AC 2011-930: MODELING IN ELEMENTARY STEM CURRICULUM

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Modeling in Elementary STEM Education

Introduction

Elementary science curriculum affords many opportunities for students to engage in inquiry science, technological problem solving and meaning making through scientific and engineering models and modeling. Modeling, and model-based reasoning is central to professional engineering work and is similarly essential in the teaching and learning of underlying science, technology, and mathematical concepts. However, students' ability to effectively use models without proper instructional support is limited. Dam construction is an example of an important activity for civil engineers and examining dam failure through modeling is an equally useful activity in the K-12 STEM classroom. These models can then become the vehicle for using student observations and sense making to develop linkages between underlying STEM concepts and the constructed world around us. The pedagogical challenge is instruction that exploits student learning around the processes and mechanisms that underlie visible phenomena, which is often temporally and spatially inaccessible within the elementary science classroom. Students remain fixed on reporting the observable aspects of the phenomena without truly understanding why. As important, when students begin thinking about phenomena at a microscopic level, they apply their macroscopic observations as to why something occurred. For instance, the collapse of a model dam is simply the result of water pressure as seen as the visible surface area of the water. The concept of erosive action at a particle level or the pressure of total water volume may not factor into student understanding. A more nuanced view of models and modeling around the invisible aspects of phenomena can facilitate student sense making. The following 2 cases provide analysis of student representations, verbal explanations and gestures after working with Landform concepts integrating graphic-modeling tools (Appendix A) anchored with two big ideas in STEM—the particulate nature of matter and models.

Background

Model-Based Reasoning

Experts across the social sciences, sciences and engineering are dependent on models to construct representations of our known world. In fact, all knowledge of the world is dependent on the ability to construct mental models—it is a necessary function in both research and the communication of knowledge [1,2]. Hence, models are used as interpretations about specific aspects of the empirical world [3, 4]. They are often a combination of written symbols, spoken language, graphics, gesture, and experienced based metaphors [5, 6, 7]. These dimensions provide readers with a way to define and situate the model within a scientific or engineering context.

The types of models are numerous; for instance, physical 3D scale models continue to be used in a variety of engineering curriculum[8] as way to support student learning. Johnson and Coyne[9] employed mathematical models to support bioengineering students engaged in physiology to better understand issues of ergonomics and body movement. Models are also created as complex visualizations used to analyze specific properties and behaviors of materials. Adhikari[10] created a virtual modeling environment to analyze specific asphalt properties using 2D and 3D discreet elemental modeling process. These examples reflect sophisticated modeling techniques that are appropriate in pre-engineering and college engineering courses. In several of these examples students are engaged in multiple drawing iterations prior to physically or virtually testing their ideas. Model-based design, aggregating stand-alone models to better understand how systems work in order to construct more robust target models, is reliant on powerful computing platforms. Mosterman[11] incorporates MathWorks™ to conduct simulations of aggregated models in the biological domain. Lastly, Batie[12] incorporates a 3D Sketch up modeling tool to support students in civil engineering. Through this modeling tool students are able to manipulate, zoom in/out and isolate on selective features of the building. This ability to use graphic-modeling tools can be very helpful for students who are increasingly asked to reason about the underlying features, properties and mechanisms of phenomena as early as the elementary grades[13]. Common features associated with paper-models, computer models, 2D, 3D or 4D models (common in virtual settings), or mathematical models adhere to certain characteristics. Halloun[14] proposes that knowledge needed to understand a scientific model is comprised of four dimensions: its domain, the overall physical system, object or referent; the composition, the context and sub-content associated with the model; the structure, including its geometry, how it interacts and behaves within a certain physical system; and organization, the principals, laws and rules that are necessary in explaining a particular phenomenon. Knowledge of these dimensions requires modeling method(s) that facilitate student opportunities to investigate science and engineering concepts.

Another aspect of model-based reasoning is its specific heuristic with the aim of refining one's mental model over time. Hence a modeler will initially have a *mental picture* which is then *expressed or made public* to the scientific community, and over time *consensus* builds as the scientific model becomes accepted by the larger technical community. Acceptance implies the consensus model is in line with the scientific communities' *target model* (or in this case, for the elementary STEM classroom). For instance, models of earth systems is a result of scientists continually testing theories (models) over a long period of time. In addition to extensive models developed over centuries around the big ideas in science, a model can also represent a modest, tangible designed product produced in the classroom around an engineering design problem. However, the basic principles of iteratively developing a consensus model based on STEM principles still holds true. Regardless of the scale of the model, to represent ones' internal ideas is difficult, but necessary, since many of a student's learning opportunities are expected to be mediated through external representations.

Recent work by Hamilton[15] suggest a Models and Modeling Perspective (MMP) is helpful in the creation of structured representations of complex systems that provide students with opportunities to connect knowledge forms and leverage the power of collaboration to further understanding. Model-based reasoning is not unlike the work by Miller[16] and Moore[17] on Model-Eliciting Activies (MEAs) whereby students are engaged in an iterative process of design-test-revise cycle in order to develop richer explanations and problem solve. An important goal in elementary STEM curriculum is the opportunity to develop a community that shares and builds on each other's STEM knowledge. As with MEAs, MPP and model-based reasoning a major goal is to create authentic learning environments that mimic ways diverse communities of learners, learn and develop understanding. It is important to realize that students engaged in visual thinking are challenged to create representations that are representative of their ideas.

Challenges include interpreting a two-dimensional representation into a three-dimensional mental image; performing a mental operation, such as rotation on the 3D image; re-representation of the newly visualized three-dimensional image as a two-dimensional diagram; student sense-making on the sub-microscopic 'reality' that macroscopic phenomena represent; and the mental demands of thinking in terms of formulas, symbols, macroscopic behavior and sub-microscopic processes[18]. How students integrate and communicate their understanding of technical content often requires a mix of modal expressions—verbal, written, gestural and graphical.

The very nature of inquiry, problem solving and generalizing (e.g., application of knowledge to seemingly unrelated experiences) requires a 'meshing' of human expressive modalities. Nathan & Johnson[19] argue modes are in service of each other, for example the use of gesturing accompanied with speech helps students organize their ideas in meaningful ways. Often phenomena is being imagined in 3-dimensions, and the use of gestures can compliment student-generated graphic models that are often in 2-dimensions. Finally, combining modalities facilitates an understanding of phenomena that varies in scale, temporality and causality. The use of multiple modes to express ideas highlights gaps in reasoning often not identified if only one mode of thinking is used. It is difficult to assess student drawings without written work, and analysis of these drawings often requires student verbal explanation to ensure accuracy of reader understanding. Given the student complexity in expressing their ideas, model-based reasoning anchored with concepts from the particulate nature of matter may provide students with a more robust foundation for sense making when encountering invisible or otherwise abstract phenomena.

Particulate Nature of Matter

The delivery of STEM-based curriculum is based on a variety of different national standards focused on process skills, habits of mind and content knowledge[20, 21, 22]. The challenge is to move away from simply teaching facts, definitions, procedures and diagrams as the means of helping students to make sense of their world, and move towards a more holistic/integrated view. An understanding of particulate nature of matter may provide an approach that fosters connections, rich experiences with phenomena, patterns, and models[23]. These are practices familiar to everyday scientist and engineers. Learners must grapple with ideas surrounding the visible and invisible properties of matter, how a small number of elements are responsible for the creation of the material world, and the relationship between substance, matter, and its forms[24]. To reason about the particulate nature of matter it is useful for students to work with scientific conceptions in conjunction with formal conceptions of form and function, space, representations (e.g., graphic inscriptions), and models[1, 25, 26]. These visual-spatial cognitive skills help students mediate between the concrete and abstract world of phenomena. The movement between the abstract and concrete requires students to observe macroscopic properties through their senses, and utilize symbolic tools that are representative of the phenomena to uncover the sub-microscopic properties (near and/or invisible phenomena) all in tandem[27, 28]. These big ideas are not learned in isolation, as students arrive in the classroom with life-world experience that must be acknowledged and used as entry points to further their sense making.

Children's ideas

What counts as evidence for students is complex. It is the result of having multiple meaningful experiences with phenomena, access to cognitive tools and resources, and appropriate and timely scaffolding[29]. Students perceive matter as continuous or static. This might be reflected in their drawings as indistinguishable markings (lines or colored region) mixed together to represent a substance[30]. Matter is thought to be appearing and disappearing which is counter to the theory of the conservation of mass. The graphical shape, proximity and arrangement of particles is an indication of students wrestling with particle ideas. Formal representation of particles is often conceived in terms of a ratio of molecular spacing between a solid-liquid-gas as being 1:1:10 (the difference between a solid and liquid representation is in configuration and not proximity). Students have similar difficulty differentiating microscopic properties from macroscopic properties[24, 31].

Students may come to a false sense of understanding because they find it easier to accept physical/visible models than they do abstract science or pre-engineering concepts. They may not see models as tools for testing abstract ideas. Instead, students often see models as scale models of reality and might think there should be a 1:1 correspondence between their internal model and expressed model (drawing)[2, 32, 33].

By the late elementary grades, students are expected to know: 1) that matter takes up space and has weight; 2) matter can exists in several forms; 3) matter is conserved; 4) matter is made up of particles that are invisible; and 5) that it is possible to exert a force on an object without touching it[20, 22, 34]. Our interest is in anchoring these conceptions of particle-theory to support a richer more connected view of landforms so that students begin to understand:

- how water flows over earth materials in a stream table
- observe and explain the process of erosion, deposition, and stream flow
- realize how slope affects erosion and deposition
- are able to model and explain the process of landform creation, and
- how aspects of particle-theory (size, proximity, organization and (in)visibility and material properties help explain the processes and landform.

All goals are expected from late elementary grade students[22] and central to later work in engineering programs such as civil engineering.

Cognitive Tools

Students mediate their world using a variety of resources. Often they are expected to understand words, pictures, multimedia, and animation with little training in how to interpret the use of color, text, and symbols used to represent a scientific or engineering concept. Our research has demonstrated the potential of foundational images (i.e. graphic tools and scale tools) to help students' reason is helpful when learning abstract concepts when they are properly supported through teacher professional development. Incorporating **Vectors** to represent direction, magnitude, force or displacement; **Particles** to suggest all matter is made of solids, liquids, and gas that interact with each other; **Frames** to denote change over time and the **Magnifier** providing students with the means of enlarging or reducing observable phenomena can support student thinking[13] (Appendix A).

This study will provide the educational research community with new insights into how to analyze student work (i.e, science notebook pages containing graphic models) and discourse within a modeling framework. Student interviews will be an important part of the data being analyzed as they provide a more comprehensive view of the intersections between verbal and non-verbal cognitions. To facilitate the flow of the paper, analysis of student representations have been placed in Appendix B. Finally, evidence-based practices in elementary science education are still emerging and evolving, hence more studies are needed that connect the psychology of the child with epistemic practices of science and engineering.

Methods

This is an ethnographic study. In this instance utilizing multiple sources of data, student interviews, their notebook pages and peer interactions to better understand how they make sense of phenomena within the STEM classroom setting[35]. The interest is in facilitating classroom practices towards more authentic ways of learning. Providing a learning environment where students leverage their individual science and pre-engineering knowledge towards a more collective understanding. In many ways viewing the students as participants in a technical cultural sharing setting [35]. Ideally developing consensus as a result of pursuing inquiry-based investigations. Over the course of three months, one urban school was studied, and in particular, one classroom Grade 5 (N=31) where engaged in modeling activities that were a) designed around a modeling pedagogy, b) leveraged graphic modeling tools to make sense of phenomena at the microscopic level, c) integrated within their existing curriculum, and d) all within a mixed-ability classroom setting. The teacher was self-selected based on an earlier two-year Graphically Enhanced Elementary Science study, where graphic-modeling tools were designed to support student representational practices in their science notebooks. This qualitative study provided in-classroom recordings (audio and video) of individual interviews, small group discourse and whole-classroom modeling activities to elicit student thinking and reasoning about phenomena.

Student artifacts, in the form of science notebook inscriptions, were photographed, catalogued and analyzed for evidence of student reasoning. A modeling lens, in conjunction with conceptions from the particulate nature of matter, was used to analyze student data. The one-on-one pullout interviews were conducted in the hallway during student scheduled reading time. Each interview lasted between 15-20 minutes. Students were asked several questions pertaining to their understanding of landforms, asked to discuss several of their science notebook entries and given a question, whereby they verbalized and illustrated their response. The semi-structured interview guide started with a structured question and was followed up with a series of discreet probing questions to facilitate student self-explanation (Appendix C). The goal was to encourage students to think about the invisible or near invisible aspects of their landform investigations. Part of this process is to facilitate student talk through the use of their own student generated graphics. Data collection included an iPod Touch w/ microphone, HD video camera and tripod, a flip camera, and a digital camera. The following results reflect the work of two Grade 5 students engaged in a series of graphic-based modeling activities around stream tables[36]. Given the depth of data for each student, only two students are reported on here as representative of the conceptual thinking being done by all the students in the classroom.

Results and Discussion

Student A is fluent in using terms to describe and explain phenomena related to why material size and density matters when certain objects sink or float (Figure 1). It is unclear if the student realized that smaller particles were being removed from the larger coffee particles inside the coffee filter. The first response that follows is of the student being probed to further unpack question 1. See appendix B for graphic analysis of student A entries.

> Interviewer (I): Where were the big parts of the coffee, do you remember?
>
> Student (S): Well uhm when it turned into a liquid most of the bigger parts were at the bottom because bigger things tend to sink {ok} and the smaller ones tend to float.

The following discussion incorporates the foundational image (i.e., **Magnifier** and **Particle** tool) to help abstract on several concepts related to the process of landform creation. The student recognizes differences in particles but is unsure how form and function play a role in why particles are found in the liquid.

> I: Is this the same coffee grinds as what's in here or is this different {pointing first to the coffee grinds and funnel then to the beaker of water and coffee grinds}.
>
> S: In some ways it's the same in some ways it's different, uhm in this one it's more a liquid but there are so few particles {referring to the beaker} and that's more solid.

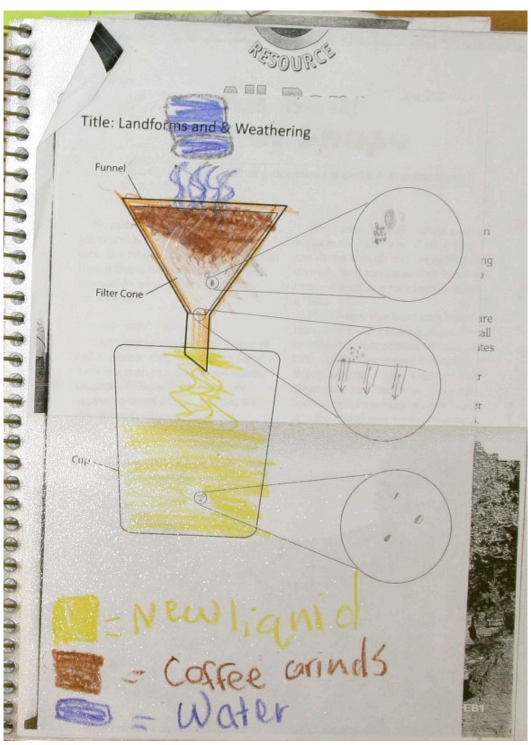

Figure 1: Coffee mini-experiment

In the following dialogue the student recognizes different forms of erosion with the aid of an analogy (e.g., physical and chemical) (Figure 2). The use of the word crumbs could be considered interchangeable with particles.

> I: Why did you use the word eroded?
>
> S: Because water did not have anything to do with it, uhm so it was, I guess you could consider uhm shaking it around, I guess you could [think of] some sort of wind {spontaneous analogy} pushing it inside the tub which is sort of crushing it, at the end there was just a lot of little crumbs.

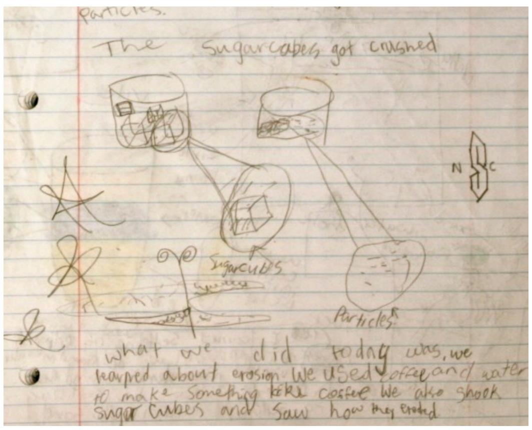

Figure 2: Sugar cube in vials

In this discussion the student uses descriptive language to explain erosion as a microscopic process (Figure 3). The student demonstrates the ability to interpret perceptual observations and expresses a top view spatial projection when discussing how the hole in the cup is facing the sand.

> I: If we were to look at the first stream table…I see this brown thing here, what is this exactly?
>
> S: That is the cup that is resting on the ruler, uhm and you pour the water into the cup and there is a dot, a hole in the bottom of the cup and so you pour water into it and the hole is really facing on to the sand, which is sort of, uhm I guess eroding it {the plateau} forming just a little bit of a hole that is breaking up into other little deltas or little rivers that lead to that hole then there is another bucket that catches the water.

The student uses color, geometric shapes, and lines to isolate on specific components of the phenomena (Figure 3). The student is describing their macro observation but misses an opportunity to visually indicate the particulate nature of the squiggly line.

> I: So the green, blue and even the brown and then I see some squiggling. So I'm trying to understand what you were trying to represent there?
>
> S: Those little ovals {labeled the original representation 01} uhm they were little sections in the tub where just sort of long, because that's where mostly the water was, it deepened

there, uhm and so. And then the blue is the water, which is coming with the sand, after it's {the water} has been poured out of the cup.

The student leverages their graphic-model to discuss observations during the use of the physical stream table model (Figure 3). The **Frames** tool provides cognitive support to help the student explain changes in landform over time, a big idea in elementary education. The diagram depicts matter as continuous (the solid lines used to depict water flow). Without a magnified view of the stream table the contents and the process associated with stream flow go unnoticed.

I: So you have three rectangles in a row does this represent something?

S: Uhm, this is what's happened, it's you can't really see it but it's the time {labels 1-2 minutes, 4-5 minutes are placed on top of the first two stream table representations}, this is what's happened after 1-2 minutes, this is what's happened after 4-5 minutes and I cannot read the time in that one.

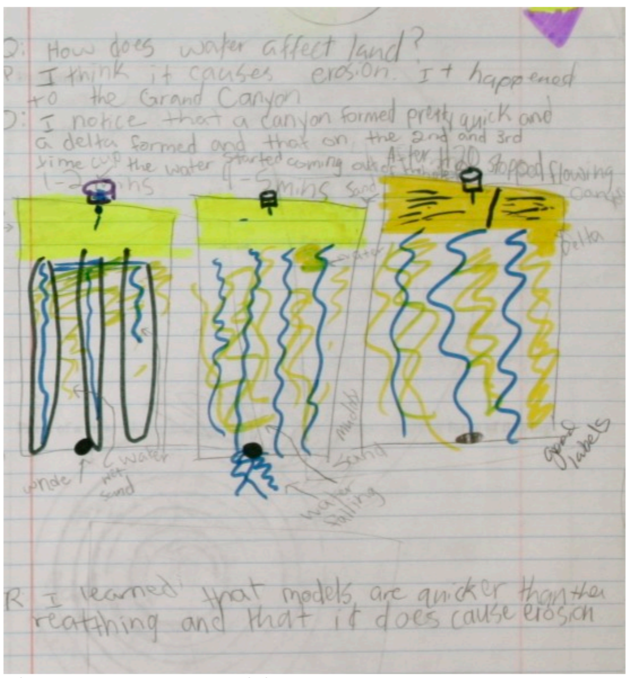

Figure 3: Stream table

Student A was often observed tapping fingers but making no formal gestures in conjunction with their explanations. They communicated moments of uncertainty and were reflective in their response, maintaining a calm and confident tone throughout the interview. There is no indication that these model entries reflect reality. The notebook entries were used as a mental referent (objects and classroom investigation) to support their self-explanations.

Student A was then asked to talk aloud and represent the following question. Over the course of several minutes we engaged in open discussion integrating her classroom experience with our earlier discussion (Figure 4). The After picture illustrates erosive properties as a result of continuous water flow. The student is aware of water as the cause of weathering and suggests material is contained in the water, yet the drawing represents the material as continuous (absence of particles in the mixture). The student is in awe of the Grand Canyon but it is unclear if she has visited the site or just seen pictures. The M**agnifier** is used to discuss the evaporation of rain as a result of the heat of the sun, further verbalizing a scientific abstraction of a concept.

I: What forces are involved in the shaping of the Grand Canyon?

S: Uhm based on what we learned it was the, I think it was the Mississippi river but I'm not sure because the Grand Canyon is in Arizona. {Begins to draw from left to right}. So some source of water, so this was I guess the canyon sides {uses purple to indicate the sides of the Grand Canyon on the Before picture}, then you had ragged sides [Student A provides no indication as to why ragged sides appear on the After picture} and then all of a sudden it starts raining and a river forms and it rubs up against the sides and then so later, now the Grand Canyon looks more like that because the water is all up against it {draws vein like rivers on either side of the walls of the Grand Canyon} and formed something like veins.

I: So what do the veins represent?

S: Um, deposition, erosion to. Uhm because deposition is usually when it's taking away here {pointing to the top of the After picture} but it is adding down here {pointing to the bottom part of the After picture}. And erosion is just taking away.

I: How would you label your diagram?

S: So um just a little bit of water after the after affects which caused all this erosion in the Grand Canyon which has carved out the parts of the walls that the river left and then what it took away. So at one point it was all straight like that {adds a series of purple lines on the before image} and it was probably just a big piece of rock and then the rain came and it took away all that rock and it just left a little bit and now it is really an interesting site to see.

Figure 4: Student representation of the Grand Canyon

Student B had more difficulty abstracting from the concrete observations they observed in the classroom, explanations of phenomenon where more descriptive in nature (Figure 5). See Appendix B for graphic analysis of student B entries.

> I: What happened when water was poured over a) the coffee beans and b) coffee grounds?
>
> **S:** (R1) Ah, the coffee in the water like mixed together and I sorta tried to draw that {so *what is that, tell me more about what you mean by that?}*. I uhm I drew like the coffee beans in the water, the water pointing down the dark spots are the coffee beans and I like drew both of them mixed together to see, to draw what happened.

The student often commented that they could not recall the events surrounding a certain activity nor could they utilize their graphic-model to help explain the phenomenon. The drawing represents the coffee+water mixture as continuous with no indication of smaller particles being removed from the larger coffee particles in the filter.

> I: When asked to elaborate on their initial response (Figure 5).
>
> S: They both uhm mixed, it is sorta hard to remember {*that's ok, so when you say mixed what do you mean}*. Like they both, like the beans in the water they both touching and so they looked a little different.

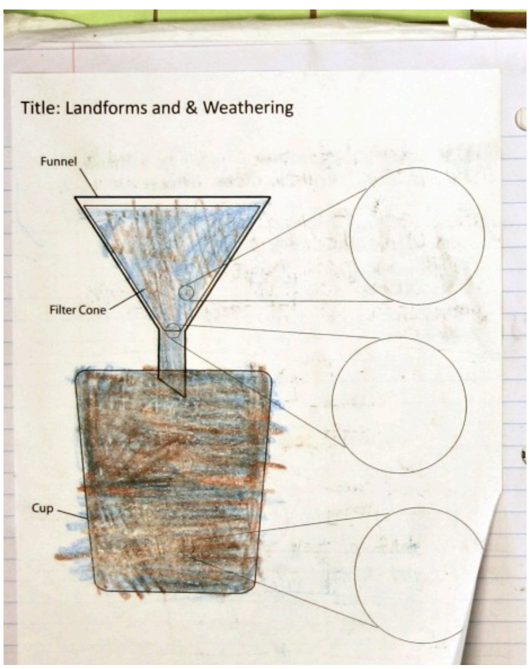

Figure 5: Coffee mini-experiment

The student used a graphic-modeling tool in combination with color to represent their investigation objects but was unable to explain why the phenomenon occurred (Figure 6). Uses the concept of erosion to describe the phenomenon but their explanation about why the chalk moves up in the water column (as it relates to density or size) is unclear. The student's observations remain at a macroscopic level.

> I: I was interested here because they were talking about chalk and you had chalk in the water, and I'm curious what you remember about this one.
>
> S: I don't remember {ok} I've been doing to much work {*that's ok*} I don't remember. {*So do you have any ideas if you put chalk and water then shaked it, what do you think might happen?*}. It would probably have erosion a mix of them both because you shake it up the water and the chalk would get all mixed up. {*So is the chalk staying the same size or what is happening with the chalk?*} It's stays the same size it just moves up because of the water {this is counter to his claim about his erosion statement} when you shake it.

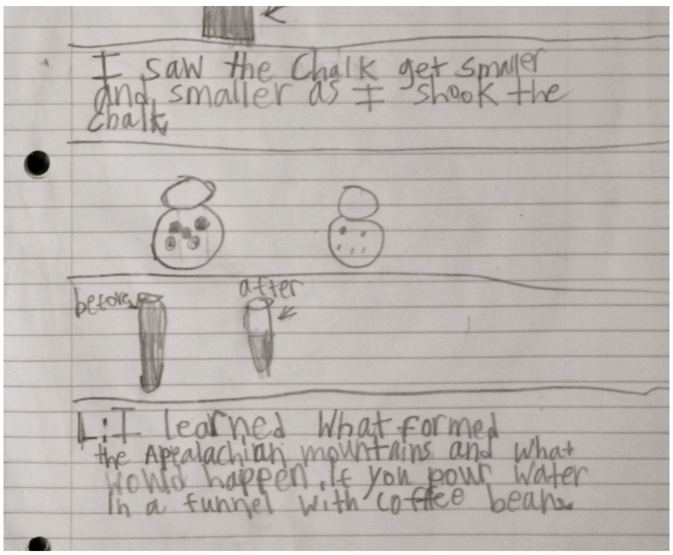

Figure 5: Chalk in a vial

Student B was then asked to elaborate on the following question (Figure 6). Student utilizes many gestures in tandem with verbal explanation to describe the formation of the Grand Canyon. Gestures became the dominant mode of communication as they continued to think through the question. The gesturing facilitated thinking in 3 dimensions, allowing the student to communicate their ideas with some coherence. There response remained at a macroscopic level with no clear indication of the view (top, side or combination thereof) being represented in their graphic representation.

> I: What forces are involved in the shaping of the Grand Canyon?
>
> S: Ah water. That's what happened, I think it was like a big flood that made a v-shaped valley [gestures, right hand moves way from the body directly in front of him to indicate a v-shaped valley] to make the Canyon.
>
> I: What might that look like?
>
> S: I'll probably have to draw it. Not really good at drawing. [draws two circles with accompanying rectangles indicating the Grand Canyons]. These are the big Grand

Canyons. Then when the water made them {changes color} all separates in, makes a valley. {Uses 2 hands to gesture the creation of a valley}. Like um {uses green to color in a valley}, makes them all disconnect so now it's flat in some parts {gestures to indicate a flattening of the canyon by first moving his hand away from the drawing than creating a sweeping affect across his body}. It [the Grand Canyon] is still the same but separated.

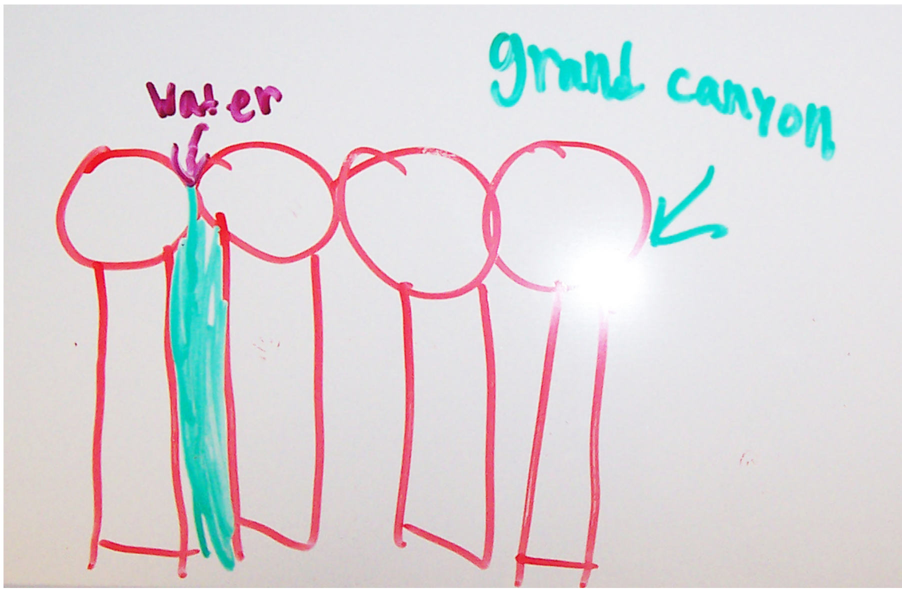

Figure 6: Student representation of the Grand Canyon

Concluding Remarks

Elementary students are willing and able to express their scientific ideas and how they might apply to solving engineering problems. Students' self-explanations use multiple modes (verbal, gestural, graphic) to model their understanding of phenomena at the macroscopic level. Modeling resources, the use of graphic representations and tools (i.e., Magnifier, Particles and Vector), hand-gestures, and physical models may help to organize student thinking and reasoning beyond surface level observations—crucial to the application of scientific principles to engineering problems. The current STEM-based curriculum used in many elementary science programs promotes science process skills that tend to focus on macroscopic observations. In order to assist students in tackling the underlying behaviors associated with their observations, they need cognitive tools—in this case modeling tools—that guide them towards thinking about other interactions that are occurring at the microscopic level. By addressing concepts related to the particulate nature of matter within a model-based reasoning framework, students are able to broaden their understanding of the interactions occurring when studying earth systems. The use of graphic-based modeling tools helps students mediate concepts of deep time (i.e., geologic time) with the physical stream table models. This provides them with opportunities to explain why a phenomenon occurred and not just how, which is often a more descriptive explanation.

Student modes of discourse need license and space if they are going to build a more robust foundation for future learning. Student assessments, both formative and summative, must take into account students' natural inclination to leverage multiple modes of discourse, as it is an important aspect of how students construct knowledge. Engineering as a profession makes widespread use of physical and virtual modeling tools and modeling opportunities in the elementary grades should be provided as a way to both understand concepts and solve scientific and technological problems. These opportunities, of course, should continue to be built upon in later grades in a variety of STEM and pre-engineering courses. Work with models and modeling is not only a meaningful way to develop deeper understanding of core conceptual knowledge, but also develop habits of mind around the deployment of modeling in multiple modalities as an engineering problem-solving tool.

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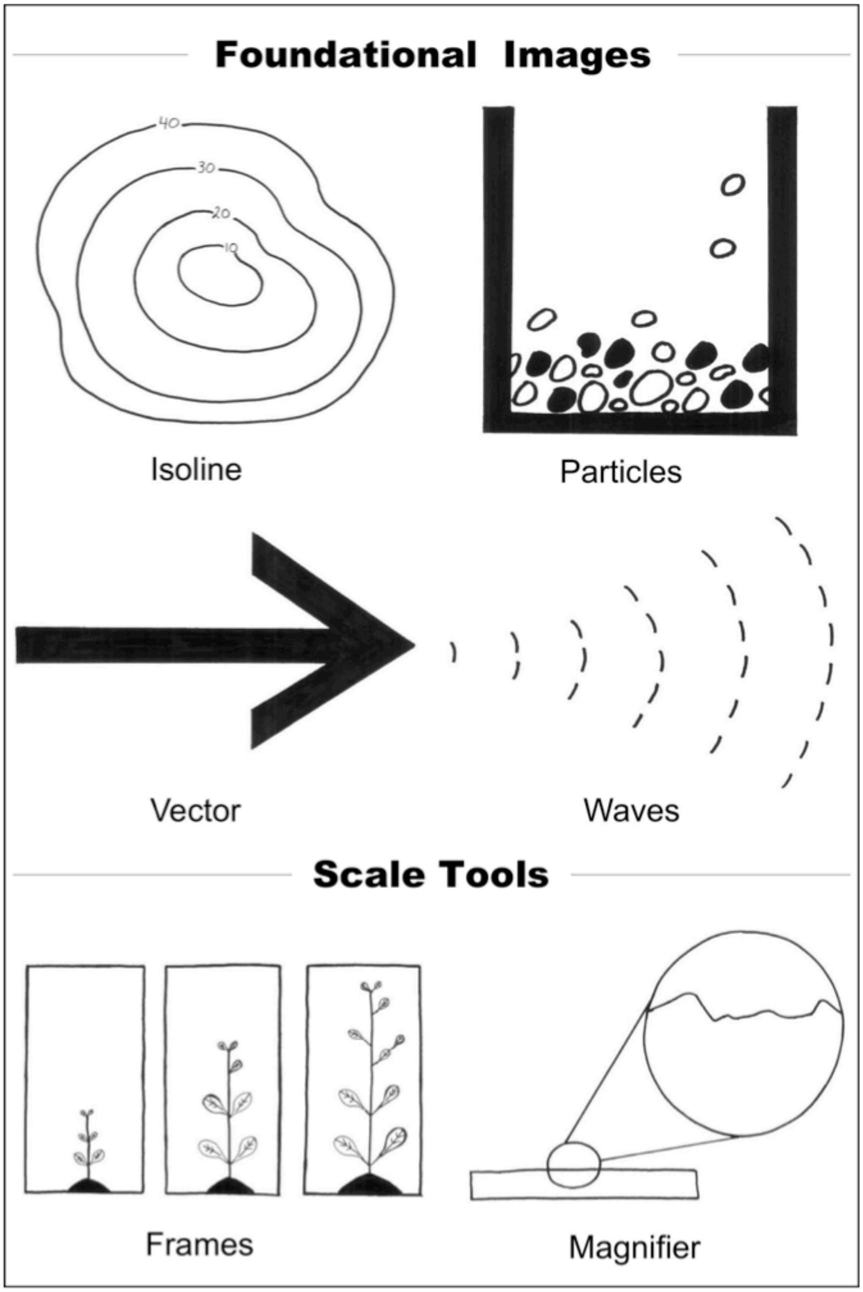
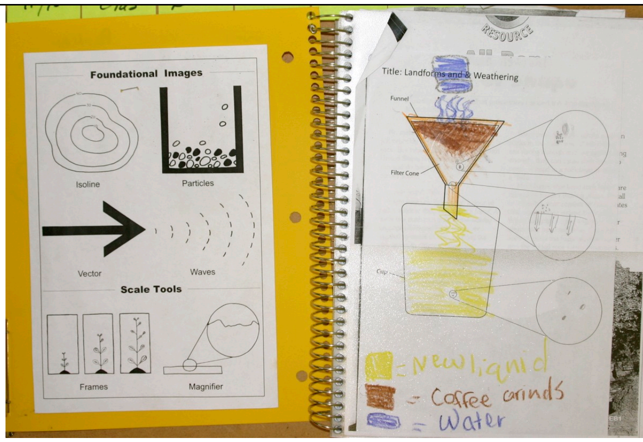
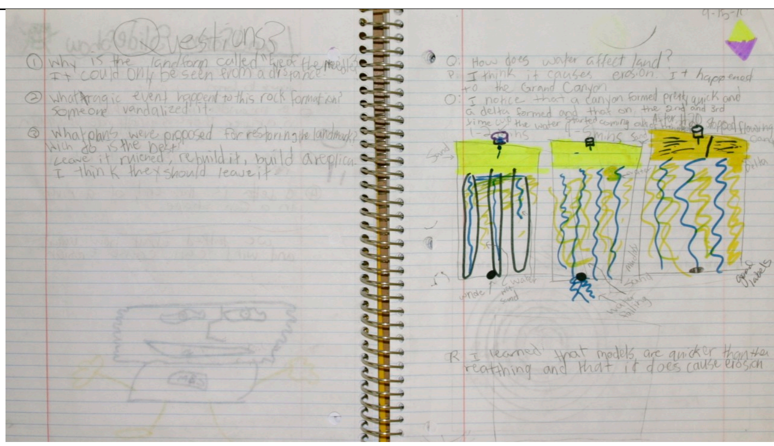
Appendix A: Foundational Images



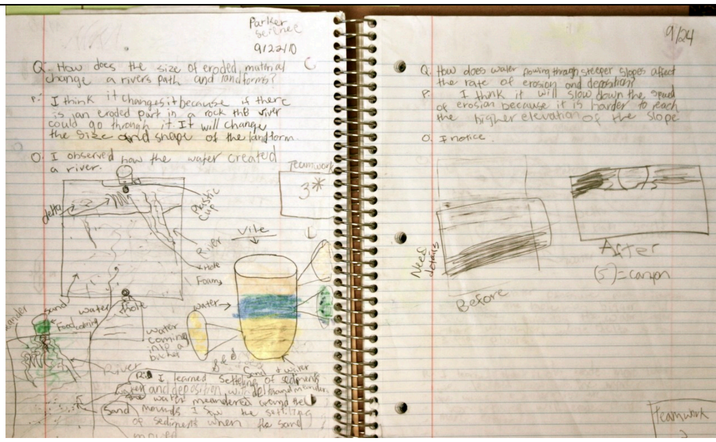
Appendix B: Student A



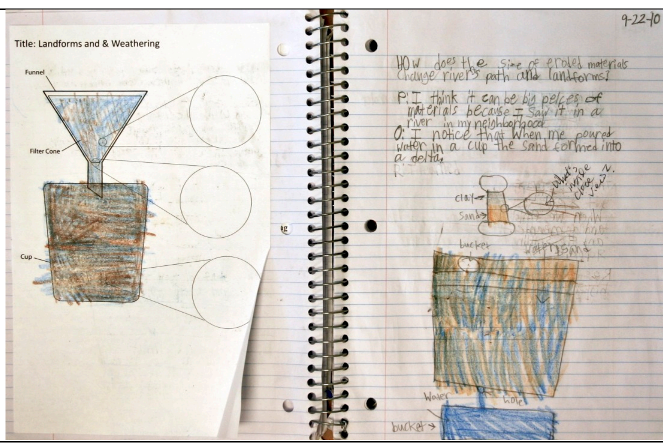
Investigation 2, Mini-Experiment, Student #01: [Right Hand Page] What happens when water is poured over the coffee grinds?
Graphic Analysis: Color was used to distinguish between the water, coffee grinds and the resulting mixture (i.e., coffee). Particles are drawn inside the magnifier tools illustrating the coffee grinds in the filter, how smaller particles from the coffee grinds passed through the coffee filter creating a mixture (i.e., coffee).
Student Meaning Making: Need to probe student on the meaning of their mixture.

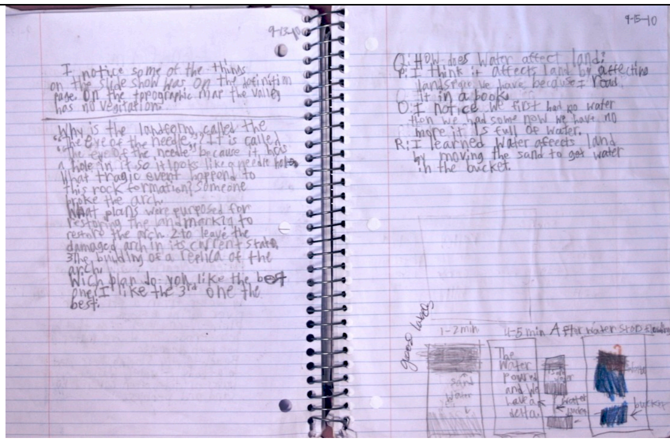


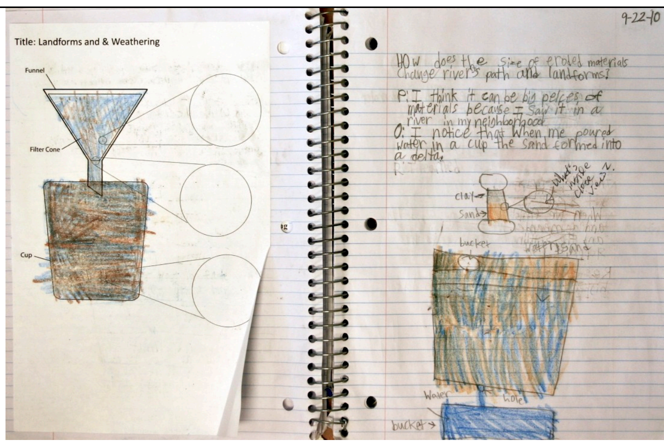
Investigation 2a, Student #01: [Right Hand Page] How does water affect the land?
Graphic Analysis: Student uses the Frames Tool to document changes in landform over time. The yellow represents the plateau and the sand being eroded. The blue represents the water which is carrying small particles of sand from the plateau and it is unclear what the backlines in the first panel represent
Student Meaning Making: *I noticed that a canyon formed pretty quick and a delta formed (see labeling)…I learned that models are quicker than the real thing and it does cause erosion.*

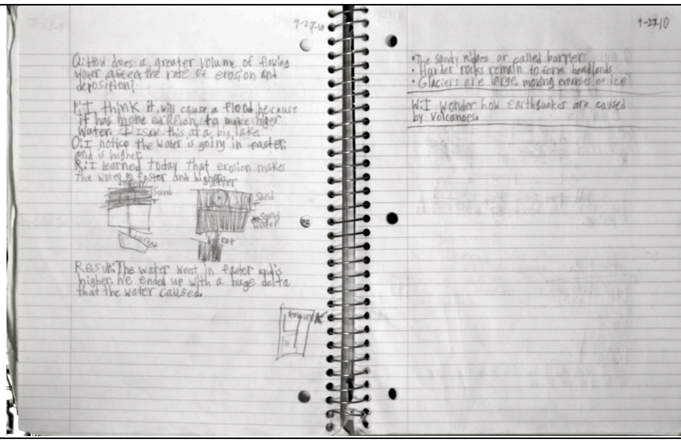
	Investigation 2b, Student #01: [Left Hand Page] How earth material alters river paths and change landform?
	Graphic Analysis: The upper drawing illustrates the stream table with newly formed landforms (e.g., a delta, river) along with evidence of erosion. In the lower left hand corner a cup with food coloring is added to magnify the specific paths water takes as it interacts with the earth material. Finally, the colored vile is illustrating the settlement rate of certain earth materials.
	Student Meaning Making: *I learned the settling of sediment and deposition with the delta and … and water meandering around the mounds. I saw the settling of sediment when the sand moved.*

Student B

	Investigation 2,Student #08: [Left Hand Side]
	Graphic Analysis: Color was used to integrate the mixture of coffee grinds and the water both in the funnel and in the beaker. Notice the beaker color is much darker than above. No indication of particles or use of the magnifier tool
	Student Meaning Making: Unclear

	Investigation 2a, Student #08: [Right Hand Side] How water affects land
	Graphic Analysis: In panel one the student creates a distinction between the plateau of sand and the water. In panel 2 the student indicates the creation of a delta as a result of the water being poured over the sand. They also note the water leaving the stream table into the empty bucket. In panel 3 the student uses color to illustrate the sand and water interaction.
	Student Meaning Making: *I learned water affects land by moving the sand to get water into the bucket.*

	Investigation 2b, Student #08: [Right Hand Side] How eroded material changes river paths and landforms
	Graphic Analysis: The upper graphic illustrates the settling vial with the mixture of sand and clay. The Magnifier Tool is drawn with two lines illustrating what appears to be the point where sand and clay are mixed together. The stream table illustration is a mixture of colors depicting water and sand moving and mixing down the stream table.
	Student Meaning Making: Unclear

<table>
<tr><td rowspan="3"></td><td>Investigation 2c Student #08: How water volume affects the rate of erosion and deposition</td></tr>
<tr><td>Graphic Description: The student provides a before and after drawing of the water being poured over the plateau</td></tr>
<tr><td>Student Meaning Making: The water went in faster and higher. We ended up with a huge delta that the water caused.</td></tr>
</table>

Appendix C: Interview Guide

1. **What happened when water was poured over a) the coffee beans and b) coffee grounds**
   a. Probe students to discuss differences in particle size
   b. Probe students to discuss differences in water color
   c. Probe students to think about the impact of temperature
   d. Encourage students to revise their drawing
   e. Probe students to compare their macroscopic observations to the microscopic phenomena (what is in the fluid)
   f. Probe students to explain their drawing in detail

2. **How would you define [erosion]?**
   a. Probe student(s) for an example of the phenomena from their notebook or personal experience
   b. Probe student(s) to discuss how weathering is tied to erosion and/or deposition.
   c. Probe student(s) to discuss change in particle size as a result of rock composition, rock properties and climate

3. **How would you define [deposition]?**
   a. Probe student(s) for their understanding of sediment
   b. Probe student(s) on their understanding of soil

4. **Explain the meaning behind the following notebook entries**
   a. Probe student(s) to elaborate on their drawing
   b. Probe student(s) to verbally integrate different properties/characteristics into their explanation (size, structure, hardness, and shape).
   c. Probe student(s) to explain how their drawing helps explain their understanding of the phenomena
   d. Probe student(s) to compare and contrast erosion to deposition

5. **What forces are involved in the shaping of the Grand Canyon?**
   a. Probe student(s) to connect the stream table experiment to the Grand Canyon
   b. Probe student(s) to discuss the relationship between forces (water motion) and invisible forces (friction, gravity, water cohesion)
   c. Probe student(s) to consider changes in water velocity and its effect on erosion
   d. Probe student(s) to re-draw or add to their existing drawing

Appendix D: Conceptions

Science Concept	Description/Definition
Erosion	Weathering of materials over time
Sedimentation	Eroded material that has settled
Physical Weathering	The disintegration of rocks into smaller pieces (particles)
Chemical Weathering	The chemical breakdown of minerals dissolved in water, the replacement of ions with weaker hydrogen ions, and the interaction of oxygen with metals
Biological Weathering	Organisms that break down rocks and minerals
Soil	A mixture or weathered rock, air, water, and organic material
Gravity	A force of attraction by which terrestrial bodies tend to fall towards the center of the earth
Slope	A change in elevation
Saturation	The maximum quantity of water air can hold at any given temperature or pressure
Cohesion	The surface tension created by a small amount of water holds sand grains together
Friction	A force that results from relative motion between objects
Mass	The amount of matter an object has
Volume	The size of a body in three-dimensional space
Force	A push or pull
Pressure	The force acting on a surface area
Particulate nature of matter	• Students should define matter as anything that takes up space and has weight. • Students should know that matter can exist in several forms—solid, liquid, or gas—and that within a sealed system, the amount of matter stays the same even if it changes form. • The ideas that the same substance can exist in multiple forms and that the amount is conserved through transformations between states • Students should understand that matter is made up of particles that are too small to see with the unaided eye. They do not need to refer to these particles as atoms or molecules at this time. In fact, students at this level tend to use the terms atom, molecule, and particle interchangeably.