Challenges in Assessing the Dynamics of Change & Coherence of Physical Science Knowledge in the Context of Model-Based Inquiry

Modeling in Primary Grades (MPG): Science Learning through Content Rich Inquiry

(Award # 1222853)

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MPG (Year 1)

- **Second grade students** taught by their regular teachers in rural, public school (34 students, 19 males, 18 females, 49% Free/Reduced Lunch)

- **Learn about particulate nature of matter** through model-based inquiry instruction

- Adapted FOSS investigations: Matter (2nd & 3rd grade) & Sound (3rd grade) to help students construct particulate models for:
  - **States** (phases) of matter: Solid, liquid, gas
  - **Phase changes**:
    - Melting (solid to liquid)
    - Freezing (liquid to solid)
    - Evaporation (liquid to gas)
    - Condensation (gas to liquid)
  - **Propagation of sound** through a medium

Instructional Context: Year 1

- **Focus on Matter Unit**
- **Two teachers:** Mrs. Hogart and Mrs. James (each taught 10+ years)
  - Received MPG PD: Scaffold discourse centered on model-based inquiry
  - Three lessons (each implemented over multiple days): Selected inquiry activities from FOSS investigations (UC Regents, 2005), complemented by modeling activities developed by the MPG team
  - Taught lessons over 3 weeks in spring (3 sessions/week; 80-100 minutes/session)
  - MPG research team members served as classroom assistants

Theoretical Framework

- **Domain-Specific Perspective:** Each conceptual domain of learning is characterized by distinct concepts, reasoning processes and activity patterns (Carey & Spelke, 1994; Gelman, & Brenneman, 2004)
- **Science** (both the formal discipline and school science) is **socially negotiated** (Boyd & Richerson, 2005; Knorr-Cetina, 1999; Laudan, 1990; Rogoff, 1990; Roth, 2005)
- **Modeling is a core scientific practice** (Del Re, 2000; Francouer, 1997; Giere, 1998, 2004)
  - Models are (idealized) analogs of phenomena that select and organize salient features of the world, fulfill descriptive, explanatory, and communication functions, and are used to make the "invisible" visible (Gilbert, 1991; Nersessian, 2008)
- **Science education research** and *Next Generation Science Standards:* important to help students understand scientific modeling (Gobert, 2000; Justi & Gilbert, 2002; NGSS Lead States, 2013)

Why Matter?

- **Daily interactions** with material phenomena at macroscopic level
- Students hold **non-normative ideas throughout formal schooling** (Porzo & Gomez Crespo, 2005; Stavy, 1990)
  - **Elementary**: Matter is continuous; Objects' smallest particles possess macroscopic properties (color, texture, taste) and are visible to the naked eye (Nakhleh & Samarapungavan, 1999; Smith, Carey, & Wiser, 1985)
  - **Adolescents**: Not all matter contains atoms and molecules; atoms and molecules are embedded in substances (Andersson, 1990; Lee et al., 1993; Nakhleh, Samarapungavan, & Saglam, 2005)

Why Matter?

- **Entry Points for Instruction**:
  - Children ages 3-7 believe that tiny particles of sugar or salt exist in aqueous solutions even though they are too small to be visible to the naked eye, and these particles affect properties of solutions, such as taste or drinkability (Au et al., 1993; Rosen & Rozin, 1993).
  - Second graders in informal museum-learning programs show understanding of microscopic material entities that can be studied indirectly (Macdonald & Bean, 2011).
  - Wiser & Smith (2008): Introduce matter instruction in elementary
- **Current elementary curricula (FOSS, STC) focus on macroscopic properties**

Overview of MPG Lessons

Lesson 1 Objectives

- Categorize common substances into three states of matter (solids, liquids, gases)
- Understand macroscopic properties of each state (e.g., solids have a definite shape)

Lesson 1 Description (adapted from FOSS – Measuring Matter, Investigation 2)

- Whole class: students discuss what state of matter to assign to exemplars of a solid, liquid, and gas (rock, water, and air) and explain reasoning.
- Small groups work at tables to sort a variety of materials (e.g., pencil, wire, cloth, sand, liquid food color, syrup, an air bubble) into states of matter. Each child records, justifies sorts in science notebook.
- Whole class discussion: groups compare and explain their categories, discuss substances that they could not agree on.
- Scavenger hunt: Small groups find examples of solid, liquid & gas in classroom & create chart.

Overview of MPG Lessons

Lesson 2 Objectives

- Describe matter as composed of tiny particles, too small to see with the naked eye
- Create models to show how differences in the arrangement and movement of invisible particles gives rise to the visible properties of matter at the macroscopic level

Lesson 2 Description (adapted from FOSS – Solids & Liquids, Investigation 2).

- Whole class: Teachers introduce idea use of models to represent things that have extreme sizes (e.g., solar system, cells, germs).
- Students discuss breaking down *visible* matter into smaller bits and pieces (e.g., grains of salt, drops of water, a log of wood and sawdust) and imagine/model invisible *particulate* composition of matter - what the smallest possible particles of matter, too small to see with our eyes, might look like.
- The teacher tapes off open "jar," calls upon small group enter jar and model of a solid, liquid, or gas sorted from Lesson 1. Each child represents one of the smallest possible particles of the object they were modeling. Other students watch and critique.
- Individual work: Students create their own models of solid, liquid, and gas, using drawings and works in science notebook

Overview of MPG Lessons

Lesson 3 Objectives

- Model phase changes of mater as changes in the arrangement and movement of its particles when heat is added or lost from a substance.

Lesson 3 Description (adapted from FOSS –Measuring Matter, Investigation 3).

- Working in small groups, students predict, observe, and record what happens when heat is added to or removed from various exemplars solids, liquids, and gases.
- Example of investigative sequence (solids melt to liquids):
  - Measured water temperature of cup of heated water
  - Predict what will happen to solids (e.g., candle wax, chocolate chip) when plastic cup containing these solids is dipped in the hot water. T
  - Observe and record observations in science notebooks.
  - Whole class discussion of what happens to particles of solid matter (wax, chocolate chip) as heat is added?
  - As in Lesson 2, students engage in constructing human models in small groups
  - Students returned to record their own models in their science notebooks.

Guiding Questions

1. How do 2nd graders' models of matter change over the course of MPG instruction?
2. As a result of MPG instruction do students use particulate models more coherently to explain varied material phenomena?

Challenges

How to aggregate data on the dynamics of change in student models over time?

How to "trace" pathways of learning?

Data Sources

- ***MPG Matter Pre and Post Interviews:*** 4 sets of questions
  - Macroscopic material properties
  - States of Mater (SOM): Five free response question sequences in which children were shown a picture of matter in a solid, liquid, or gas state and asked to explain its composition and behavior in terms of its smallest possible divisible pieces
  - Phase Changes (PC): Two free response sequences and two forced choice items examined models of particulate changes during phase transitions from one state of matter to another when heat is added or lost
  - Models of sound propagating in a medium

Data Sources

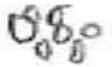
- ***Emergent Models of Matter (EMM)***
  - Models students created individually during inquiry after reflecting on investigations
  - Digital copies of students' science notebook entries analyzed
  - Transcripts of videotaped classroom inquiry discourse used to clarify the representational intent of students' drawings and notations. The coding scheme from the *MPG Matter Interviews* was adapted for EMM data

SOM-Liquid: Coding Categories and Sample Responses

a. Describe the water/milk in this glass. What is it made up of? b. Is it made up of little pieces or is it one big thing? (If child says it is made of pieces / drops etc., ask c through e) c. Think of the smallest possible pieces that water is made of. What shape are they? Can you draw them for me? d. Can we see the smallest possible pieces that water is made of with our eyes? e. Think about each smallest possible piece that water is made of. Does it take up space?

5. Advanced Particulate

Emily: a. (Milk) is a liquid. It comes from cows. b. Teensy particles. c. Round. d. No, not without a microscope. e. (Nods) Because it's matter.



4. Initial Particulate

Pierre: a. (Milk) is a liquid. Little droplets of milk. b. Little pieces. c. (see drawing). d. No, they are tiny. e. No, not really.

3. Macroscopic Pieces

Shelly: a. (Water) is clear. You can put your hands through it. b. It can form from little drops. c. It can be puddles or drops of any shape. d. Yes.

2. Continuous Substance

Casey: a. (Milk) is white. We can drink it. I don't know what it is made of. b. It is just one big thing.

1. Mixed / Unclear

Dev: a. (Water) 1% bacteria, gas. b. One thing and pieces. (No Response on c., d., e.)

PC: Water Evaporating (Free Response)

a. This is steam from the kettle. What is steam made of? b. Is steam in the same state or phase of matter as water? (If child says steam comes from water ask c through e) c. Why does the water look like this when it becomes steam? d. Does the amount water in the kettle change or remain the same when water becomes steam? (If child say the amount changes on d ask e) e. How does it change/ what makes it change?

5. Advanced Particulate

Robbie: a. Evaporating particles. The water particles get heated and move around quickly. b. Steam is a gas, water is a liquid. c. The heat is making the water go up into steam. d. It changes. The little tiny circles of water jump out of the kettle and the water goes down.

4. Initial Particulate

Melanie: a. It's made of little teeny bits of gas that are too small to see. b. Steam is not the same 'cause water is liquid. c. It is evaporating. d. It changes. There's less in it. e. To go from water to steam it has to be hot.

3. Macroscopic Pieces

Riley: a. It is made from water. b. Steam is different. Gas. Water is not. c. When you heat it the water breaks up into bits of gas, into little clouds of gas that we see. d. Less. It is boiling away. Because the heat is breaking water up into air.

2. Continuous Substance

Casey: a. Steam is made from gas. b. It is different. c. Because it's steam and stem is different from water. d. Changes a little.

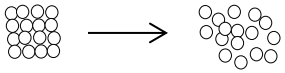
1. Mixed / Unclear

Bill: a. It's made of water. b. Steam is water. c. Heat under stove makes it. d. Same.

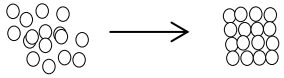
PC: Solid to Liquid (Forced Choice)

Which of these is the best model of what happens to the particles of matter in a solid when the solid melts?

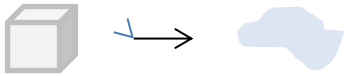
5. Advanced Particulate



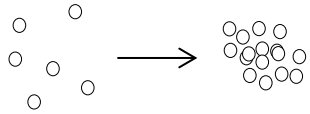
4. Initial Particulate



3. Macroscopic Pieces



2. Continuous Substance



1. Mixed / Unclear *(selects more than one option)*

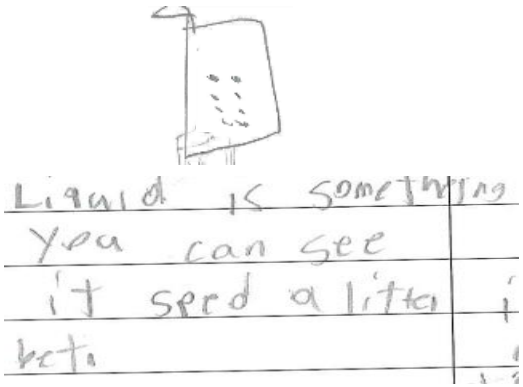
EMM Coding: Examples

States of Matter - Liquid

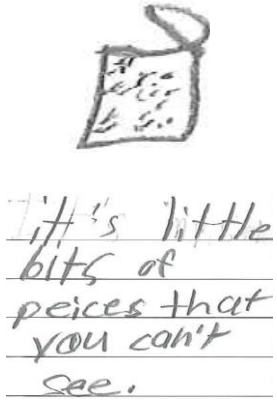
1. Mixed

2. Continuous

3. Macroscopic Pieces

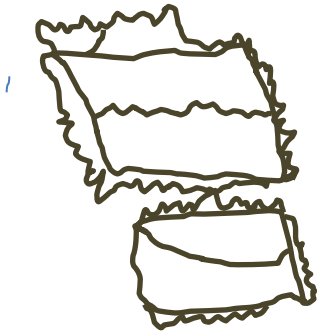


4. Particulate

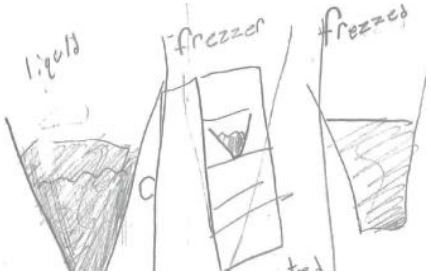


Phase Changes – Liquid Freezing to Solid

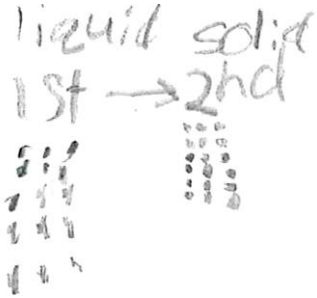
1. Mixed



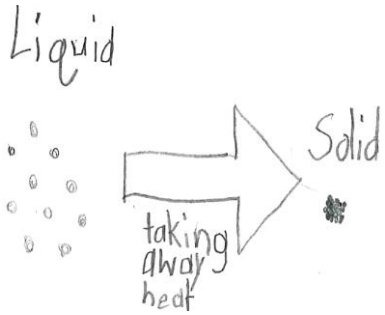
2. Continuous

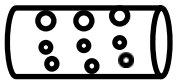


3. Mixed Macroscopic



4. Particulate



Cory SOM	Wood-Pre	Wood -Post	Solid-EMM
a. Describe the smallest possible particles of wood. Draw them for me. b. Can we see them with our eyes?	 a) Like little specks of dust if you cut it b) (Nods) Kinda hard to see each one but if you put them in a big pile of sawdust …	 a) Circle thingies, You can't really see them without a microscope - the log is made up of them … b) No – that's why I made the model	 little pcs of particles that are solid

3. Macroscopic Pieces	5. Advanced Particulate	4. Particulate

Cory SOM	Air-Pre	Air-Post	Gas-EMM
a. Describe the air in the balloon. What is it made up of? b. Is it made up of little pieces or is it one big thing? (If child says it is made of pieces/ drops etc., ask c through e) c. Think of the smallest possible pieces that air is made of. What shape are they? Can you draw them for me? d. Can we see the smallest possible pieces that air is made of with our eyes? e. (If pieces) Think about each of the smallest possible pieces that air is made of. Does each of these pieces take up space?	a. Air. b. One big thing.	a. Little gas particles b. NA c. Round. d.  d. No, it's too little e. Not really. Each of them doesn't need space, only all together.	 
	2. Continuous Substance	**4. Initial Particulate**	**4. Particulate**

Willa PC	Steam-Pre	Steam-Post	Evaporation-EMM
a. This is steam from the kettle. What is steam made of? b. (if water) Is steam in the same state or phase of matter as water? (If child says steam comes from water ask c through e) c. Why does the water look like this when it becomes steam? d. Does the amount water in the kettle change or remain the same when water becomes steam? (If child say the amount changes on d ask e) e. How does it change/ what makes it change?	a. Steam is hot water and hot air. b. Little puffy things. c. It evaporates into tiny pieces of cloud that you can't see. d. Less. e. Steam comes out. It evaporates.	a. Steam is made from water b. Same. c. The heat under the stove makes it evaporate. d. It's the same	
	5. Initial Particulate?	**1. Mixed**	**1. Mixed**

Coding Coherence: Challenges

Coherence Scores by Conceptual Category (SOM and PC)

6. Particulate: Consistent *Initial/Advanced Particulate* responses

5. Mixed Particulate: Combines *Initial/Advanced Particulate* responses with *Continuous* or *Macroscopic Pieces* responses

4. Macroscopic Pieces: Consistently responds that matter is made of or can be broken into smaller pieces that can be seen, felt, etc.

3. Mixed Macroscopic: Combines *Continuous* and *Macroscopic Pieces* responses

2. Continuous: Describes matter as a continuous visible substance with inherent properties / behaviors

1. Unclear: Majority of item level questions not answered or coded as mixed

Cory	SOM Wood	SOM Sand	SOM Milk	SOM Gas1	SOM-Gas2	PC Evap1	PC Evap2	PC Melt1	PC Melt2	SOM COH	PC COH
Pre	3	3	3	2	0	2	4	2	2	3	5?
Post	5	5	5	4	4	5	3	5	4	6	6

EMM	S 4	L 4	G 4

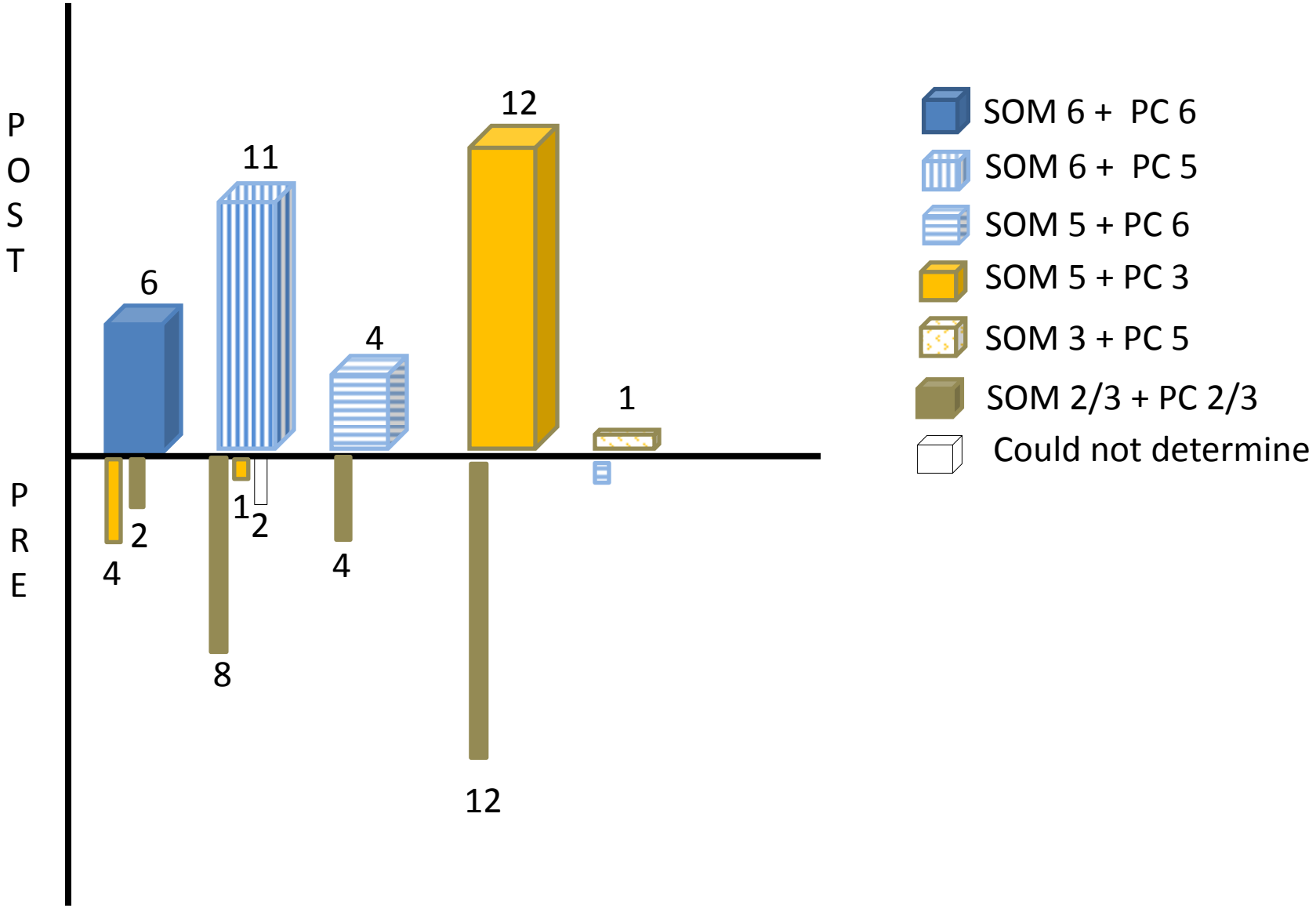
Ev 0	Fr 4	M 4	Co 1

Willa	SOM Wood	SOM Sand	SOM Milk	SOM Gas1	SOM-Gas2	PC Evap1	PC Evap2	PC Melt1	PC Melt2	SOM COH	PC COH
Pre	5	3	5	5	3	4	4	4	3	5?	6
Post	0	3	2	2	3	1	5	5	5	3	5?

EMM	S 4	L 0	G 0

Ev 1	Fr 5	M 5	Co 2

Graphic Mapping



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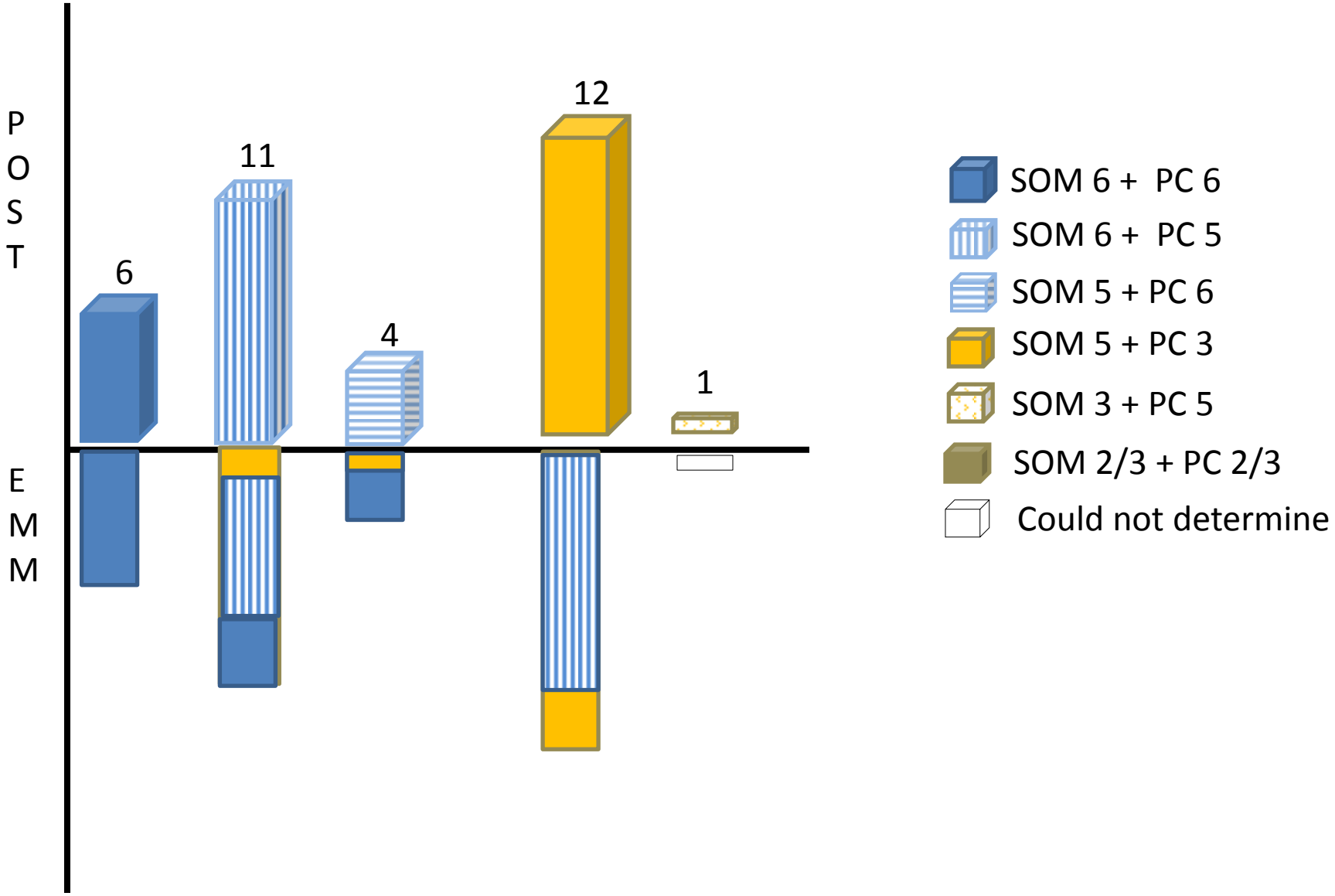

Graphic Mapping