CONSTRUCTING SCIENTIFIC MODELS THROUGH KINULATIONS

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Models are useful instructional supports in cases where the phenomena being studied occur at rates that are either too fast or slow to observe, take place on scales that are too large or small to see, or happen in hidden or concealed locations. This article describes an approach to modeling that involves having students take on active roles of key elements of natural systems to cooperatively act out and kinesthetically model scientific phenomena. We refer to these models as *kinulations* (***kin**esthetic sim**ulations***).

Research on movement education and embodied cognition (Griss 2013; Shapiro 2010;) tells us that students can develop deep and lasting conceptual understanding as a result of participating in bodily and social experiences while learning new concepts. While having students participate in these kinds of human-based simulations is not a new instructional strategy, our interest lies in exploring the ways teachers can best support students' engagement in, modeling of, and reasoning about abstract scientific concepts during these simulations. It is through this type of experience that true model-based learning can occur.

Examples of middle-level kinulations

Our team has recently developed a collection of kinulation lessons designed to cognitively and physically engage K–12 students in learning about a variety of science concepts and phenomena. (See Resources for the link to a free web-based collection of over 30 kinulation lesson plans and classroom video exemplars) Herein we briefly highlight three that apply specifically to middle level science curricula, outline the process teachers can use to develop their own classroom kinulations, and describe the discussion-leading strategies that teachers can use during the activities to engage students in thinking and reasoning about how and why the associated natural phenomena occur.

Propagation of sound waves

In this kinulation, the class constructs a room-sized model of an enclosed three-dimensional space filled with a fluid (gas or liquid), in which students play the roles of particles of the fluid responding to sound waves passing through the space. If available, this works best in an open area devoid of desks or chairs. The speed, direction, and energy of the sound waves, as well as their ability to reflect off surfaces and barriers and even interfere with one another, is portrayed through the actions of the fluid molecules (students). Variables such as the temperature and density of the fluid occupying the space can be modeled through the responsiveness of students to the passing sound waves, as well as their relative proximity to one another in the space.

Chemical reaction rates

During this kinulation, the class portrays the combining of simple molecules (such as H_2 and O_2) to form more complex molecules as a type of classroom-sized dance party. Pairs of students with linked arms first break apart from their diatomic partners, and then rearrange into three-student combinations of H_2O. Music of varying

CONTENT AREA

Physical science, Earth/space science, life science

GRADE LEVEL

6–8

BIG IDEA/UNIT

Kinesthetically modeling science concepts and phenomena

ESSENTIAL PRE-EXISTING KNOWLEDGE

A basic understanding of models and modeling as a means of understanding, explaining and predicting

TIME REQUIRED

45–90 minutes (one or two class periods per kinulation activity)

COST

Low or no cost as most materials can be sourced from home, the physical education teacher, theatre, or drama teacher, etc.

SAFETY

Students need to be made aware that the activities involve full body movement (depending on physical ability level) and physical contact between students. Cooperation and respect for others is imperative. Having spacious and clear spaces to conduct the activities is important.

tempos is used to represent the rates at which the initial reactants are made available to each other, and additional "catalyst" student helpers can be introduced to speed up the reactions by helping simple molecules find partners of the correct type and number with which to combine. Students can wear different colored pinnies (as used in physical education class) to help observers and participants differentiate between the various types of atoms.

FIGURE 1: Solar system kinulation

Scale of the solar system

The class constructs a football field–sized scale model of the solar system in which students assemble in small groups at varying distances from a center point (Sun) to represent the planets (Figure 1). The relative spacing of the human planet models can be easily calculated by referring to the spacing of the actual planets in the solar system and scaling down accordingly (a great math activity). The larger the planet being represented, the greater the number of students in the group. Again, the number of students required to represent each planet can be determined through scaling calculations after students determine the relative sizes of the actual planets. Like the celestial bodies they are representing, the human planets revolve around the Sun at various rates to represent the different lengths of a year on each planet, and rotate on their own axes at various speeds to model the widely differing lengths of day and night that are experienced. We have found that using a timed pulse from a metronome or smart phone amplified through a megaphone is a great way to establish a unified rhythm for students to gauge when they should be stepping and spinning.

Developing your own kinulation activities

The process of developing kinesthetic simulations as explanatory teaching models in your classroom is a relatively simple endeavor and involves the following steps:

1. Select concepts in the science curriculum you are teaching that are abstract in that they are difficult for students to readily visualize and understand. The middle level science curriculum is rich with these types of "unseen" concepts and phenomena. See Figure 2 for a list of topics that can be "kinulated."
2. Investigate common textual, diagrammatic, graphical, analogical, and digitally-based models and simulations that are traditionally used to explain the concepts. How are the phenomena usually modeled? For example, are they usually portrayed in a series of static diagrams to imply change over time such as with cell division or metamorphosis? The focus is to determine what the "big ideas" portrayed in the traditional representations are and whether they can transfer well into a kinesthetic approach.
3. Identify causal agents in those models and simulations that can be enacted kinesthetically; determine what the root causes of certain phenomena are and think about ways students can portray these with their bodies. For example, in the sound wave kinulation described above, students will need to invent a mechanism by which the energy of the initial wave can travel through the medium. One possibility is for

FIGURE 2: Kinulations for middle level science topics

Physical science	Life science	Earth science
MS-PS1-1: Matter and Its Interactions Develop models to describe the atomic composition of simple molecules and extended structures.	**MS-LS1-2: From Molecules to Organisms: Structures and Processes** Develop and use a model to describe the function of a cell as a whole and ways parts of cells contribute to the function.	**MS-ESS1-1: Earth's Place in the Universe** Develop and use a model of the Earth-Sun-Moon system to describe the cyclic patterns of lunar phases, eclipses of the Sun and Moon, and seasons.
MS-PS1-4: Matter and Its Interactions Develop a model that predicts and describes changes in particle motion, temperature, and state of a pure substance when thermal energy is added or removed.	**MS-LS1-7: From Molecules to Organisms: Structures and Processes** Develop a model to describe how food is rearranged through chemical reactions forming new molecules that support growth and/or release energy as this matter moves through an organism.	**MS-ESS1-2: Earth's Place in the Universe** Develop and use a model to describe the role of gravity in the motions within galaxies and the solar system.
MS-PS1-5: Matter and Its Interactions Develop and use a model to describe how the total number of atoms does not change in a chemical reaction and thus mass is conserved.	**MS-LS2-3: Ecosystems: Interactions, Energy, and Dynamics** Develop a model to describe the cycling of matter and flow of energy among living and nonliving parts of an ecosystem.	**MS-ESS2-1: Earth's Systems** Develop a model to describe the cycling of Earth's materials and the flow of energy that drives this process.
MS-PS3-2: Energy Develop a model to describe that when the arrangement of objects interacting at a distance changes, different amounts of potential energy are stored in the system.	**MS-LS3-1: Heredity: Inheritance and Variation of Traits** Develop and use a model to describe why structural changes to genes (mutations) located on chromosomes may affect proteins and may result in harmful, beneficial, or neutral effects to the structure and function of the organism.	**MS-ESS2-4: Earth's Systems** Develop a model to describe the cycling of water through Earth's systems driven by energy from the Sun and the force of gravity.
MS-PS4-2: Waves and Their Applications in Technologies for Information Transfer Develop and use a model to describe that waves are reflected, absorbed, or transmitted through various materials.	**MS-LS3-2: Heredity: Inheritance and Variation of Traits** Develop and use a model to describe why asexual reproduction results in offspring with identical genetic information and sexual reproduction results in offspring with genetic variation.	**MS-ESS2-6: Earth's Systems** Develop and use a model to describe how unequal heating and rotation of the Earth cause patterns of atmospheric and oceanic circulation that determine regional climates.

students to sway side to side and gently bump against one another to model the transfer of energy. You can tap into the intuitive kinesthetic or tactile knowledge that most students have developed through their everyday bodily interactions with the physical world (Stephens and Clement 2008). This includes such bodily experiences as moving in various directions and at differing rates, applying forces of push and pull, stretching and compressing, bending and twisting, rotating and revolving, and so on.

4. Select materials, costumes, props, and music that provide strong visual and auditory cues to help students organize and manage important details of the model. This may include colored pinnies (worn over shirts) to distinguish components of the model (i.e., protons, electrons, and neutrons), colored floor tape to section off parts of the classroom (i.e., chambers of the heart or electric circuit pathways), signs that students can hold or wear to identify their roles in the simulation (i.e., positive and negative ends of a battery), and music of varying styles and tempos to signify important changes (i.e., seasons, temperatures, pressures, velocities).

5. Create lesson plans for the kinulation activities that include all or as many students as possible. This may require accommodating students with physical, cognitive, and/or behavioral challenges and enlisting the assistance of aides or parent volunteers. In all cases, the focus is on engaging students kinesthetically, verbally, visually, auditorily, and socially in investigating the scientific concepts and figuring out how to model them with their bodies in a collaborative way.

6. Since kinulation activities are designed to get students physically and collaboratively acting out scientific concepts and phenomena, it is important they are conducted in a safe environment. As with any movement activity, it is important that students properly warm up through simple stretches, arm and neck circles, ankle rotations, and so on. Also, because many of the kinulations represent physical interactions between parts of systems (i.e., atoms, blood cells, tectonic plates) that students will portray, it is important that they are given guidelines for how these interactions can safely occur. Students should be encouraged to use their hands, feet, arms, and legs in gentle and respectful ways while interacting with their classmates. Finally, it is important that any objects like desks, chairs, tables, book bags, and so on are moved away from the activity area to prevent collisions or tripping. Always plan with student safety foremost in mind.

7. Preplan the use of effective discussion-leading strategies (Keeley 2008; Williams and Clement 2015) for supporting students' evolving explanations of the scientific phenomena being modeled through the kinulations. This includes being aware of common student naïve understandings and misconceptions about the concepts. An important part of model-based instruction and the kinesthetic simulation learning process in particular is not to preteach students the specific functions and mechanisms

Student science journal excerpts

Learning about how sound travels in the air by acting it out and talking about it really helped me understand better. Thinking about how air particles would be affected by the waves of energy passing through them and then acting it out was cool because you can understand things better if you can see it happening in front of you. When we watched the video recording of the class modeling the sound waves passing through the room full of air particles [us], you could actually see the energy moving from front to the back [of the room], bounce off the wall, and then go back the other way. That helped me understand how echoes work. One question I have is how would the sound travel if there were more air particles packed into the room—faster or slower?"

by which the phenomena being modeled occur, but rather to foster students' construction of explanations that make sense to them and align with scientifically-accepted reasoning.

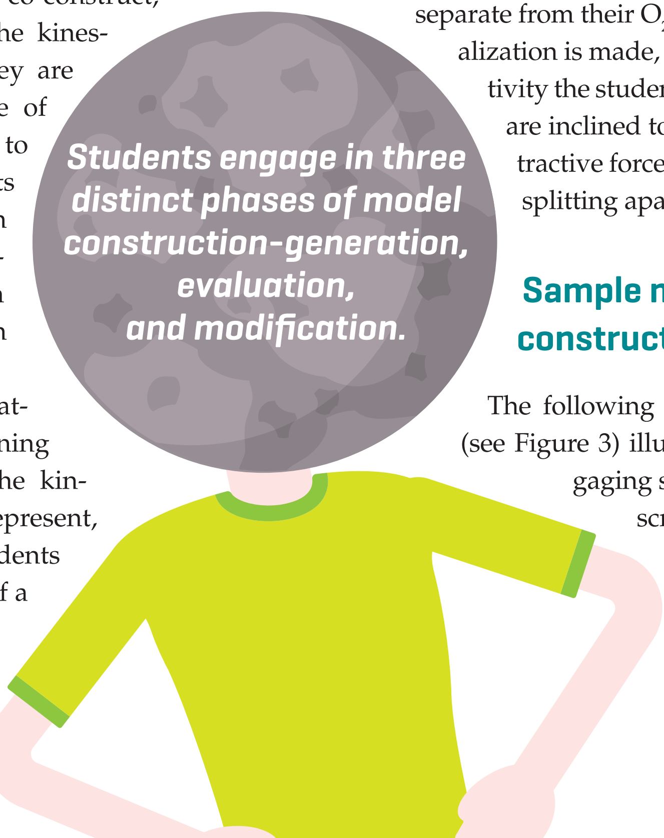
It will require you to:

- challenge students' thinking with discrepant questions,
- engage students in the evaluation of their own and one another's explanatory models,
- provide students with sufficient think time,
- refrain from passing judgment on their ideas, and
- foster the revision or modification of students' models over time.

Engaging your students in modeling cycles

In all of the kinulation lessons we have developed, the intention is for students to play active roles in the modeling of and reasoning about abstract scientific concepts, as opposed to simply following teachers' directions and going through the motions. Fostered by intermittent rounds of whole-group discussion, students and the teacher co-construct, evaluate, and critique the kinesthetic simulations as they are enacted for the purpose of making improvements to them. It is these aspects of student engagement in explanatory model construction that make such kinulation activities both hands-on and minds-on.

We suggest that, in attempting to foster reasoning about what and how the kinesthetic simulations represent, teachers engage their students in three distinct phases of a model construction process as described by Price and Clement (2014). These three model construction process are collectively referred to as the GEM (generation, evaluation, and modification) cycle:



1. Starting from students' prior knowledge about the concepts being explored, teachers can engage students in the *generation* of models to explain the phenomena.
2. By asking students to observe, critique, and predict, teachers can scaffold students' *evaluation* of the models' explanatory power.
3. If there are aspects of the models that students see as problematic or insufficient, teachers can encourage them to make *modifications* to the models.

It is common for students to cycle through the evaluation and modification phases in the development of intermediate, or partially developed models. For example, in the chemical reaction kinulation we describe above, we often see students in the O_2 pairs start splitting apart before they are even approached by an H_2 pair. These intermediate models are stepping stones on a learning pathway to a *target model*, or desired knowledge state (Clement 2000). In this kinulation, for example, the target model is for students to understand that it is the attractive forces of the H_2 molecules on the oxygen atoms that cause them to separate from their O_2 configurations. Once this realization is made, in subsequent trials of the activity the students representing O_2 molecules are inclined to wait until they "feel" the attractive force from the H_2 molecules before splitting apart.

Sample model co-construction class discussion

The following classroom transcript excerpt (see Figure 3) illustrates a teacher actively engaging students in the previously described GEM model construction cycle while teaching the Propagation of Sound Waves Kinulation. The

FIGURE 3: Transcript of class discussion and model construction processes taking place during sound propagation kinulation activity

Key
Green: Model generation ● Blue: Model evaluation ● Purple: Model modification

Speaker	Statement	Model construction process
Teacher	Let's pretend you are all air particles inside this big box. So, if I was the source of the sound, I want you to show me how you think you would respond as particles of air in the box. So, is everybody ready for the sound to pass through the box of air?	Teacher asks students to generate a model
Students	Yes!	
Teacher	[Makes a dramatic motion, extending arms outward while stomping foot once loudly on the floor.]	Teacher contributes to model
Students	[Students respond in various degrees and manners.]	Students generate a model
Teacher	Okay, I saw some people move around a little bit. I saw some people look like "I don't know what I'm supposed to do." Let's make a decision. How are we going to show that the sound travels from up here to the back of this box? What do you think?	Teacher asks students to evaluate the model
Student 1	Well, I think when you made that sound it actually made the particles jump and move around	Student evaluates model
Teacher	Interesting, so you think the particles should jump and move around when they get hit with the sound wave? How can we change our model to show that?	Teacher asks students to modify the Model
Student 2	I think the particles closest to the front should move first. They should be moving while the ones back here are standing still.	Student modifies model
Teacher	What do people think of what Jordan is saying?	Teacher asks students to evaluate the model
Student 3	That makes sense to me because the energy from the sound is moving in that direction, from up front to back there.	Student evaluates model

Teacher	Oh, okay, the energy is coming this way, so it hits you guys first?	Teacher asks students to evaluate the model
Student 4	Yes. We're the closest.	Student evaluates model
Teacher	Who should be the last ones to jump and move around?	Teacher asks students to evaluate the model
Student 5	We will	Student evaluates model
Teacher	You guys in the back row? How are you going to know when to jump and move around?	Teacher asks students to evaluate the model
Student 6	Right after the people in front of us do.	Student evaluates model
Teacher	Why is that?	Teacher asks students to evaluate the model
Student 5	Because the sound has to go through them before it gets to us.	Student evaluates model
Teacher	Does anybody else have any other modifications they'd like to make to our model?	Teacher asks students to modify the model
Student 7	Yeah, I think the way we are moving isn't right. We are jumping straight up in the air and putting our hands up when the sound reaches us but wouldn't it make more sense if we moved backward a little bit to show the direction the sound wave is hitting us; like from the front?	Student modifies the model
Teacher	What do we think about Marci's idea?	Teacher asks students to evaluate the model
Student 4	Yep, that's a good idea. We just have to be careful not to bang in to the people behind us.	Student evaluates the model
Student 8	But that would be fun. Can we do that?	Student evaluates the model
Teacher	I think for now, we'll keep everyone in their own space, but maybe bumping into each other is how particles really behave. What do you think?	Teacher asks students to evaluate the model

questions and comments from the teacher were intended to foster students' generation, evaluation, and modification of the models as they evolved. During the discussion, students appear to be collaboratively constructing understandings of their participation as components in the kinulation. We refer to this shared teacher/student process as the *co-construction of an explanatory model*.

Assessment of student understanding

As can be seen in the previous classroom discussion transcript, the teacher is engaging students in an ongoing type of formative assessment by providing them with opportunities to express their understanding of the concepts. Through probing questions and requests for explanation, elaboration, and application of ideas, the teacher is able to gain a sense of what students are grasping and areas where they may need additional support. We have found that an excellent way to determine whether students understand the big ideas is to step away from the group and tell them that now it is time for them to "run through" the model one more time without teacher input or commentary. Specific students can be called on to describe and explain what is taking place in the model and the teacher can ask other students to comment on these explanations. Additional assessment of student understanding can be conducted through post-activity science journaling, diagramming of models, and paired reflection.

See the sidebar on page **XX** for examples of students' science journal entries that demonstrate the depth of their understanding as developed through engaging in kinesthetic simulations.

Conclusion

In this article, we described a type of teaching process in which students and teachers collaboratively develop models they can physically engage in to better understand abstract scientific concepts. By having students take on active roles of key elements of natural systems, they can be encouraged to cooperatively act out and kinesthetically simulate particular scientific phenomena. Through a whole-class discussion process guided by the teacher, students are encouraged to generate, evaluate, and modify these human-sized explanatory models while they are being developed. Our belief is that this kind of student-centered pedagogy is crucial to having students critically develop personally relevant explanations for abstract scientific concepts. We encourage you to look for such concepts in the science units you are teaching and consider ways you can engage your students in the construction of explanatory models for them by becoming the models themselves. ●

REFERENCES

Clement, J. 2000. Model based learning as a key research area for science education. *International Journal of Science Education* 22 (9): 1041–53.

Griss, S. 2013. The power of movement in teaching and learning. *Education Week. www.edweek.org/tm/articles/2013/03/19/fp_griss.html.*

Keeley, P. 2008. *Science formative assessment*. Thousand Oaks, CA: Corwin Press.

Price, N., and J. Clement. 2014. Generating, evaluating, and modifying scientific models using projected computer simulations. *Science Scope* 38 (2): 39–46

Shapiro, L. 2010. *Embodied cognition*. New York: Routledge.

Stephens, L., and J. Clement. 2008. Anchoring student reasoning in prior knowledge: Characteristics of anchoring cases in a curriculum. Proceedings of the 2008 annual meeting of the National Association for Research in Science Teaching, Baltimore.

Williams, G., and J. Clement. 2015. Identifying multiple levels of discussion-based teaching strategies for constructing scientific models. *International Journal of Science Education* 37 (1): 82–107.

RESOURCES

Kinulation lesson plans and classroom video exemplars—*www.kinulations.com*

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