Causal Patterns in Density Rubrics: Understandings of Consequence Project

These rubrics are intended to help see whether students have achieved certain understandings and to diagnose the level of students' models and how they are structuring the causal concepts. For each question, the first rubric focuses on causal understandings. It specifies what a good model at each causal level looks like (however, students may not draw the best model at that level and their response can still be at that level.) This is followed by a checklist of science concepts that students should also understand and by a list of other misconceptions that students may reveal in the context of their answers. The final rubric for each question is to help you judge the quality of the students' written response and model drawing. This is aimed at helping students generate the best explanations that they can so that you will understand their reasoning and they will grow in their ability to explain themselves in writing and model drawing.

Scoring Advice:

- Decide on the answer or level of response that is closest to the student's and record it on the student's summary sheet.
- If a student gives two explanations where a lower level one is elaborated by a higher level one, score for the higher one. If a student gives two competing explanations, average the score of the two unless he or she clearly weights one much more than the other.
- Be sure to include information in a student's diagram when scoring his or her response.
- When scoring for causality, don't punish your less articulate students. Score for the level of causal model that they most likely understand even if they are not articulate about it. This helps you diagnose whether they understand the causal model even if they did not write a full explanation.
- Score with the same level of rigor on the pretest as on the post-test. Otherwise it will be difficult to see whether learning has taken place.
- Use each rubric to score only the dimension that it focuses on.
- Use the examples to offer an idea of what the level is asking for but don't let it limit your analysis. Use the description at that level instead.
- When a rubric says "OR" it means that an answer only has to satisfy one part of what it says in order to qualify at that level. If the student used two or more of the "OR" statements, it still gets scored at that level.

Question 1. Your teacher shows you two objects that are exactly the same size (volume). When you pick them up, however, one feels much heavier than the other. Explain what you think is going on to account for the difference in mass or "felt weight." Draw two models comparing the objects that show in as much detail as possible what causes the difference. Then give a written explanation of what is going on.

Assessment Aim: Density is an intensive quantity. That means you can't see it. This question asks whether students recognize that there can be non-obvious causes for differences in density and that these impact the relationship between mass and volume (relational causality). At some point, students connect their intuitive sense that there are different kinds of materials to the idea that materials are made up of particles and eventually to the idea that there can be certain numbers of particles in a given space. At the highest level of response, students recognize that non-obvious and microscopic causes of differences in density at the atomic level account for how much mass there is per a given amount of volume.					
Content Understandings: Mass per Unit Volume, Atomic Mass, Atomic and Molecular Bonds, Mixed Density, Microscopic Causes of Differences in Density.					
Causal Understanding: Relational Causality, Obvious and Non-obvious Causes					
Level 1	Level 2	Level 3	Level 4	Level 5	Level 6
Attributes the difference to obvious features. Examples: "It is because of the shape." "They have different weight." "One is bigger." "One is wider."	Attributes the difference to macroscopic but non-obvious features/ Includes mixed density arguments that are not at the level of particles. Examples: "One object is hollow or "filled with air." "The objects are made of different types of materials."	Attributes the difference to the relationship between the obvious variables of mass and volume (but not describing it at the non-obvious particulate level) OR talks about non-obvious variables (but doesn't control for mass per unit volume.) Examples: "Since both objects have the same volume, one must have greater mass and therefore be more dense." "Density is the mass of a substance per unit of volume." "There are more particles (or uses "molecules" for "particles") in one than the other." "One has more crowdedness (closer or further apart) or the particles are more packed."	Attributes the difference to non-obvious and microscopic variables specifically controlling for the amount of mass per unit of volume at the particle or microscopic level. OR attributes the difference to non-obvious and microscopic variables at the atomic level but does not recognize all of the multiple possible causes. Examples: "The difference is because of the crowdedness of particles or molecules in a given amount of space." Uses a dots-per-box model that shows different numbers of dots in a given space. "The difference is due to atomic mass." "The difference is due to the bonds" (using more than a crowdedness argument.) Says that the difference is due to mixed density and shows either atomic mass, OR bonds.	Attributes the difference to microscopic variables at the atomic and/or molecular levels (but does not recognize all of the multiple possible causes.) AND recognizes that these variables affect how much mass there is per unit of volume. OR attributes the difference to the three causes recognizing that all need not be in play but does not recognize that these variables affect how much mass there is per unit of volume. Examples: "The difference is due to atomic mass and this makes the amount of mass in a given amount of volume greater." "The difference in density could be caused by several things. First, it could be caused by the amount of empty space in between the molecules. Second, it could be caused by the atomic mass of the atoms. Finally, it could be caused by the strength of the bonds of the atoms. Or some of these things can work together."	Attributes the difference to non-obvious and microscopic variables at the atomic level AND recognizes the three possible causes, but that not all three are necessarily in play AND recognizes that these variables affect how much mass there is per unit of volume. Example: "The difference in density could be caused by several things. First, it could be caused by the amount of empty space in between the molecules. Second, it could be caused by the atomic mass of the atoms. It could also be caused by the strength of the bonds of the atoms. Or some of these things can work. AND that each of these impacts how much mass there is in a given amount of volume."
The best models at this level show…					
___ 2 objects. ___how the obvious features differ.	___ 2 objects. ___how the macroscopic features differ.	___ 2 objects. ___ volume as controlled for. ___that the mass differs.	___2 objects. ___ volume as controlled for. ___mass differing as a function of the particles. ___a given number of particles in a given amount of space. ___a microscope's view of atomic mass or atomic/ molecular bonds or mixed density.	___2 objects. ___volume as controlled for. ___a microscope's view of atomic mass or atomic/ molecular bonds or mixed density. ___a given number of particles in a given amount of space.	___2 objects. ___volume as controlled for. ___a microscope's view of atomic mass and atomic/ molecular bonds and mixed density. ___how the atomic and molecular variables account for a given amount of mass in a given amount of space.

Science Understandings That May be Revealed in Students' Response:		Misconceptions That May Be Revealed in Students' Responses:	
	Understands that the spaces in solids of the same substance are uniform (may express this by showing boxes of the same size with the same number of dots evenly spaced in them.		Thinks atoms in different objects or atoms in the same object can have very different sizes.
	Expresses an understanding of atomic mass.		Confuses mass, weight, and density.
	Expresses an understanding of atomic or molecular bonds.		Thinks that the spaces between particles can vary a lot.
	Understands that if you have two materials together, you have mixed density of the two materials.		Thinks that the spaces between the particles must have air in them (even though it won't always fit there.)
			Thinks of bonds as material or stuff rather than electrical attraction.
			Talks about particles "in" or "inside" the object, but does not see them as what constitutes the object.
			Confuses more dense and less dense/thinks that more packed means less dense and vice versa.

Quality of the Explanation/Models			
Level 1	Level 2	Level 3	Level 4
Restated the facts but did not offer an interpretation.	Used words to label the difference(s) but did not explain them.	Went beyond labeling what the difference(s) are but did not explain them in depth.	Explained what the differences are in depth.
It is difficult to understand most of the explanation.	It is difficult to understand some parts of the explanation.	It is possible to understand the basic ideas in the explanation.	It is easy to understand the explanation.
Did not answer most of the question.	Answered most of the question but without detail.	Answered without detail everything that the question asked or most of the question with detail.	Answered in detail everything that the question asked.
Didn't make any models.	Made models without labels.	Made detailed models without labels or sketchy models with labels.	Made detailed models and labeled all of the parts or included a key.

Question 2. A person drops an object into a liquid to see if it will float. Draw a model explaining the possible outcomes and WHY, in as much detail as possible, each outcome could happen. Then give a written explanation of what determines what will happen.

Assessment Aim: This question assesses whether students frame the problem in terms of the relationship between the density of the object and the density of the liquid—that the outcome is caused by a relationship. Most of students' experiences with sinking and floating are with objects in water. This typically leads to a focus on the object and the tendency to ignore the liquid. In essence, the liquid becomes a non-obvious variable. Attending to just the object results in a linear causal explanation, typically of the form, "the weight makes it sink." The question also reveals whether students think of the object in terms of the relationship between mass and volume. Some students also reveal understanding of the micro-causes of density—though this level of response is not expected here. Some students include all three possible outcomes, some forget to include suspension but if they understand relational density, it can be assumed that they can deduce this case.				
Content Understandings: Role of Density in Sinking and Floating				
Causal Understanding: Relational Causality				
Level 1	Level 2	Level 3	Level 4	Level 5
Gives a non-causal response. Examples: Repeats information in the problem, but does not explain what is going on. Lists things that float and things that sink.	Uses a simple linear model that focuses on the obvious variable—the object. Examples: "Weight (or mass) causes the outcome--heavy objects sink, light ones float." Uses density in a token way: "It happens because of density." Says that it is due to other attributes of the object: trapped air; shape; water soaking into the object, solid, non-solid, or hollow, type of material, air particles inside a material without explaining these in terms of the relationship between densities. Focuses on the density of the object or how packed the molecules of the object are.	Uses a simple linear model that focuses on the non-obvious variable—the liquid. Examples: Talks about a liquid being "thick" or having a lot of particles so that certain things may float on it. "The particles in the water hold it up." "Salt water makes things float."	Uses a relational causal model either without a focus on density (or the relationship (of mass to volume) OR limits it by using water as a standard and not extending it to other liquids. Examples: "If the object's density is greater than 1.0 g/ml, (the density of water) it sinks, and if it's less than 1.0g/ml, it floats." "If the liquid's (mass/volume/weight,/etc.) is greater than the object's, the object will sink or vice versa. "	Uses a relational causal model with a focus on density and/or in terms of the relationship (of mass to volume) that results in density Examples: "If the object is denser than the liquid, it will sink, and if it is less dense, it will float." "If the object has air in it, it may float because the density of the material plus the density of the air is often less dense than the density of the liquid." "If water soaks into the object, it changes its density and affects the relationship of the densities between the object and the liquid." "The mass to unit volume of the object compared to the mass to unit volume of the liquid causes the outcome."
The best models at this level show…				
	___all 3 possible outcomes, sinking, floating (or rising) and suspending. ___how some attribute of the object is responsible for the outcome. ___that variables such as the size of the container, height of the water, and the volume of the object are controlled for in each case.	___all 3 possible outcomes, sinking, floating (or rising) and suspending. ___how some attribute of the liquid is responsible for the outcome. ___ that variables such as the size of the container, height of the water, and the volume of the object are controlled for in each case.	__all 3 possible outcomes, sinking, floating (or rising) and suspending in relation to water. ___the relationship of the density of the water to the density of the object in some ways (dots-per-box models, particles, or atomic mass and/or atomic or molecular bonds, for instance. ___ that variables such as the size of the container, height of the water, and the volume of the object are controlled for in each case.	___all 3 possible outcomes, sinking, floating (or rising) and suspending. ___the relationship of the density of the liquid to the density of the object in some way(s) (dots-per-box models, particles, or atomic mass and/or atomic or molecular bonds, for instance). ___ that variables such as the size of the container, height of the water, and the volume of the object are controlled for in each case.

Science Understandings That May be Revealed in Students' Response:		Misconceptions That May Be Revealed in Students' Responses:	
	Understands that the spaces in solids are uniform (may express this by showing boxes of the same size with the same number of dots evenly spaced in them.)		Thinks particles in different object or particles in the same object can have very different sizes.
	Expresses an understanding of atomic mass.		Confuses mass, weight, and density.
	Expresses an understanding of atomic or molecular bonds.		Thinks that the spaces between particles can vary a lot.
	Understands that if you have two materials together, you have mixed density of the two materials.		Thinks that the spaces between the particles must have air in them (even though it won't always fit there.)
			Thinks of bonds as material or stuff rather than electrical attraction.
			Confuses density and viscosity
			Talks about particles "in" or "inside" the object or liquid, but does not see them as what constitutes the object or liquid.
			Confuses more dense and less dense/thinks that more packed means less dense and vice versa.

Quality of the Explanation/Models			
Level 1	Level 2	Level 3	Level 4
Restated the facts but did not offer an interpretation.	Used words to label the difference(s) but did not explain them.	Went beyond labeling what the difference(s) are but did not explain them in depth.	Explained what the differences are in depth.
It is difficult to understand most of the explanation.	It is difficult to understand some parts of the explanation.	It is possible to understand the basic ideas in the explanation.	It is easy to understand the explanation.
Did not answer most of the question.	Answered most of the question but without detail.	Answered without detail everything that the question asked or most of the question with detail.	Answered in detail everything that the question asked.
Didn't make any models.	Made models without labels.	Made detailed models without labels or sketchy models with labels.	Made detailed models and labeled all of the parts or included a key.

Question 3. A chunk of gold is heated, but not to the point where it gets soft or melts. Draw a model showing, in terms of density, the gold before it is heated and the gold once it is heated. Then write a written explanation of what happens and why.

Assessment Aim: This question whether students have a dynamic or static view of density and can translate what applying heat means for the expansion of the metal (increase in volume), the conservation of the mass, and the subsequent lowering of density. Because the question is asked in a open-ended way to allow for the students to frame their response, students may answer in other ways including conduction, melting/phase change, and so on. Some students may show what happens using a microscopic view and the micro-causes of density—though this level response is not expected.				
Content Understandings: Density is dynamic (despite the fact that there are given quantities for density under standard conditions of temperature and pressure.)				
Causal Understanding: Reasoning about Relational Causality in Dynamic Contexts				
Level 1	Level 2	Level 3	Level 4	Level 5
Gives a non-causal response or offers effects unrelated to density. Examples: Repeats information in the problem, but does not explain what is going on. "The gold will melt or will get hot."	Argues that density does not change. Examples: "Metals expand, but it will not affect the density because density is always the same." Says that the mass and volume must both change because the density cannot change. Discusses density as a property or standard and therefore it cannot change.	Argues that the density must change but does not frame it in terms of what happens to the three component variables. Example: Says that heating makes the density change but does not address the relationship between mass, volume or density at all.	Argues that the density must change but does not frame it in terms of what happens to all of the three component variables. Or states that the density changes *because* the relationships change, but does not elaborate on what this means. Examples: Says that the volume gets bigger so density must decrease, but doesn't explicitly address mass. "When you heat the gold, the relationship between mass and volume will change." (but doesn't say how.)	Uses a relational causal model with a focus on the dynamic or changing density. Includes all three of the component variables and explains what happens (mass is conserved, volume increases, and therefore density must decrease as a function of the change in the relationship between mass and volume. Example: "The mass will stay the same, the volume is greater, and so the density must be less." Shows how the particles must spread out in the available space given the increase in volume and conservation of mass.
The best models at this level show…				
	___before and after heating. ___what is going on to account for why density cannot change.	___before and after heating. ___that density changes (even if they do not discuss the relationship that accounts for it and do not detail what that means at this level.)	___before and after heating. ___that the relationship changes (even if they do not detail what that means at this level.)	___before and after heating. ___the relationship of the mass to the volume and the subsequent density in each of the two instances. In the "after" case, mass is shown as conserved, volume is shown to increase and density to decrease.

Science Understandings That May be Revealed in Students' Response:		Misconceptions That May Be Revealed in Students' Responses:	
	Understands that the atoms move faster when metals are heated.		Thinks that the particles in metals cannot move.
	Expresses an understanding of conservation of mass.		Confuses mass, weight, and density.
	Expresses an understanding of atomic mass.		Thinks that the spaces between particles can vary a lot.
	Expresses an understanding of atomic or molecular bonds.		Thinks that the spaces between the particles must have air in them (even though it won't always fit there.)
	Realizes that metals can expand.		Thinks of bonds as material or stuff rather than electrical attraction.
			Talks about particles "in" or "inside" the gold, but does not see them as what constitutes the gold.
			Thinks particles in different object or particles in the same object can have very different sizes.
			Thinks that metals cannot change phase.

Quality of the Explanation/Models			
Level 1	Level 2	Level 3	Level 4
Restated the facts but did not offer an interpretation.	Used words to label the difference(s) but did not explain them.	Went beyond labeling what the difference(s) are but did not explain them in depth.	Explained what the differences are in depth.
It is difficult to understand most of the explanation.	It is difficult to understand some parts of the explanation.	It is possible to understand the basic ideas in the explanation.	It is easy to understand the explanation.
Did not answer most of the question.	Answered most of the question but without detail.	Answered without detail everything that the question asked or most of the question with detail.	Answered in detail everything that the question asked.
Didn't make any models.	Made models without labels.	Made detailed models without labels or sketchy models with labels.	Made detailed models and labeled all of the parts or included a key.

Questions 4, 5, and 6: Thinks that cutting a solid object made of only one material in half results in…

Assessment Aim: This question considers whether students view density as an intensive quantity or not. Cutting an object in half result sin half the volume, half the mass but the same density. The question can also reveal confusions about the terms—not knowing what mass and volume are; thinking that more particles in less space means less dense (a common confusion, especially for students who interpret "density" as 'room" or "space"), etc. Some answer choices are the likely result of guessing or term confusions since they don't reflect how materials behave in a micro or macro-sense.

Content Understandings: Density is an intensive quantity.

Causal Understanding: Reasoning about Density as a Relational Concept

Level 1

Confusion about terms; Misread; or Guessed; No indication of understanding density as intensive quantity

Examples:

V	M	D
g	g	g
g	g	h
s	s	g
h	g	g
s	s	h
s	h	h
g	h	h

Level 2

Understands terms; Does not understand density as an intensive quantity

Examples:

V	M	D
h	h	h

Confusion about all or some terms; misread; guessing but with possible sense of density as an intensive quantity if also interpreting denser and less dense in the opposite sense of the term.

Examples:

V	M	D
s	s	g
h	h	g

Level 3

Confusion about terms; misread; guessing but with possible sense of density as an intensive quantity

Examples:

V	M	D
g	g	s
g	s	s
s	s	s
h	s	s

Level 4

Understands terms and understands density as an intensive quantity

Volume will be half; mass will be half, and density will be the same.