

Understandings of Consequence Project Teacher Overview

Understanding Density

What is density and why is it hard to understand? This overview outlines concepts in the Density curriculum and explains difficulties that students have when learning the concepts. It illustrates how understanding the underlying causality is important to a deep understanding of density.

Section one explains the scientific concept. Section two reviews how students' ideas typically progress and what problems they encounter. Section three illustrates how causal restructuring is important in gaining a deep understanding. Section 4 outlines misconceptions about density and is divided into two types—those that require learning a new causal structure and those that do not.



What is the scientific concept?

Scientists define density as the mass of a substance *per* unit volume. The word “per” signals that thinking about density requires thinking about a relationship. It is the relation between the mass (or weight) of one unit of a material and the volume of that one unit. Density cannot be directly perceived or measured. It must be inferred from the relationship of the mass and volume. However, it can be determined by calculation which is how many schools teach it. To calculate density, you first measure the weight and volume of an object precisely, then you divide the mass by the volume (i.e. $d=m/v$, density equals mass divided by volume). So for example, the density of water is 1 gram per cubic centimeter because a volume of 1 cubic centimeter of water has a mass of 1 gram. A substance which has a mass of greater than one gram per cubic centimeter has a density greater than 1.0 gram per cubic centimeter; a substance which has a mass of less than one gram per cubic centimeter has a density of less than 1.0 gram per cubic centimeter.

Differences in density are also discussed as a function of atomic mass, atomic or molecular bonds, and mixed density. The greater the atomic mass of a given substance (number of protons and neutrons making up each atom), the more mass per unit volume. Similarly, the tightness of the atomic and/or molecular bonds impacts how closely packed they are and therefore how much mass fits in a given volume. The greater the mass is in a given space, the greater the density is. When more than one material is present, one must consider the density of each material in assessing the

overall density. Under standard conditions of temperature and pressure, the density of a material stays the same. However, changes in temperature and/or pressure can lead to changes in density.

Whether something sinks or floats depends upon the relationship of the density of the object or substance to the substance that it is in. If the density of the object or substance is greater, it will sink, if it is less, it will float.



How do students' ideas typically progress?

Children often develop an intuitive sense of density long before it is taught in school. They develop these intuitions from their observations—that solid objects can be the same size but have different weights; that very large¹ objects can weigh less than much smaller ones, and so on. For students to deeply understand density, they need to integrate their intuitive, qualitative sense with the quantitative concepts that they learn in school.

By one year of age, infants already adjust their grasping strategy for different sized objects, suggesting that they predict an object's weight based on its size.² By 3 to 4 years old, children appear to have distinct concepts of weight and size, but not a complete understanding of “heavy for size.” Deciding that something is ‘heavy’ involves an implicit comparison to some standard, whether to a particular object (as in “a heavy book”) or for a particular person (e.g. heavy for a child, but not for an adult).³ Preschoolers can successfully predict whether an object would cause a foam rubber bridge to collapse when dropped on it, but still have difficulty judging smaller heavier items against larger lighter ones even with training.⁴

“Heavy for size” is one of the earliest notions of density. It grows out of concepts about weight and can lead to understanding that the heaviness of the kind of material is a *property* of that particular material. Eventually, it can lead to distinguishing the concepts of weight and density. In the primary years, as children notice that objects are made of different materials, they realize that there are heavier and lighter kinds of materials and the heaviness of the material kinds is a defining factor in the resulting weight of the objects made from them.

Between the ages of six and nine, children often come to think about density as a notion of being more or less “packed in” or “spread out”⁵ even though they don't yet hold a particulate theory of matter. This may be surprising, but even historically the concept of density existed before matter was conceptualized at an atomic level.⁶

Eventually students develop an intuitive theory of matter which helps them develop an intuitive sense of density. Students come to understand the following ideas about matter (however, many still hold misconceptions about many of these ideas.) Matter has weight and takes up space, and although usually observable, it does not have to be. Matter continues to exist when it can no longer be seen or felt. Material kind maintains

its identity even during decomposition when perceptual properties change. For example, if you cut a tiny piece of Styrofoam in half and in half again, and keep on cutting it, it will always have mass and take up space even though you will not be able to see it, even with a microscope.

Typically the concept of density is taught to middle school science students as a ratio quantity, (the mass to volume ratio), or as a *per* quantity (the mass per unit volume) which is a characteristic property of different materials (i.e. a property that can be used to distinguish one material from another).⁷

Research shows that students tend to hold many misconceptions about density concepts and have a difficult time integrating their intuitive concepts and formal learning. The following sections discuss why density concepts are so hard for students and what causality has to do with it.



What does causality have to do with it?

Students typically use a simple linear causality in their learning. They reason that one thing makes another thing happen. They also tend to focus on obvious variables—ones that they can perceive, such as weight. They can feel the weight of an object so they confound weight and density. They say things like “the weight causes the object to sink.”

Helping students reason well about density involves using relational causality. In relational causality, the relationship between two variables, usually one of balance or imbalance, causes –or results in– an outcome. One way to think about the cause of differences in density is to focus on the relationship between mass and volume. A strong relational causal model supports both qualitative and quantitative understanding of density. Students can picture the amount of mass in a given amount of space and can deduce the formulas for density from the inherent *per* relationship.

Without opportunities to learn about relational causality, students often focus on one side of the relationship or the other but do not consider the two in relationship to each other. For example, they think about how much mass two objects have in an absolute sense but do not think about the amount of mass per unit of volume. Not reasoning relationally can lead to confounded weight and density concepts. Why? ...because density must be inferred from a relationship. You can't directly perceive or measure it. Neither feature (mass or volume) is sufficient to explain the outcome. Without a firm grasp of the relational causality, students tend to substitute obvious variables in a simple linear relationship.

It *IS* cognitively harder to reason relationally than linearly. The challenges inherent in understanding density as a relationship include the cognitive load of holding two or more features in mind, reasoning abstractly as one attends to the relations rather than the absolutes, and understanding that there are dual features through which variation

can be introduced (so one needs to attempt to isolate and control for variables.)

In addition to teaching relational causality, an important component of teaching about the “cause” of differences in density is to focus on the micro- and macro- features that constitute density. This includes differences in atomic mass, atomic and molecular bonds, and instances of mixed density. Understanding these differences can lead to a deep understanding of material kind and to integrating material kind conceptions with relational causality conceptions (including “dots-per-box” models.) This is important because most students reason from “material kind” models instead of “ratio models.” Thinking about atomic particles can be challenging and again involves causes that cannot be directly observed. However, it offers a critical bridge between intuitive notions that there are different kinds of materials and mathematical models of differences in density.

Relational causality comes up again in sinking and floating. When students are trying to reason about sinking and floating, they need to think about two relationships in relation to each other—The relationship of the mass per unit volume of the object or substance in relation to the mass per unit volume of the liquid. As one considers increasingly complex phenomena, the cognitive load and level of abstraction required to balance the components of each causal relation within the system becomes increasingly challenging. This is why it is important to build the understanding of the simple relation that is density as a platform upon which to base understandings of more complex phenomena.

Dynamic elements make the model even more complex. For instance, explaining convection currents requires reasoning about the changing relationship between two relationships. As warm air rises to float on colder air, it then cools and then it sinks on the air that is now warmer by comparison. Student must conceptualize the change in the relationship of mass per unit volume for the air as it changes temperature. There are many everyday applications where students must engage in this type of reasoning, such as weather patterns and hot water heaters to those based upon processes of photosynthesis, such as when duckweed on a pond stores enough sugar to become too dense to float on the water surface and sinks to the bottom of the pond for the winter as it uses its stored sugars and subsequently becomes less dense, enough so that it floats back to the surface in the spring.



What are typical misconceptions or difficulties in students' understanding of density that relate to causal structure?

- Students substitute weight for density. They assume that heavier objects are denser without considering weight per size.
- Students find it hard to attend to two variables at once and focus on the relationship between them as understanding density requires. They attend to only one variable at a time (weight, size, shape, etc.) Often they attach more

importance to one variable than the others.

- When learning about density, students often think that density cannot change. Textbooks that present the concept of a standard, but are not clear that it is under certain conditions of temperature and pressure can lead to this misunderstanding. This makes it difficult for students to understand a host of real world phenomena. They need to understand that if the variables in the relationship change, then the density can change.

Students think that....

- Weight is additive and so is density, so if you have twice as much material, you have twice as much weight and twice as much density. (Again, this stems from an undifferentiated weight/density concept).
- Volume is additive and so is density, so if you have twice as much material, you have twice as much volume and twice as much density.
- Heavy things sink and light things float.
- Objects either sink or float and it is possible to make a list of “sinkers” and “floaters.”



What are other (non-causality-related) typical misconceptions or difficulties in students' understanding of density?

Students think that...

- Fluids (especially gases) are not “materials” and don't have density. Gases have no mass and therefore no density.
- The spaces in between the particles of an object are air. (They can be in some instances of mixed density where air molecules fit in the gaps in the object material, but the spaces between particles are typically not air.)
- Differences in felt weight are always due to one object being hollow (or mixed density).
- Objects that don't have felt weight do not have weight at all. (Students often use felt-weight as their concept of weight so they think that tiny visible pieces of Styrofoam have no weight at all because you can't feel any pressure on your hand.)
- Materials cease to exist when they are no longer visible. Students think that the material kind of the object or substance only maintains its identity if large-scale

perceptual properties are preserved.

- Wood always floats.
- Plastic always floats.
- Hollow objects always float (when it actually depends upon the ratio of the density of surrounding material to the inside air and how that ratio compares to the density of the liquid.)
- Particles (or atoms) are very different sizes.
- Frozen means that something feels cold to the touch (rather than the scientific meaning that it is in a solid state.)

¹ Smith, Maclin, Grosslight, & Davis 1997

² Mounoud & Hauert, 1982

³ Smith et. al 1985

⁴ Smith, Carey & Wiser, 1985

⁵ Smith et al., 1985

⁶ Smith et al, 1985

⁷ Smith, Maclin, Grosslight, & Davis 1997