Causal Patterns in Science
a professional development resource

Questions to Ask About Complex Causality:
With Applicable Notes to Density Concepts Where Relevant

Questions:	Notes:
Obviousness/Concreteness of the Variables:	
1. Are there important variables that are non-obvious or hard to detect? (ex: air pressure, gases)	Density is about the crowdedness of particles of matter. It cannot be directly felt or observed. Weight can be directly felt and volume can be directly observed so students often substitute these more concrete variables.
2. Are there important variables that students are likely to take for granted? (ex. the liquid in sinking and floating)	When thinking about sinking and floating, students often focus on the object and ignore the liquid that it is in. This can lead to a simple linear explanation instead of a relational one between the object and liquid or between two liquids.
3. Are there variables that are inferred or constructed as part of the currently accepted explanation, but not necessarily accessible? (ex: electrons and protons)	Density is an inferred or intensive quantity. You need to figure it out from the relationship between mass and volume. You cannot directly measure it. The microscopic causes of density have to do with atomic mass, how "tightly" the atoms and molecules are bonded and how the types of molecules lead to certain kinds of spacing (as in polymers, for example). None of this is accessible to students. Therefore, they often resort to talking about mixed density in terms of air plus another substance, to explain differences in felt mass.
4. Are there important variables that play a passive role? (ex: protons)	Students view the liquid in sinking and floating as "passive" and often don't realize that it is part of the relational density involved in the outcome.
5. Are there causes that are spatially far away from their effects or vice versa? (ex: the forces that cause satellites to orbit, how Hurricane Katrina affected gas prices nationally)	
6. Are there time delays or gaps between causes and effects? (ex: eating of infected beef and onset of Mad Cow Disease)	

7. Are there preconditions that are not necessarily part of the causal story, but are related to it in some way? (ex: Lightning typically occurs during temperature changes or when there are temperature differentials)	Temperature and pressure impact density and when numbers are assigned to density in a density chart, it is under "standard" temperature and pressure. Students are often unaware of these preconditions and think that density cannot change. Even if they do know that it can change, they typically do not know how to reason about the causal potency of temperature and pressure in reasoning about density in the real world.
Location of the Causes or Agents:	
8. Are there contributing causes in many different places (as compared to a cause in a central place)? (ex: the actions of the many individual voters or bloggers as compared to a president's decision)	The overall density can be the sum of different densities in an object of mixed density and students may not realize this. However, it is not as complex as reasoning about causes that are widely dispersed or that are intentional.
9. If yes to Question 8, are those actions/intents uncoordinated as compared to coordinated? (ex: a lot of people driving cars contributing to global warming or individual actions that result in wide scale civil unrest vs. voting for a president)	
Interaction between Causes and Effects:	
10. Is the effect different in size/magnitude than the cause? (ex: repeated cause and no obvious effect until there is a very large effect (as in the point where the environment can no longer accommodate pollution, as in tipping point phenomena), smallish causes that precipitate complex interactions until there is a big outcome (such as the accident at the Chernobyl Nuclear Power Plant)	
11. Do the causes or effects add up or interact with each other? (ex: accumulation or where one set of effects amplifies another set of effects, etc., accumulation of pollution, greenhouse gases.)	

12. Are there multiple possible causes where any of the causes is enough to get the effect? (ex: application of heat or pressure are each sufficient to make something boil.)	Analyzing overall density involves reasoning about multiple sufficient causes—atomic mass, atomic and/or molecular bonds, and in some case, mixed density—any of which can "cause" the given density at the microscopic level. At the macroscopic level, because the relationship between mass and volume accounts for density, changing either one (not in relation to the other) can result in a change in density.
13. Are there multiple causes where causes work together to make something happen (and you need all of them)? (ex: certain chemicals for a chemical reaction to occur.)	Together, atomic mass and atomic and/or molecular bonds are essential parts of the causal story of density at the microscopic level (except for the "noble gases" made up of just one atom).
Causal Pattern:	
14. Are there indirect effects? (ex: the loss of green plants on carnivores)	
15. Are there non-linear cause and effect relationships? (ex: as in home heating systems, etc.)	Reasoning about density involves relational causality where the relationship between two or more variables results in an outcome. This requires holding both variables in mind and being able to reason about how changes to each impact changes to the relationship. Analyzing instances of dynamic density, such as in a lava lamp or a Galileo's thermometer, involve reasoning about cyclic causality. Changes in temperature result in changes in volume—impacting the mass/volume relationship and thus the density—and resulting in cyclic sinking and floating patterns.
16. Are there bi-directional effects or causes? (ex: as in symbiotic relationships)	
17. Are there causes that impact the effect of another cause (act as a mediator—a catalyst or a barrier)? (ex: Insulation mediates the process of thermal equilibrium)	
18. Are there multiple causes or multiple effects? (ex: an oil spill affects birds, sea life, cleanliness of beaches, and the fishing industry)	Analyzing overall density involves reasoning about multiple sufficient causes—atomic mass, atomic and molecular bonds, and in some case, mixed density.
19. Can you make predictions about the causal system by reasoning about its constraints? (ex: reasoning from Ohm's Law)	It is common to reason about density by reasoning through the formula of D = M/V. Knowing the formula should make it possible to reason about what would happen if mass were manipulated, volume were

	manipulated, and so on.
Contiguity:	
20. How much consistency is there between the cause and the effect? Does it always happen, some of the time, etc.? (ex: Deterministic causality where every cause is followed by an effect vs. probabilistic causality where the outcomes happens some of the time in response to the cause but not consistently.)	The density relationships that students are asked to reason about in school are mostly deterministic, making them less difficult.
21. Is there "noise" that makes it hard to see the relationship between causes and effects? (ex: seasonal effects in detecting global warming)	
Levels:	
22. Is there order at one level and not at another? (ex: the gas laws where disorder at one level is orderly at another)	
23. Do you need to understand the concepts at more than one level to understand what is going on? (ex: Understanding a circuit at the level of the individual electrons and protons vs. at the level of the system) If so, what is the relationship between the levels? Are there different sets of variables or causal patterns at different levels?	Microscopic variables give rise to macroscopic qualities related to density. Students can reason at the level of "material kind," particles, or at the level of atoms and molecules.