greatest density? Do objects with the least mass have the least density? Answer both of these questions and prove your answers with examples from the data tables for this lab. **4 points**

   Objects with the greatest mass do not have the greatest density. The gold jewelry has the greatest mass (507,500 g) but it has the least density (0.62 g/cm^3). Objects with the least mass do not have the least density. The wall paintings have the least mass (158,400 g) but they have neither a low nor a high density (0.99 g/cm^3).

4. Look at your data tables from this lab. Do objects with the greatest volume have the greatest density? Do objects with the least volume have the least density? Answer both of these questions and prove your answers with examples from the data tables for this lab. **4 points**

   Objects with the greatest volume do not have the greatest density. The gold jewelry has the greatest volume (825,000 cm^3) but it has the least density (0.62 g/cm^3). Objects with the least volume do not have the least density. The papyrus scrolls have the least volume (120,000 cm^3) but they have the highest density (2.6 g/cm^3).

5. What would be interesting to find out about density next? Put your idea in the form of a testable, inquiry question. **1 point**

Density of Irregularly Shaped Objects (Step-by-step)

Teacher Notes

Supplies needed for each group:
- graduated cylinder
- beaker
- overflow can
- triple beam scale
- 8 irregularly shaped objects with different masses (like rocks)
- calculator

1. **Whole class:** read through first page of lab together and check for understanding.

2. **Table groups:** find mass, volume, and density of each object.

3. **Individual:** create bar graph showing density of each object.

4. **Individual:** answer conclusion questions.

5. **Whole class:** "Science talk" about the conclusion questions; correct misconceptions when needed.

Objective for this activity

1. Determine the density of irregularly shaped objects.

Density of Irregularly Shaped Objects (Step-by-step)

Name ____Core

Juliette Schwimmer was found dead in her home, and investigators have ruled it a homicide. The victim died from blunt force trauma to the forehead. Investigators have determined that because of the depth of the wound, the object that hit her forehead most likely had a density greater than 2.5g/mL but less than 4g/mL and was likely thrown with some type of slingshot. Several objects are found near the body. You have been asked by the investigators to determine which of the objects most likely caused the wound.

Question: Which object most likely caused the wound?

Hypothesis: I think ______________ most likely caused the wound because

Materials:
- Overflow can
- Graduated cylinder
- Beaker
- 8 irregularly shaped objects, each labeled with an identification number

Procedure:
1. Balance the scale to zero.
2. Place the object on the scale and find its mass. Record this on the data table below.
3. Use the overflow can or the graduated cylinder to find the object's volume by displacing water. Refer to the Exploring Volume lab for directions. Record this volume on the data table.
4. Use a calculator to divide the mass by the volume. Round to the nearest hundredth if the decimal repeats. Record this density on the data table.
5. Repeat steps 1 through 4 to find the density of the other objects.
6. Highlight all objects that have a density between 2.5 g/mL and 4g/mL to identify the object most likely used to cause the wound.

Data Table:

Object #	Mass (g)	Volume (mL)	Density (g/mL)

Graph: Create a bar graph showing the density of each object. Make the bars for any object that could have been used in the murder stand out using color or pattern. Label the x axis and the y axis. Be sure to include a title and key.

Rank the eight objects used in this lab by density:

____, ____, ____, ____, ____, ____, ____, ____

most dense **least dense**

Conclusion: Using what you have learned so far about density, answer the following questions. Be sure to study the data table and graph from this lab.

1. Which objects could have been used in the murder? How do you know?

2. Describe how to find the <u>density</u> of an irregularly shaped object.

3. Look at your data table from this lab. Do objects with the greatest mass have the greatest density? Do objects with the least mass have the least density? Answer <u>both</u> of these questions and <u>prove</u> your answers with <u>examples</u> from the data table for this lab.

4. Look at your data table from this lab. Do objects with the greatest volume have the greatest density? Do objects with the least volume have the least density? Answer <u>both</u> of these questions and <u>prove</u> your answers with <u>examples</u> from the data table for this lab.

5. Think about errors and weaknesses in the design (procedures) of this lab. How might you improve the design so the results are more accurate?

6. What would be interesting to find out about density next? Put your idea in the form of a question.

Density of Irregularly Shaped Objects Key (Step-by-step)

34 points total

Juliette Schwimmer was found dead in her home, and investigators have ruled it a homicide. The victim died from blunt force trauma to the forehead. Investigators have determined that because of the depth of the wound, the object that hit her forehead most likely had a density greater than 2.5g/mL but less than 4g/mL and was likely thrown with some type of slingshot. Several objects are found near the body. You have been asked by the investigators to determine which of the objects most likely caused the wound.

Question: Which object most likely caused the wound?

Hypothesis: I think **__1 point_________** most likely caused the wound because

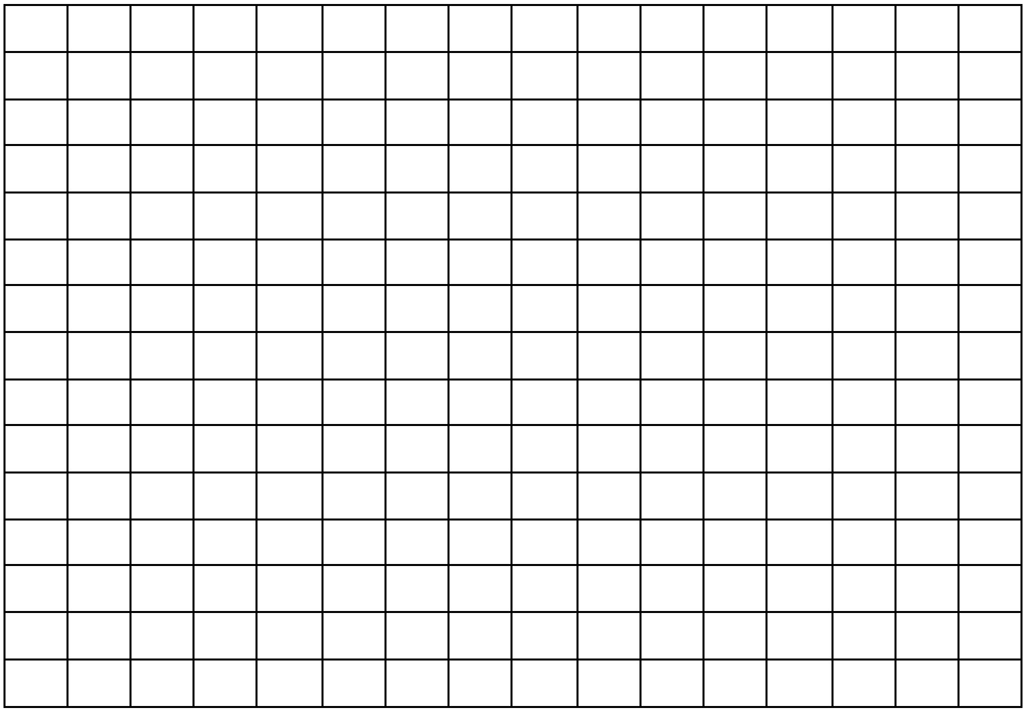
Materials: Overflow can
Graduated cylinder
Beaker
8 irregularly shaped objects, each labeled with an identification number

Procedure:
1. Balance the scale to zero.
2. Place the object on the scale and find its mass. Record this on the data table below.
3. Use the overflow can or the graduated cylinder to find the object's volume by displacing water. Refer to the Exploring Volume lab for directions. Record this volume on the data table.
4. Use a calculator to divide the mass by the volume. Round to the nearest hundredth if the decimal repeats. Record this density on the data table.
5. Repeat steps 1 through 4 to find the density of the other objects.
6. Highlight all objects that have a density between 2.5 g/mL and 4g/mL to identify the object most likely used to cause the wound.

Data Table: 8 points, 1 for each object

Object Description	Mass (g)	Volume (mL)	Density (g/mL)
Large nut	49.1	5.6	8.767
Fishing weight	137.2	14.5	10.84
Dinosaur	50.1	37.5	1.336
Marbles Container	52.6	44	1.19
Hole punch mechanism	44.3	5.4	8.2037
Shell	56	20	2.8
Bolt	97.2	13.0	7.476
Heart	52.6	24	2.19166

Graph: Create a bar graph showing the density of each object. Make the bars for any object that could have been used in the murder stand out using color or pattern. Label the x axis and the y axis. Be sure to include a title and key. **10 points total.**



Rank the eight objects used in this lab by density:
8, 7, 3, 5, 4, 6, 1, 2 1 point
most dense least dense

Conclusion: Using what you have learned so far about density, answer the following questions. Be sure to study the data table and graph from this lab.

1. Which objects could have been used in the murder? How do you know? **1 point**

Shell because it is the only object with a density between 2.5 and 4.0 g/mL.

2. Describe how to find the density of an irregularly shaped object. **3 points**

•Find the mass of the object.
•Find the volume of the object by displacing water.
•Divide the mass by the volume to calculate the density.

3. Look at your data table from this lab. Do objects with the greatest mass have the greatest density? Do objects with the least mass have the least density? Answer both of these questions and prove your answers with examples from the data table for this lab. **4 points**

   An object with the greatest mass sometimes has the greatest density but sometimes not. The fishing weight had the greatest mass (157.2 g) and the greatest density (10.84 g/mL). On the other hand, the hole punch mechanism had the least mass (44.3 g) but the one of the highest densities (8.2 g/mL).

4. Look at your data table from this lab. Do objects with the greatest volume have the greatest density? Do objects with the least volume have the least density? Answer both of these questions and prove your answers with examples from the data table for this lab. **4 points**

   Objects with the greatest volume do not have the greatest density. Marbles had the greatest volume (44 mL) but the least density (1.1 g/mL). Objects with the least volume do not have the least density. The nut and the hole punch had the lowest volumes (5.6 mL and 5.4 mL) but they had very high densities (8.7 g/mL and 8.2 g/mL.)

5. Think about errors and weaknesses in the design (procedures) of this lab. How might you improve the design so the results are more accurate? **1 point**

6. What would be interesting to find out about density next? Put your idea in the form of a question.
   1 point

Density of Liquids (Step-by-step)
Teacher Notes

Supplies needed for each group: small graduated cylinder (10mL)
larger graduated cylinder (20mL or more)
medicine dropper
triple beam scale
liquids: rubbing alcohol, water, corn syrup, glycerin, mineral oil
calculator

1. **Whole class:** read through and demo the procedure for this lab.

2. **Table groups:** keep the volume constant (10mL) and find the density of each liquid (part 1).

3. **Table groups:** find the density of each liquid when you increase the volume to 20 mL (part 2).

4. **Individual:** rank the liquids from most dense to least dense.

5. **Individual:** graph the density of each liquid.

6. **Individual:** answer conclusion questions.

7. **Whole class:** "Science talk" about the conclusion questions; correct misconceptions when needed.

Objective for this activity

1. Determine the density of various liquids.

Density of Liquids (Step-by-step)

Name ____ Core

Friday morning, a neighbor found John Smith unconscious on his living room floor. The neighbor called 911 and an ambulance took John to Mercy Hospital. John had traces of a clear, odorless liquid in and around his mouth. He is currently in a coma. The cause of his illness is unknown.

Dr. Homes, a brilliant diagnostician who loves the challenges of a medical mystery, is assigned to the case. He believes that identifying the liquid may provide a vital clue that can be used to save John's life. The liquid is tested in the hospital lab. It is found to be colorless and clear. It also has a density of 1.25g/mL.

Dr. Homes sends his team to John's house to bring back samples of all possible liquids. They return with five liquids. Your teacher has samples of each of the liquids. Your task is to discover the identity of the liquid found in and around John Smith's mouth.

Question: Which liquid has a density of 1.25 g/mL?

Hypothesis: I think _________________ will have a density of 1.25 g/mL because

Materials:
triple beam scale
small graduated cylinder
large graduated cylinder
medicine dropper
calculator
5 liquids: rubbing alcohol, water, corn syrup, glycerin, mineral oil
test tube in holder

Procedure:

<u>Part 1</u>

1. Balance the scale to zero.
2. Place the clean, dry graduated cylinder on the scale and find its mass. Record this on the data table on the back of this page in the "Mass of empty cylinder" column.
3. Pour 10mL of the first liquid into the graduated cylinder. Next, use the medicine dropper to remove or add small amounts of liquid until there is precisely 10mL in the cylinder. Place the cylinder back on the scale and find its mass. Record this on the data table in the "Mass of cylinder + liquid" column.
4. Subtract the mass of the cylinder from the total mass to find the mass of the liquid only. Record this on the data table in the "Mass of liquid" column. Rinse and dry the cylinder.
5. Record the volume (10mL) on the data table in the "Volume of liquid" column.
6. Use a calculator to divide the mass of the liquid by the volume of the liquid. Round to the nearest hundredth if the decimal repeats. Record this density on the data table.
7. Repeat steps 1 through 6 to find the density of the other liquids.

Part 2

8. Take each of the liquids and repeat steps 1 through 6 but this time increase the volume of each liquid to 20mL. If your small cylinder will not hold 20mL, use the larger cylinder. Don't forget to measure its empty mass first. Find out if the density changes when you increase the volume. Record your data on the data table.

Data Table:

	Liquid	Mass of empty cylinder (g)	Total Mass of cylinder + liquid (g)	Mass of liquid (g)	Volume of liquid (mL)	Density (g/mL)
Part 1	Rubbing Alcohol					
	Water					
	Corn Syrup					
	Glycerin					
	Mineral Oil					
Part 2	Rubbing Alcohol					
	Water					
	Corn Syrup					
	Glycerin					
	Mineral Oil					

Rank the five liquids you tested from *most* dense to *least* dense:

1.________2.______________ 3. ______________ 4. ______________ 5. ____________

most dense least dense

Graph: Create a graph showing the density of each liquid. Label the x axis and the y axis. Be sure to include a title and a key.

Conclusion: Using what you have learned so far about density, answer the following questions. Be sure to study the data table and graph from this lab.

1. What is the liquid from John's mouth? How do you know this is the correct identity of the liquid?

2. Look at your data table from this lab. Do liquids with the greatest mass have the greatest density? Do liquids with the least mass have the least density? Answer both of these questions and prove your answers with examples from the data tables for this lab.

3. If you increase the volume of a liquid (by adding more of the same liquid), will it have a higher density, lower density, or the same density? Prove your answer with examples from the data table.

4. Can you tell by looking at a liquid whether it will have less, the same, or more density than water? Prove your answer with examples from the data table.

5. Think about errors and weaknesses in the design (procedures) of this lab. How might you improve the design so the results are more accurate?

6. What would be interesting to find out about density next? Put your idea in the form of a question.

Density of Liquids (Step-by-step)

Teacher Notes

Supplies needed for each group: small graduated cylinder (10mL)
larger graduated cylinder (20mL or more)
medicine dropper
triple beam scale
liquids: rubbing alcohol, water, corn syrup, glycerin, mineral oil
calculator

1. **Whole class:** read through and demo the procedure for this lab.

2. **Table groups:** keep the volume constant (10mL) and find the density of each liquid (part 1).

3. **Table groups:** find the density of each liquid when you increase the volume to 20 mL (part 2).

4. **Individual:** rank the liquids from most dense to least dense.

5. **Individual:** graph the density of each liquid.

6. **Individual:** answer conclusion questions.

7. **Whole class:** "Science talk" about the conclusion questions; correct misconceptions when needed.

Objective for this activity

1. Determine the density of various liquids.

Density of Liquids Key (Step-by-step)

34 points

Friday morning, a neighbor found John Smith unconscious on his living room floor. The neighbor called 911 and an ambulance took John to Mercy Hospital. John had traces of a clear, odorless liquid in and around his mouth. He is currently in a coma. The cause of his illness is unknown.

Dr. Homes, a brilliant diagnostician who loves the challenges of a medical mystery, is assigned to the case. He believes that identifying the liquid may provide a vital clue that can be used to save John's life. The liquid is tested in the hospital lab. It is found to be colorless and clear. It also has a density of 1.25g/mL.

Dr. Homes sends his team to John's house to bring back samples of all possible liquids. They return with five liquids. Your teacher has samples of each of the liquids. Your task is to discover the identity of the liquid found in and around John Smith's mouth.

Question: Which liquid has a density of 1.25 g/mL?

Hypothesis: I think _________________ will have a density of 1.25 g/mL because

Materials:
- triple beam scale
- small graduated cylinder
- large graduated cylinder
- medicine dropper
- calculator
- 5 liquids: rubbing alcohol, water, corn syrup, glycerin, mineral oil
- test tube in holder

Procedure:

Part 1

1. Balance the scale to zero.
2. Place the clean, dry graduated cylinder on the scale and find its mass. Record this on the data table on the back of this page in the "Mass of empty cylinder" column.
3. Pour 10mL of the first liquid into the graduated cylinder. Next, use the medicine dropper to remove or add small amounts of liquid until there is precisely 10mL in the cylinder. Place the cylinder back on the scale and find its mass. Record this on the data table in the "Mass of cylinder + liquid" column.
4. Subtract the mass of the cylinder from the total mass to find the mass of the liquid only. Record this on the data table in the "Mass of liquid" column. Rinse and dry the cylinder.
5. Record the volume (10mL) on the data table in the "Volume of liquid" column.
6. Use a calculator to divide the mass of the liquid by the volume of the liquid. Round to the nearest hundredth if the decimal repeats. Record this density on the data table.
7. Repeat steps 1 through 6 to find the density of the other liquids.

Part 2

8. Take each of the liquids and repeat steps 1 through 6 but this time increase the volume of each liquid to 20mL. If your small cylinder will not hold 20mL, use the larger cylinder. Don't forget to measure its empty mass first. Find out if the density changes when you increase the volume. Record your data on the data table

Data Table: 10 points

	Liquid	Mass of empty cylinder (g)	Total Mass of cylinder + liquid (g)	Mass of liquid (g)	Volume of liquid (mL)	Density (g/mL)
Part 1	Rubbing Alcohol	7.9	16.7	8.8	10	0.88
	Water	7.9	17.9	10	10	1.0
	Corn Syrup	8	22	14	10	1.4
	Glycerin	7.9	20.5	12.4	10	1.24
	Mineral Oil	8	16.9	8.9	10	0.89
Part 2	Rubbing Alcohol	7.9	25.5	17.6	20	0.88
	Water	7.9	27.9	20	20	1.0
	Corn Syrup	8	36	28	20	1.4
	Glycerin	7.9	32.7	24.8	20	1.24
	Mineral Oil	8	25.8	17.8	20	0.89

Rank the five liquids you tested from *most* dense to *least* dense: 1 point

1. corn syrup 2. glycerin 3. water 4. mineral oil 5. rubbing alcohol

most dense least dense

Graph: Create a graph showing the density of each liquid. Label the x axis and the y axis. Be sure to include a title and a key. **10 points**

Conclusion: Using what you have learned so far about density, answer the following questions. Be sure to study the data table and graph from this lab. 12 points total

1. What is the liquid from John's mouth? How do you know this is the correct identity of the liquid?

2 points

- **glycerin**
- **has a density closest to 1.25 g/mL**

2. Look at your data table from this lab. Do liquids with the greatest mass have the greatest density? Do liquids with the least mass have the least density? Answer <u>both</u> of these questions and <u>prove</u> your answers with <u>examples</u> from the data tables for this lab. **4 points**

   - **Liquids with the greatest mass have the greatest density. Corn syrup has the greatest mass (14 g) and the greatest density (1.4 g/mL).**
   - **Liquids with the least mass have the least density. Rubbing alcohol has the least mass (8.8 g) and the least density (0.88 g/mL).**

3. If you increase the volume of a liquid (by adding more of the same liquid), will it have a higher density, lower density, or the same density? <u>Prove</u> your answer with <u>examples</u> from the data table.

2 points

- **The density will remain the same because as you increase the volume, you also increase the mass. For example, 10 mL of water has a mass of 10 g, which gives it a density of 1.0 g/mL, and 20 mL of water has a mass of 20 g, which still gives it a density of 1.0 g/mL.**

4. Can you tell by looking at a liquid whether it will have less, the same, or more density than water? <u>Prove</u> your answer with <u>examples</u> from the data table. **2 points**

•This can be answered both ways. No, you can't tell because mineral oil appeared thick (and dense) yet had low density. Yes, you can tell because corn syrup appeared thick (and dense) and it did have high density.

5. Think about errors and weaknesses in the design (procedures) of this lab. How might you improve the design so the results are more accurate? **1 point**

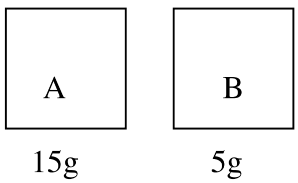
6. What would be interesting to find out about density next? Put your idea in the form of a question.
1 point

Density Final Review

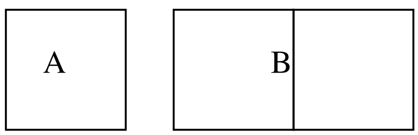
(Do this orally, as a class, with students taking notes the day before the final assessment.)

Size = Volume
Weight = Mass

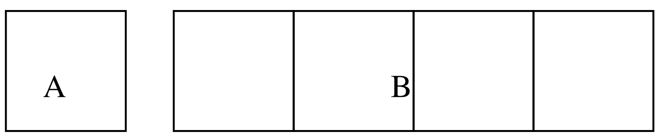
<u>Part A: Size & Density</u> (A is one material, B is a different material…doesn't matter what you call them. One cube of A weighs 15 grams and one cube of B weighs 5 grams)



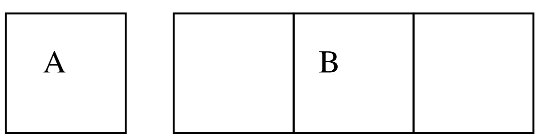
•objects are same size
•objects have different weights
•Which object has more density?



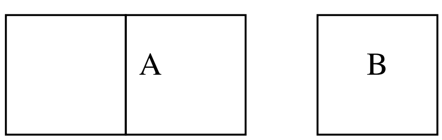
•Which is heavier?
•Has the density of B changed?



•Which is heavier?
•Has the density of B changed?



•Which is heavier?
•Has the density of B changed?



•Which is heavier?
•Has the density of A changed?

1. The weight changed in each example above. What else changed? What did not change?

Part B: Material & Density

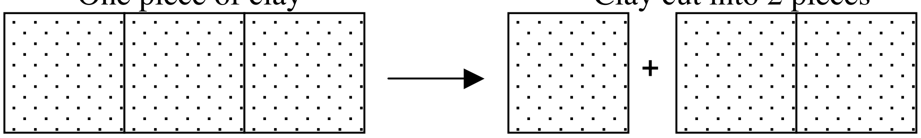
One square represents cork, another represents clay, and a third rectangle represents gold.

3. Assume that the volumes are exactly the same. Which is the densest? Which weighs the most? (Think back to your density lesson to answer this question).

4. Which material weighs the least? Which is the least dense?

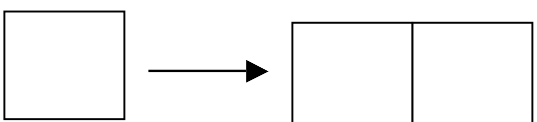
cork gold clay

One piece of clay — Clay cut into 2 pieces



A B C

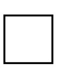
3. Which has the most density: A, B, or C? Explain.



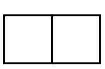
D E

4. Which has the most density: D or E? Explain.

Part C: Visual Calculations of Density

 This picture represents 1 cube unit. One cube unit = $1cm^3$

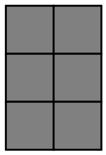
Material A

 2 cube units = 6 grams → What is the density? Answer $\boxed{3g \mid 3g}$ = 3g/cube unit

or

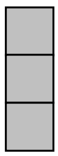
$3g/cm^3$

Material B



6 cube units = 24 grams → 1. What is the density of one

Material C



= 3 cube units = 12 grams → 2. What is the density of the object?

3. Is the density of one cube of material C the same as the density of three cubes of material C? Explain?

4. Is the weight of one cube of material C the same as the weight of three cubes of material C? Explain.

5. Is the volume of one cube of material C the same as the volume of three cubes of material C? Explain.

6. Which of the above materials was the densest?

<u>Part D: Unit Rate = Density Per Cube Unit</u>

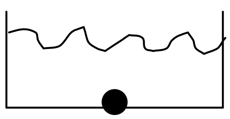
1. Draw an object that is 4 cube units and weighs 16 grams. Use the drawing to calculate the **unit rate** (density per cube unit). Will this object sink or float in water?

2. Draw an object that is 8 cube units and weighs 4 grams. Use the drawing to calculate the **unit rate**. Will this object sink or float in water?

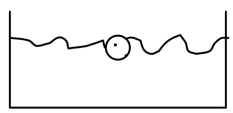
3. Draw an object that is 6 cube units and weighs 6 grams. Use the drawing to calculate the **unit rate**. Will this object sink or float in water?

<u>Part E: Density & Weight</u>

1. Object A weighs 20 grams and displaces 10 mL of water.
   Object B weighs 20 grams and displaces 20 mL of water.
   Which weighs more, A or B? Which is more dense, A or B? Explain.



this piece of clay sinks
this piece weighs 10 grams



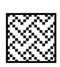
this pumice floats in water
this piece weighs 2.5 grams

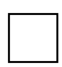
2. If you pinch off a small piece of this clay, will it sink or float?

3. If you had a very large piece of pumice, will it sink or float?

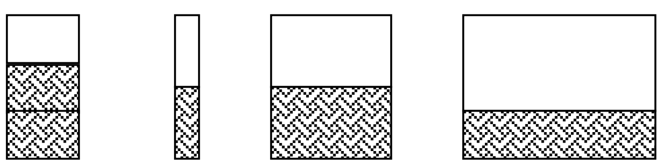
4. Explain your answers.

Part F: Density of mixed objects – Mixing two substances together that have different densities.

 clay

 cork

1. Recall from your studies, which is the densest? Clay or cork?



A B C D

Objects A, B, C, and D are a mixture of clay and cork.

2. Which of the above objects have the same density?

3. Which of the above object has the greatest density?

4. Which of the above object has the least density?

5. How do you know? Explain your answers.

<u>Part G: Simple density calculations.</u> ***Use the density formula to calculate the following densities. If the decimal repeats, round to the nearest hundredth.***

1. mass = 14g
   volume = 15mL
   density = _____g/mL

2. mass = 14g
   volume = 13mL
   density = _____g/mL

3. mass = 7.5g
   volume = 6.5mL
   density = _____g/mL

4. mass = 7.5g
   volume = $8.2cm^3$
   density = ______g/cm^3

5. mass = 8g
   volume = $2.5cm^3$
   density = _____g/cm^3

6. mass = 2.5g
   volume = $8cm^3$
   density = ______g/cm^3

7. mass = 12g
   volume = 6mL
   density = _____g/mL

8. mass = 24g
   volume = 8mL
   density = _____g/mL

9. mass = 8g
   volume = $2cm^3$
   density = ___________

10. mass = 40g
    volume = 5mL
    density = ____________

11. mass = 3g
    volume = 3mL
    density = ___________

12. mass = 10g
    volume = $7.2cm^3$
    density = ____________

<u>Part H: Density Word Problems –</u> ***Putting it all together.***

1. The initial readings of the water level in a beaker is150 mL. After placing an object in the beaker the level rises to 220 mL. The object weighs 35 grams Calculate the density of the object; show your calculations. Will this object sink or float in water?

2. Calculate the density of an object that weighs 450 grams and has a rectangular shape with the following dimensions: height = 7 cm, width = 5 cm, and length = 10 cm. Show your calculations. Will this object sink or float in mercury if mercury's density is 13.55 g/mL?

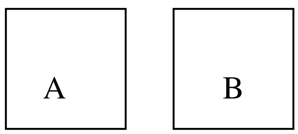
3. Calculate the density of a liquid. It has a volume of 25 mL and weighs 15 grams. If you were to pour this liquid into a graduated cylinder that had water in it, would this liquid sink below the water or float on top of the water? Would cork float or sink in this liquid if cork's density is $.22 g/cm^3$?

Density Final Review - Key

(You can this orally, as a class, with students taking notes the day before the final assessment or you can hand this out to students and do together.)

Size = Volume
Weight = Mass

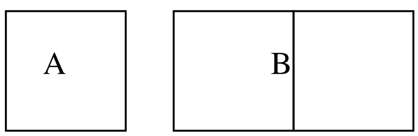
<u>Part A: Size & Density</u> (A is one material, B is a different material…doesn't matter what you call them. One cube of A weighs 15 grams and one cube of B weighs 5 grams)



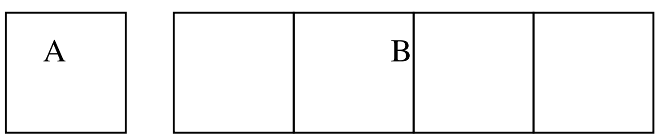
•objects are same size
•objects have different weights
•Which object has more density?

A is the most dense. It has the same volume as B, but it weighs three times more.

15g 5g

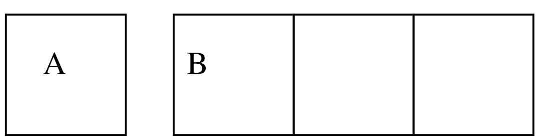


•Which is heavier? A is heavier. A = 15 g, B= 10 g
•Has the density of B changed? No.

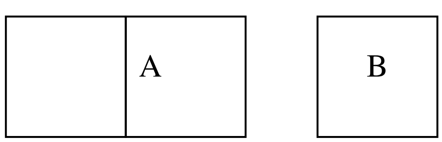


•Which is heavier? B is heavier. A = 15 g, B= 20 g

•Has the density of B changed? No



•Which is heavier? Neither. A = 15 g, B= 15 g
•Has the density of B changed? No



•Which is heavier? A is heavier. A = 30 g, B = 5 grams

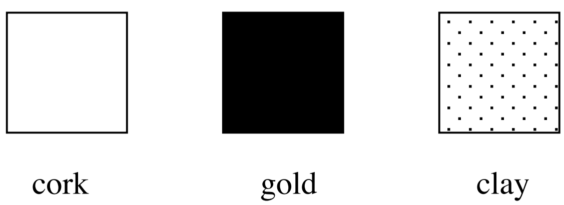
•Has the density of A changed? No

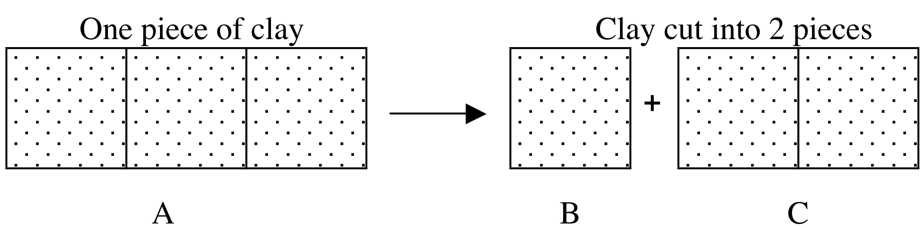
1. The weight changed in each example above. What else changed? What did not change?
The volume changed in each example. The density of the objects A and B did not change.

Part B: Material & Density

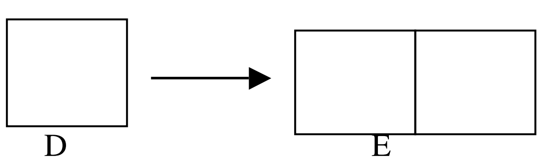
One square represents cork, another represents clay, and a third rectangle represents gold.

3. Assume that the volumes are exactly the same. Which is the densest? Which weighs the most? (Think back to your density lesson to answer this question). Gold is the densest and it weighs the most.
4. Which material weighs the least? Which is the least dense? Cork is the least dense and weighs the least.



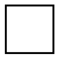


3. Which has the most density: A, B, or C? Explain. A, B, and C all have the same density. Changing the object into two pieces does not change its density. Density is a characteristic property of matter. If the matter stays the same, then the density stays the same.

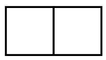


4. Which has the most density: D or E? Explain. Both are the density. Having a piece of cork that is twice as big does not change the density. The mass increases in proportion to the volume.

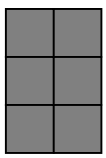
Part C: Visual Calculations of Density

 This picture represents 1 cube unit. One cube unit = $1cm^3$

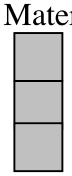
Material A

 2 cube units = 6 grams → What is the density? Answer | 3g | 3g | = 3g/cube unit or $3g/cm^3$

Material B

 6 cube units = 36 grams → 1. What is the density of one cube of material B? 6 g/cm^3

Material C

 = 3 cube units = 12 grams → 2. What is the density of material C? 4 g/cm^3

3. Is the density of one cube of material C the same as the density of three cubes of material C? Explain. Yes. One cube's density = 4 g/cm^3, all cubes density together = 4 g/cm^3

4. Is the weight of one cube of material C the same as the weight of three cubes of material C? Explain. No. Three cubes of material C weighs 12 grams, one cube weighs 4 grams.

5. Is the volume of one cube the same as the volume of three cubes? Explain. No. Three cubes has the volume of 3 cm^3, one cube has the volume of 1 cm^3

6. Which of the above materials was the densest? Material B was the densest at 6 g/cm^3

Part D: Unit Rate = Density Per Cube Unit

1. Draw an object that is 4 cube units and weighs 16 grams. Use the drawing to calculate the **unit rate** (density per cube unit). Will this object sink or float in water? It will sink.

4g	4g	4g	4g

= 16 grams total. The unit rate or density is 16 g/ 4 cube units =4 g/cm^3

2. Draw an object that is 8 cube units and weighs 4 grams. Use the drawing to calculate the **unit rate**. Will this object sink or float in water? It will float.

.5 g	.5 g	.5 g	.5 g
.5 g	.5 g	.5 g	.5 g

= 8 grams total. The unit rate or density is 4 g/8 cube units =0.5 g/cm^3

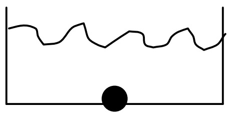
3. Draw an object that is 6 cube units and weighs 6 grams. Use the drawing to calculate the **unit rate**. Will this object sink or float in water? Neither. It is neutral buoyant. It has the same density as water.

1 g	1 g	1 g
1 g	1 g	1 g

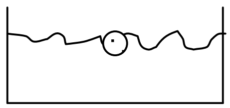
= 6 grams total. The unit rate or density is 4 g / 8 cube units = 1 g/cm^3

Part E: Density & Weight

1. Object A weighs 20 grams and displaces 10 mL of water.
Object B weighs 20 grams and displaces 20 mL of water.
Which weighs more, A or B? B Which is more dense, A or B? A Explain.
Object A displaced 10 mL of water, so its volume is 10 cm^3. The density of Object A is 20 g/10 cm^3 and that equals 2 g/ cm^3. Object B displaces 20 mL of water, so its volume is 20 cm^3. The density of Object B = 20 g/ 20 cm3 = 1 g/cm^3.



this piece of clay sinks
this piece weighs 10 grams



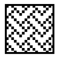
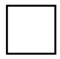
this pumice floats in water
this piece weighs 2.5 grams

2. If you pinch off a small piece of this clay, will it sink or float? It will still sink. Changing the size of an object does not change its density.

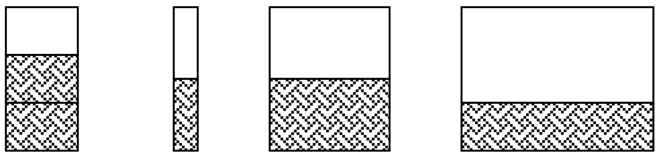
3. If you had a very large piece of pumice, will it sink or float? It will still float. Changing the size of an object does not change its density.

4. Explain your answers. If the material stays the same, then changing the size of an object does not change its density.

Part F: Density of mixed objects – Mixing two substances together that have different densities.

 clay  cork

1. Recall from your studies, which is the most dense? Clay or cork? Clay is the most dense.



A B C D

Objects A, B, C, and D are a mixture of clay and cork.

2. Which of the above objects have the same density? B and C. The proportion of clay to cork is the same in these objects
3. Which of the above object has the greatest density? A. It has the greatest proportion of clay.
4. Which of the above object has the least density? D. It has the least proportion of clay.
5. How do you know? Explain your answers. The ratio of the amount of low density to high density materials in an object determines its density. If there is a greater proportion of higher density materials, the object will have a greater density.

Part G: Simple density calculations. ***Use the formula to calculate the following densities. If the decimal repeats, round to the nearest hundredth.***

1. mass = 14g
volume = 15mL
density = 0.93g/mL

2. mass = 14g
volume = 13mL
density = 1.07g/mL

3. mass = 7.5g
volume = 6.5mL
density = 1.15g/mL

4. mass = 7.5g
volume = 8.2cm^3
density = 0.91g/cm^3

5. mass = 8g
volume = 2.5cm^3
density = 3.2g/cm^3

6. mass = 2.5g
volume = 8cm^3
density = 0.31g/cm^3

7. mass = 12g
volume = 6mL
density = 2g/mL

8. mass = 24g
volume = 8mL
density = 3g/mL

9. mass = 8g
volume = 2cm^3
density = 4g/cm^3

10. mass = 40g
volume = 5mL
density = 8g/mL

11. mass = 3g
volume = 3mL
density = 1g/mL

12. mass = 10g
volume = $7.2cm^3$
density = $1.39g/cm^3$

<u>Part H: Density Word Problems - </u>*Putting it all together*.

1. The initial readings of the water level in a beaker is150 mL. After placing an object in the beaker the level rises to 220 mL. The object weighs 35 grams. Calculate the density of the object; show your calculations. Will this object sink or float in water?

220 mL – 150 mL = 70 mL. 70 mL/ 35 g = 2 g/mL It will sink because its density is greater than water (1 g/mL)

2. Calculate the density of an object that weighs 450 grams and has a rectangular shape with the following dimensions: height = 7 cm, width = 5 cm, and length = 10 cm. Show your calculations. Will this object sink or float in mercury if mercury's density is 13.55 g/mL?

7 cm x 5 cm x 10 cm = 350 cm^3 450 g/ 350 cm^3 = 1.29 g/ cm^3 It will float in mercury because it has a lower density than mercury.

3. Calculate the density of a liquid. It has a volume of 25 mL and weighs 15 grams. If you were to pour this liquid into a graduated cylinder that had water in it, would this liquid sink below the water or float on top of the water? Would cork float or sink in this liquid if cork's density is $.22g/cm^3$?

15 g/25 mL = 0.6 g/mL
This liquid would float on top of the water. The density is less than the density of water (1 g/mL). The cork would float in this liquid because the cork's density (o.22 g/cm^3) is less than the liquid (0.

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