Seeing Weight, Grasping Density

The Inquiry Project
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What does it look like to begin reasoning early about density before definitions and formulas?
What sorts of classroom activities and teaching approaches might support this?

Although it may be too early to introduce density formally in grade 4, it is not too early to begin reasoning about the concept.

Here density is broached indirectly in activities of:
(1) ordering materials of equal volumes by weight;
(2) ordering equal weights of materials by volume; and
(3) inferring the materials of covered objects.

Students eventually realize that certain materials have the property of being "heavy for their size" and that this is different from their scale weight.

In grade 5, this working knowledge of density will come in handy when students face issues related to change of state—for example, when liquid water transforms into a larger volume of ice having the same mass.

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1-Ordering Materials of Equal Volumes by Weight

Students are given equal-volume samples of different materials and encouraged to order them by weight. The activity serves to introduce conventions by which physical quantities are represented through distances. The order is also related to each material's density, so this sets the stage for discussions about the ratio of weight to size (volume) for different materials.

Teacher: "I want to see whether you can put the materials on the line, from heavier to lighter."

Figure 1: A student orders the materials (from left to right): humus, water, mineral oil, sand. A discussion ensues about the relative placement of the mineral oil and the water.

How can I get the students to express the magnitudes of the *differences* in weights?

Teacher: "Ok, let's think about this. Can we tell how much more something weighs just by looking at the line?"

Figure 2: A student spreads out the materials evenly. Other students suggest alternative spacings. They come to the conclusion that the line needs to be a number line. Initially there is some doubt as to whether the numbers will represent distances (cm) or weights (g).

Some materials are heavier than others.

Teacher: Is he referring to weight or heaviness for size?

Figure 3: A student orders equal volumes of different materials by weight. A teacher might use the activity to introduce *heavy for size* (the ratio of weight to volume) as a bridge between weight and density.

2-Ordering Equal Weights of Materials by Volume

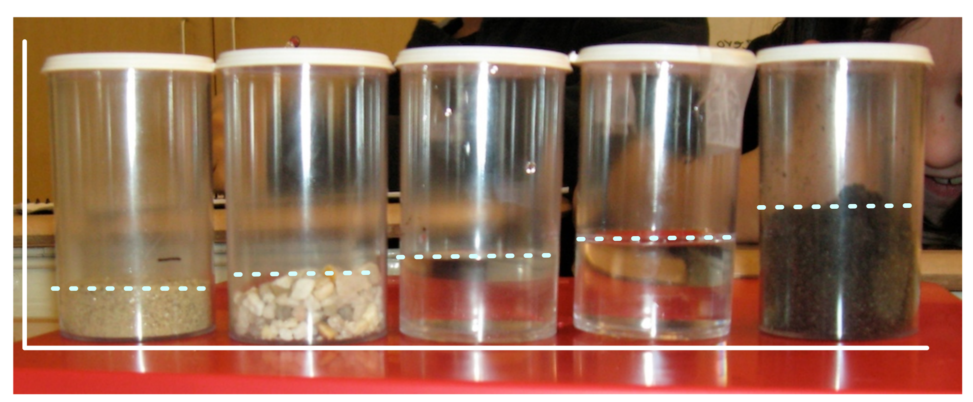

Figure 4: Students measure out 40 g of sand, gravel, water, mineral oil, and humus and examine the differences in volume. Why do some samples take up less (or more) space than others?

Students determine the volume of equal-weight samples of materials. This provides another context for exploring the relations among weight, volume, and material and to allude to density well before introducing a formal definition or referring to the division of an object's weight by its volume.

The weight of some materials is more spread out.

Teacher: This is like the ratio of volume to weight (the reciprocal of density)

Figure 5: A student orders equal weights of different materials by volume. Students sometimes are drawn to the ratio of volume to weight (how much the weight is spread out or distributed). This is the reciprocal of density.

3-Inferring Materials of Covered Objects

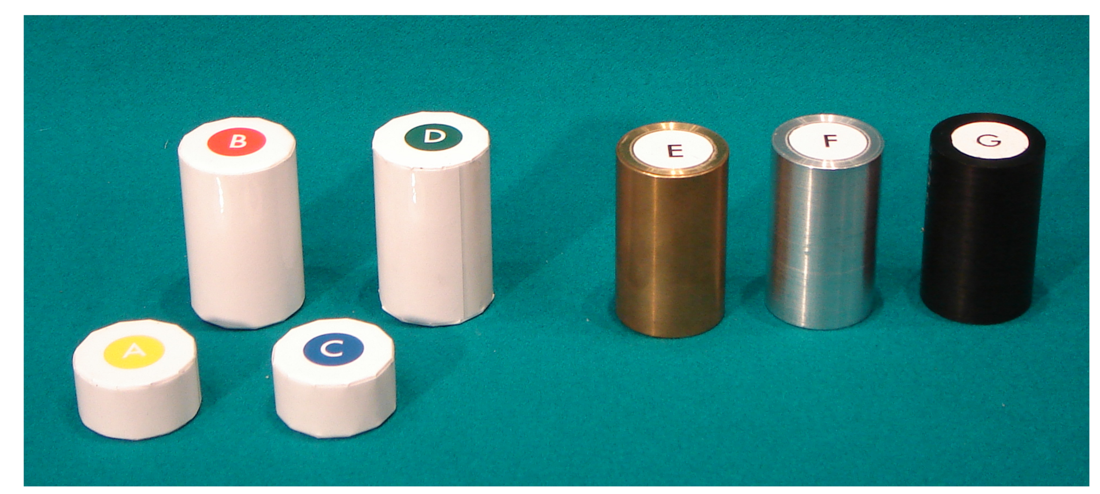

Figure 6: During individual interviews, students are challenged to determine whether cylinders A, B, C, and D might be made of brass (E), aluminum (F) or Delrin (G). A and C have 1/3 the volume (and height) of the other cylinders. Multiple copies of the smaller cylinders (A & C) are readily available.

Even though students could neither define nor calculate density, they were able to indicate their understanding through other means. Students were asked to determine possible materials for the four covered cylinders in Figure 6. It was relatively easy (86% correct) to reason about the case of cylinder B (aluminum) because the weight comparison on the balance scale was straightforward.

The short cylinders (A and C) could not be directly compared to the tall cylinders. (But there were multiple copies of the short cylinders!)

Of those students who had the insight to systematically stack copies of cylinders C, nearly 9 out of 10 correctly concluded that C could be made of aluminum. (Only 1 out of 7 of those who did not stack made such an inference.)

	Control G4	Treatment G4
Correctly inferred material	35.1%	54.6%
Correctly stacked cylinders	32.4%	47.2%
Improved since grade 3	19.2%	41.3%

Table 1: Performance of control and treatment (Inquiry Project) students in inferring the material of cylinder C. $N_{controlG4}$=37 $N_{treatG4}$=54. Grade 3-4 improvement: $N_{control}$=26 N_{treat}=46.

"Developmental Readiness"

The Piagetian Dilemma (Duckworth, 1979): "Either we're too early and they can't learn it or we're too late and they know it already".

How can students reason about *density* if they don't already have the concept?

The Learning Paradox (Bereiter, 1985): "if one tries to account for learning by means of mental actions carried out by the learner, then it is necessary to attribute to the learner a prior cognitive structure that is as advanced or complex as the one to be acquired".

Why teach students definitions and formulas they are not ready to understand?

The above are *false dilemmas* because they treat concepts as things students either know or do not know. Teachers can promote various forms of tacit understanding of a concept before it is explicitly represented.

The Inquiry Project

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The Inquiry Project—a collaboration between TERC, Tufts University, and two schools in Greater Boston—investigates students' scientific understanding from 8 to 11 years of age (Grades 3-5), with special emphasis on their evolving concepts of material, weight, volume, density, and states of matter.

As a research endeavor, it aims to clarify how these concepts develop over time, how they can be successfully nurtured through instruction, and how they prepare students for later learning about the atomic theory of matter.

As an endeavor in curriculum development and teacher education, it tests ideas about the teaching and learning of these concepts.

Bereiter, C. (1985). "Toward a Solution of the Learning Paradox." Review of Educational Research 55(2): 201-226.

Duckworth, E. R. (1979). "Either we're too early and they can't learn it or we're too late and they know it already: the dilemma of 'applying Piaget'." Harvard Educational Review 49(3): 297-312.

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