We analyzed Year 2 Science Notebook data for only IN schools and Year 3 MM-K Pre and Post Interview data for both IN and MA to address the following research questions:

Q1. How do kindergarten students' concepts of matter change as they engage in S2M2 instruction?

Q2. Are different digital simulation tools associated with differences in students' learning of particle models?

Q3. Do students' particle models cohere as they explain varied macroscopic phenomena?

1. Analyzing Classroom Learning in Situ: Year 2 Emergent Models of Matter (EMM)

To address our first research question (see Q1 above), **we completed mixed methods analyses of Year 2 students Emerging Models of Matter (EMM) from the following Year 2 Site 1 data sources:** (a) the artifacts such as drawings or other model inscriptions that students created and recorded in their science notebooks during inquiry; and (b) video-recordings of relevant science lessons, used to contextualize and clarify science notebook entries. The methods for collecting, digitizing, and coding artifacts were adapted from prior research.

Qualitative analyses: To initially explore and inductively derive patterns of change across students' science notebook model inscriptions, we used qualitative interpretive techniques. These analyses suggest that **as students progressed through the investigations, their predicted models for SOM and PC were increasingly influenced by their previous Thermoscope investigations of particulate models.** This pattern is evident in the sequence of Seth's science notebook models (see Figures 1 and 2 in attached file, Year3_Results_Tables_Figs.pdf). Seth's predicted model for oil was macroscopic continuous; after the Thermoscope observation, he constructed a microscopic particle model for the oil (Figure 1). Later, he predicted a microscopic particle model for dish soap and mentioned that his prediction for dish soap was based on his earlier Thermoscope observation of oil. Like Seth, **many students spontaneously generalized particle models among exemplars within a state (e.g. from oil to dish soap for liquids) rather than across states (e.g., from dish soap to wood).** For example, in the following investigation of solids, Seth's initial prediction for wood was again macroscopic, but after changing to a particle model of wood following his Thermoscope investigation, Seth spontaneously predicted a particle model for the next exemplar of solid, the rock (see Figure 1).

Quantitative Analyses

Subsequently, all data were coded using cognitive science bootstrapping techniques of iterative "top-down" and "bottom-up" analysis. The initial coding scheme, based on prior published empirical and theoretical work was iteratively refined through inductive coding of the current data. The coding consisted of two tiers: (1) component coding and (2) coherence coding. In the first tier component coding, students' models for each exemplar/phenomenon were coded for the following components: (a) composition (e.g., composite whole, macroscopic pieces or microscopic particles, and if applicable, (b) behavior of pieces/particles (e.g. whether or not they move), (c) type and speed of particle movement, (d) arrangement or pieces/particles in space, if applicable (e.g., regular and lattice like or irregular), and distance between particles (e.g., touching, close together, or far apart). After completing component coding, we coded for the overall quality and consistency of particle models across each material phenomenon by assigning a coherence score based on the decision rules summarized in the Year 2 Science Notebook Codebook (see attached file, Y2 Student Notebook Codebook_V3.pdf). Examples of responses for Science Notebook Coherence codes are provided in Table 1 (see file, Year3_Results_Tables_Figs.pdf).

EMM Models Heat Map. We created a heat map (see Figure 3 in file, Year3_Results_Tables_Figs.pdf) to represent the changes across individual students' models from prediction and observation. Each cell in the map represents a model created by a single child on a particular component activity. Each row represents all models created by a single child in sequence, while each column represents all models created by the set of students for a particular component activity. As can be seen in from the heat map data in Figure 1, **a majority of the Year 2 – Site 1 students were able to construct particle-based model representations** (see color key for Figure 3) for at least some SOM and PC phenomena. Further, the distribution of SOM models in the heat map suggests a sequential shift with the frequency of macroscopic models (shown in yellow) decreasing and the frequency of microscopic particle models (shown in blue) increasing as students worked through more exemplars of matter. A similar pattern appears to hold for PC models although relative to the SOM models, a greater proportion of the PC models remained macroscopic. In particular, there appears to be a greater frequency of macroscopic (yellow) or unclear (white) models on the PC prediction activities suggesting that children are starting at a lower level in their understanding of phase change phenomena. It should be noted that one of the two teachers ran out of time to complete the last phase change investigation of condensation and her students did not have a chance to create models for condensation. Therefore, we had to code these students' condensation models (see last column of heat map) as undetermined/no response (shown in white).

Chi Square analysis of distribution of students' models. We conducted a series of chi square analyses to compare: a) distributions of prediction versus observation models within SOM and PC models respectively, and b) distributions of all SOM versus all PC models. **There were statistically significant differences in prediction versus observation models for both SOM [$X2(4, N = 390) = 42.59, p < .01$] and PC [$X2(4, N = 312) = 61.764, p < .01$].** As can be seen from Table 2, the percentage of microscopic particle models increased from 58% of SOM prediction models to 79% of SOM observation models while the proportion of macroscopic models decreased from 18% of SOM prediction models to 4% of SOM observation models. The percentage of microscopic particle models increased from 5% of PC prediction models to 43% of PC observation models while the proportion of macroscopic models decreased from 37% of PC prediction models to 17% of PC observation models. These results, along with our qualitative findings described above, indicate that the Thermoscope simulations served as a powerful context for supporting young students' construction of particle models.
There were also statistically significant differences in the overall distribution of SOM and PC models [$X2(4, N = 678) = 135.144, p < .01$]. Overall, 20% of all SOM models were macroscopic models or mixed models while 54% of all PC models were macroscopic or mixed models. **Together, these data indicate that phase change phenomena were harder for the students to model at the particulate level.** In

future analyses, we will qualitatively examine lesson video data to try and further understand the reasons for differences in patterns of student performance. Our findings suggest that students can make sense of and apply simple particle models to describe material phenomena.

2. Changes in Student Models over S2M2 Year 3 Instruction

Participants

Demographic data is provided in Tables 3 and 4. In School 1 (a public school in a small midwestern city), three public kindergarten teachers and their students (n=56) implemented the Technology 1 version of the S2M2 Curriculum which included a new digital simulation tool - the Particle Modeler. School 2 and School 3, (public schools in a large northeastern metropolitan area) participants (n=83) included four kindergarten teachers and their students (see Tables 1 and 2). Two of these teachers (Teacher 4 and 7) also implemented the Technology 1 version of the S2M2 Curriculum. Teacher 5 and Teacher 6 implemented the Technology 2 version of the S2M2 Curriculum, which included a new digital simulation tool called the Thermonator. All classrooms also used a digital tool called the Thermoscope.

Measures – MMK. In order to address our three research questions (see above), we collected and analyzed data from a semi-structured Models of Matter-Kindergarten (MMK) interview assessment which was administered before and after the completion of Year 3 S2M2 project lessons. The key features of the MMK were described in our prior (Year 2) annual report. The administration procedures and question protocol are provided in the MMK Year 3 Examiner Booklet (see file, MM-K Y3 ExaminerBooklet.pdf)

Coding and Analysis of MMK Data

Cognitive science bootstrapping techniques for the analysis of verbal protocol data were used to code students' responses to interview questions. These bootstrapping procedures represent a combination of "top down" theoretically derived coding, combined with "bottom up" or inductive coding modifications based on an analysis of the data. We developed a two-tier coding scheme for the interview data. The initial or *item level* coding focused on students' responses to individual question sequences. For purposes of item level coding, the response unit was defined as a student's complete set of answers to each question sequence. Because there were multiple item sequences for each SOM (Solid – Clay, Liquid-Syrup, Gas-Air) and PC phenomenon (Evaporation, Melting Freezing, Condensing), after item level coding was completed, a coherence analysis was conducted to examine the degree of consistency in students' use of particle models across question sequences for each SOM and PC phenomenon. *Coherence codes* were assigned to differentiate students based on their consistency in using particle models within each SOM and PC question set respectively. Details of the coding rubrics are provided in the Year 3 MMK Codebook (see file Yr3 Codebook MMK.pdf).

Item level coding. Initial codes for each question sequence were developed based on a theoretical analysis of the literature on students' developing knowledge of the nature of matter. This initial coding scheme was used to code responses from a randomly selected subset of 15 students and then modified to accommodate new response types that emerged from the data. For all item sequences, a response code of zero was assigned if students did not respond or said they did not know the answer to a question.

MMK Total scores were obtained by summing item level scores across all questions.

MMK Component scores were obtained by summing item level scores for each conceptual component as follows: **Materiality** Q1 + Q2; **States of Matter (SOM):** Q3A-F + Q4A-F + Q5A-F; Phase Changes (PC): Q6 + Q7A-B + Q8A-B

Reliability of coding: Inter-rater agreement was computed separately for item level coding and coherence coding on MMK responses 20 randomly selected students (10 MMK Pre Interview and 10 MMK Post Interview). Item level inter-rater agreement was .91 and coherence coding inter-rater agreement was .94. Disagreements were resolved through discussion

Statistical Analyses. Descriptive statistics (Mean and Sd) are provided for the whole sample (Table 5), by Technology type (Table 6) and Teacher (Table 7). ANOVA were conducted to examine if there were differences by Technology and Teacher on the Pre MMK Total scores. There were no statistically significant differences on Pre MMK Total scores by Technology, indicating that the two technology groups were equivalent in their initial knowledge of matter. We found small (η_p^2=.19) statistically significant differences on students' Pre MMK Total scores by Teacher (F (5,132) = 6.178, p<.01,). However, Repeated ANOVA showed no significant interaction effects of teacher on gains from Pre to Post MMK total scores. Means and standard deviations for Pre and Post MMK Total scores by teacher are provided in Table 3. After we had determined that the two Technology groups were equivalent with regard to their initial knowledge of matter, we ran repeated measures analyses of variance to better understand whether and how students' knowledge of matter changed over time.

Results

Q1. Do kindergarten students' concepts of matter change as they engage in S2M2 instruction?

The **analyses of MM-K Pre and Post Interview Total scores indicate significant gains in S2M2 students' ability to understand and use simple particle models to explain material phenomena** both in terms of MMK Total scores (F (1,137) = 237.97, p<.01, η_p^2=.64) and on each of the component scores: Materiality, States of Mater (SOM) and Phase Changes (PC). Repeated measures ANOVA showed that there was a statistically significant difference in Pre-and Post MPG Matter Interview Total Scores.

Q2. Are different digital simulation tools associated with differences in students' learning of particle models?

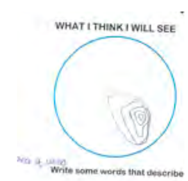
There was also a small but statistically significant effect for Technology (F (1,134) = 7.65, p<.01, η_p^2=.05). **Students who used the Thermonator tool had higher MMK Total scores and component scores than those who used the Particle Modeler tool** (see Table 4).

Q3. Do students' particle models cohere as they explain varied macroscopic phenomena?

MMK Models Heat Map. Using the same overall procedure as described for Year 2 EMM models above, we constructed heatmaps to provide a visual representation of changes in coherence of students' models from pre and post MMK data (see Figure 4) by geographic site. The two darkest colors represent the most coherent particle models (see key, Figure 4). **Students at both sides showed a shift towards more coherent particle model use for both SOM and PC phenomena, although the heat maps indicate a more pronounced shift on PC phenomena for Site 2 students.**

Coding of Year 3 EMM measures is currently in progress and will be completed by December 2018.

Table 1. *Examples of Coherence Codes for SOM/PC Models*

Code	**Science Notebook Drawing**
0. Undetermined/ no response. *Example:* during investigations of liquids, Mario did not have an entry under predicted or observed models for oil and drew the following model for dish soap:	
1. Draws/described matter as a continuous composite whole. *Example:* Josie made the following predicted model for wood and told the teacher that her observation model was “a piece of wood.”	
2. Macroscopic pieces: Child draws matter as comprised macroscopic pieces. *Example:* Ned described his predicted model of wood as pieces of wood that are joined together.	
3. Mixed microscopic and macroscopic: Child models matters as a composite whole with some microscopic particles embedded in or broken off from the whole. Descriptions of behavior arrangement and motion are mixed. *Example:* Brandon constructed a mixed model of evaporation showing water in its initial liquid state as made up of particles becoming a gas (represented as wavy lines)	
4. Microscopic incorrect: Child describes matter as comprised of microscopic particles but indicates incorrect behavior, arrangement, or motion of particles for the target state or phase transition. *Example:* Melanie describes her model of evaporation by saying that the water will get some steam as it gets hotter and the particles that remain in the water will vibrate.	

5. Microscopic correct: Child describes matter as comprised of microscopic particles with correct behavior *Example*. Alyssa's observed model of rock shows microscopic particle moving slowly, in a wobbly, jiggly, motion.	

Table 2. *Distribution of Year 2 (Site 1) EMM Models*

Model	States of Matter				Phase Changes			
	Prediction		Observation		Prediction		Observation	
	Fr	%	Fr	%.	Fr	%	Fr	%.
5. Microscopic Correct	16	8	50	26	0	0	4	3
4. Microscopic Incorrect	97	50	103	53	8	5	62	40
3. Mixed Microscopic and Macroscopic	21	11	7	4	50	32	34	22
2. Macroscopic Pieces	1	0	0	0	0	0	0	0
1. Macroscopic Continuous	35	18	8	4	58	37	27	17
0. Undetermined/ No Response	25	13	27	14	40	26	29	19

Note. Percentages are rounded to the nearest whole number and may not add to 100%.

Table 3. *Participant Demographics: Gender*

		Male		Female		
Site	Teacher	Fr	%	Fr	%	N
School 1	1	13	65.0%	7	35.0%	20
School 1	2	8	53.3%	7	46.7%	15
School 1	3	8	38.1%	13	61.9%	21
Site 1	Total	29	51.8%	27	48.2%	56
School 2	4	12	66.7%	6	33.3%	18
School 2	5	14	60.9%	9	39.1%	23
School 3	6	12	57.1%	9	42.9%	21
School 3	7	9	42.9%	12	57.1%	21
Site 2	Total	47	56.6%	36	43.4%	83
					Total N	139

Table 4. Participant Demographics: Race/Ethnicity

		White		African American/ African		LatinX		Asian		More than one race identified		
Site	Teacher	Fr	%	Fr	%	Fr	%	Fr	%	Fr	%	N
School 1	1	20	100%	-	-	-	-	-	-	-	-	20
School 1	2	15	100%	-	-	-	-	-	-	-	-	15
School 1	3	19	90.5%	1	4.8%	1	4.8%	-	-	-	-	21
Site 1	Total	54	96.4%	1	1.8%	1	1.8%		-	-	-	-
School 2	4	14	77.8%	-	-	-	-	4	22.2%	-	-	18
School 2	5	16	69.6%	1	4.3%	-	-	6	26.1%	-	-	23
School 3	6	2	9.5%	13	61.9%	2	9.5%	3	14.3%	1	4.8%	21
School 3	7	1	5.0%	14	70.0%	-	-	5	25.0%	0		20
Site 2	Total	33	40.2%	28	34.1%	2	2.4%	18	22.0%	1	1.2%	82

Table 5. *Descriptive statistics MMK Pre and Post Interview Total and Component Scores*

	Minimum	Maximum	Mean	Sd	N
Pre MMK Total	12	150	43.47	12.93	139
Post MMK Total	12	150	79.05	24.53	139
Pre Materiality	2	15	5.59	2.16	139
Post Materiality	2	15	8.43	2.86	139
Pre SOM	3	96	20.97	9.91	139
Post SOM	3	96	46.79	19.40	139
Pre PC	7	39	16.92	4.84	139
Post PC	7	39	23.83	7.44	139

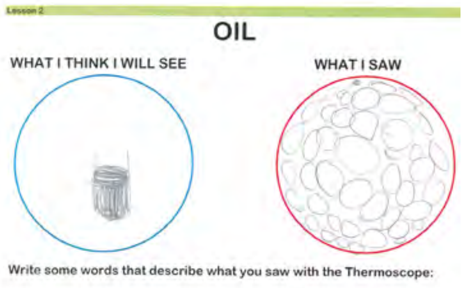
Table 6. *Descriptive statistics MMK Pre and Post Interview Total and Component Scores by Technology*

Scores	Technology	Mean	Sd	N
Pre MMK Total Score	Particle Modeler	42.034	12.89	95
	Thermonator	46.59	12.60	44
Post MMK Total Score	Particle Modeler	75.92	25.81	95
	Thermonator	85.79	20.16	44
Pre Materiality	Particle Modeler	5.13	1.91	95
	Thermonator	6.59	2.34	44
Post Materiality	Particle Modeler	8.15	3.03	95
	Thermonator	9.05	2.37	44
Pre SOM	Particle Modeler	19.88	9.65	95
	Thermonator	23.32	10.18	44
Post SOM	Particle Modeler	45.34	19.95	95
	Thermonator	49.93	18.00	44
Pre PC	Particle Modeler	17.03	5.24	95
	Thermonator	16.68	3.88	44
Post PC	Particle Modeler	22.44	8.20	95
	Thermonator	26.82	4.17	44

Table 7
Descriptive statistics MMK Pre and Post Interview Total Scores by Teacher

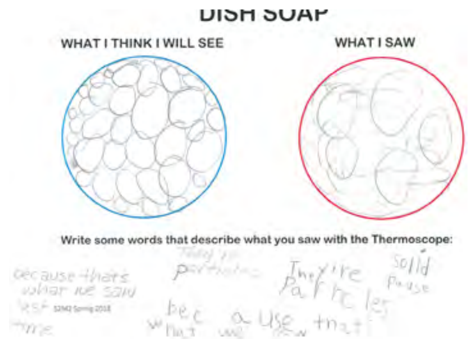
	Teacher	Mean	Sd	N
Pre MMK Total	1	34.60	9.265	20
	2	44.62	11.60	15
	3	49.62	16.27	21
	4	46.11	11.51	18
	5	50.74	13.17	23
	6	42.05	10.45	21
	7	36.19	7.55	21
Post MMK Total	1	68.85	26.75	20
	2	71.93	22.96	15
	3	71.57	24.24	21
	4	92.17	22.89	18
	5	83.96	18.99	23
	6	87.81	21.66	21
	7	75.95	27.06	21

States of Matter (liquid)



A. Seth's predicted and observed models of oil.

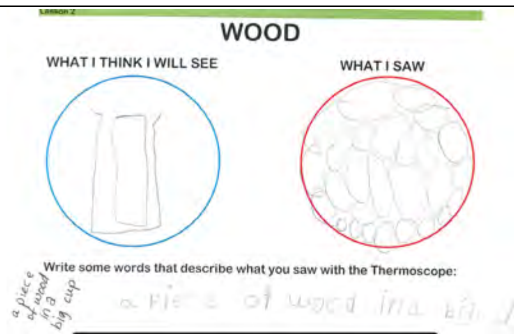
Note. Seth's prediction for oil reflects a macroscopic representation of oil as a composite whole. After the Thermoscope observation, he represents oils as composed of particles



B. **Seth's predicted and observed models of dish soap**.

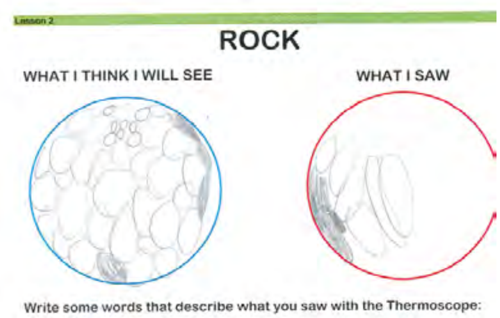
Note. Seth's prediction indicates that dish soap is composed of particles. He explains this prediction by saying, "that's what I saw" (in the oil earlier).

States of Matter (solid)



C. Seth's predicted and observed models of wood.

Note. Although Seth had spontaneously predicted that dish soap was comprised of microscopic particles, he did not generalize this prediction to wood, which he initially represented as a macroscopic whole. After the Thermoscope observation, he changed his representation of wood to a particle model.

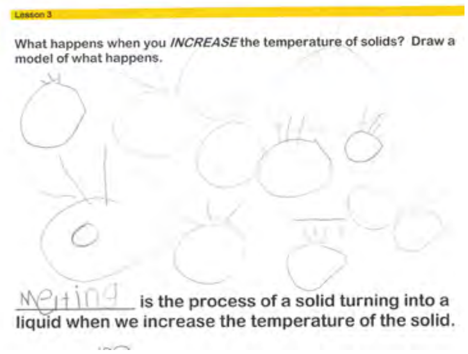


D. Seth's predicted and observed models of rock.

Note. Following the Thermoscope exploration of wood, Seth spontaneously generalizes a particle model in his prediction about the composition of rock.

Figure 1. Excerpts of Seth's predicted and observed models for States of Matter (SOM)

Phase Change (melting)



E. Seth's observed model of melting

Note. After the Thermoscope investigation of ice melting, Seth draws the model showing liquid particles start to move faster.

Phase Change (evaporation)

F. Seth's observed model of evaporation

Note. After the Thermoscope investigation of water evaporating, Seth draws the model showing that water changes into the gas after heating and the particles start moving.

Figure 2. Excerpts of Seth's predicted and observed models for Phase Changes (PC).

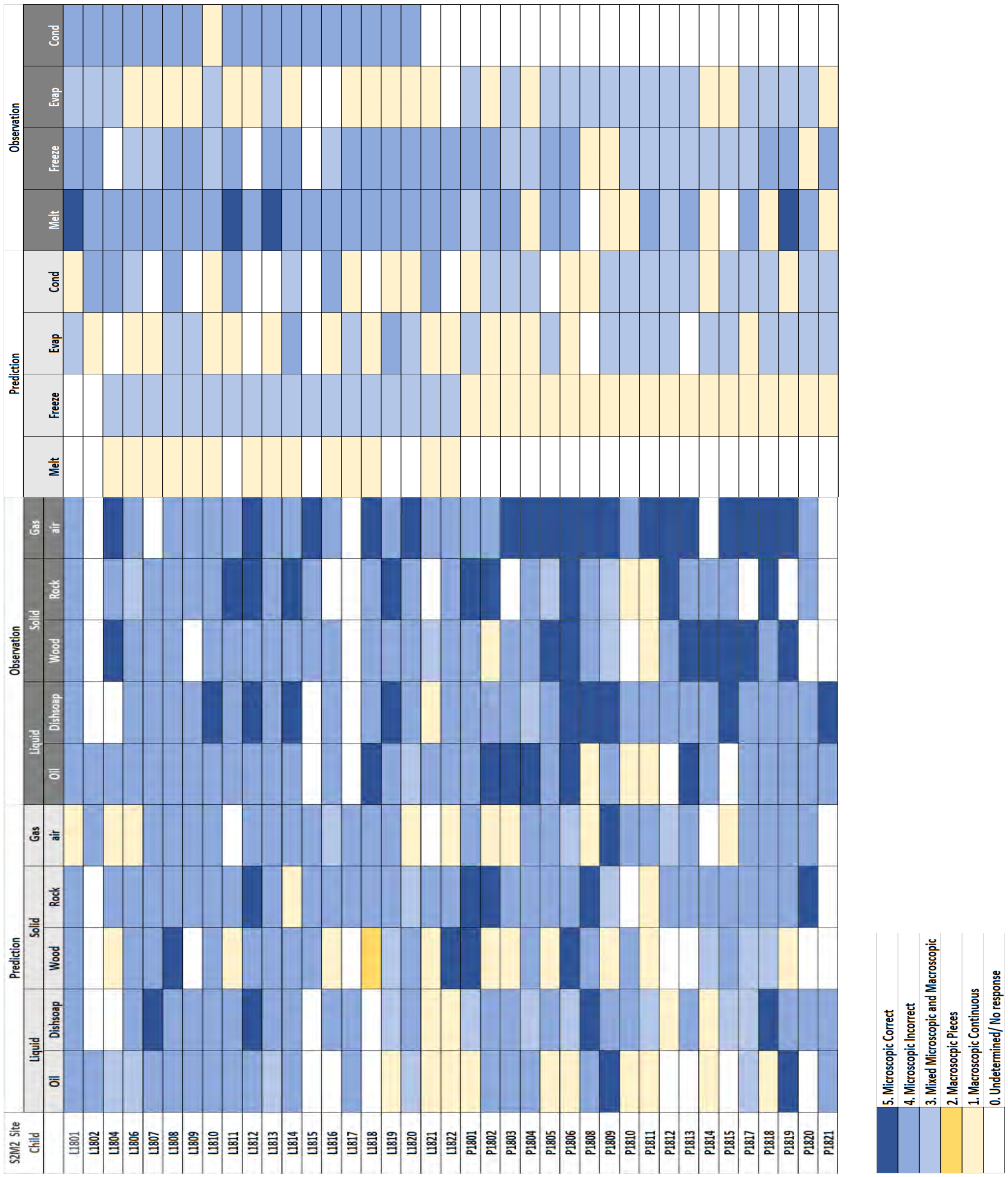
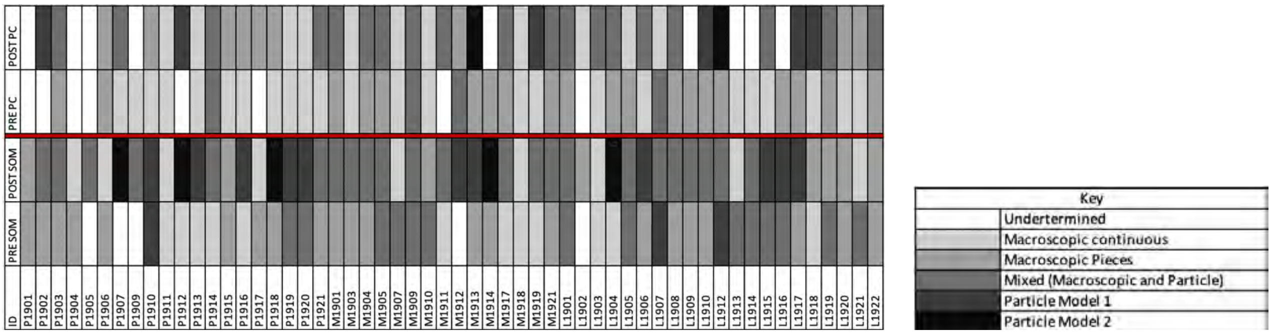


Figure 3. Heat map of students' science notebook models.

A. Site 1



B. Site 2

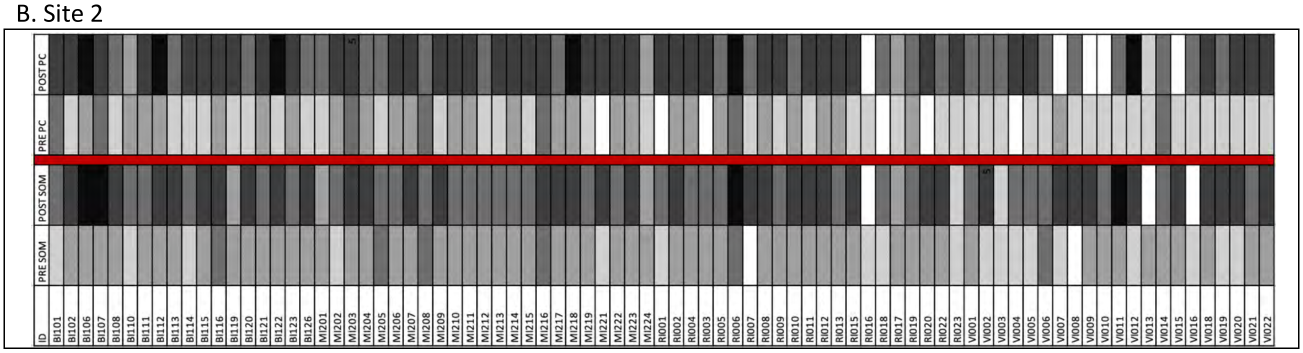


Figure 4. Heat Map: Year 3 Pre -Post MMK Coherence Scores for States of Matter (SOM) and Phase Changes (PC).