Supporting Scientific Model Thinking through Curriculum-based Making

Sharon Lynn Chu
The StoryLab@Texas A&M
Texas A&M University
sharilyn@tamu.edu

Genna Angello
Department of Visualization
Texas A&M University
gennaangello@tamu.edu

Francis Quek
TAMU Embodied Interaction Lab
Texas A&M University
quek@tamu.edu

Sara Pyle
Department of Psychology
Texas A&M University
sarapyle@tamu.edu

Abstract
Our work investigates how electronics Making may support the development of scientific model thinking in elementary school students in formal learning contexts. This paper presents initial themes uncovered through video-based analysis of fourth-grade students engaging in Making activities to create *simulation, concept-relation*, and *illustrative* models in the science classroom. Key themes were found in how the Making activities supported the students' articulation of the science concepts, as well as their sense of ownership towards the projects. Our findings indicate that there are numerous factors, including the role of Making, allowance for creative freedom, and the level of Making complexity, that need to be taken into account in the design of curriculum-based Making kits and activities for model thinking. We conclude that Making has the potential to support the development of model thinking in the elementary science classroom, but much further research is needed.

Author Keywords
Making; Children; Science; Science models; Model thinking; Electronics

ACM Classification Keywords
H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

Introduction

In their discussion of the impact of the Maker Movement on education, Halverson and Sheridan [1] highlight significant challenges that hinder the use of Making for learning in the classroom. For instance, because the American classroom is 'learning goals' driven, while Making is hands-on, exploratory, and creativity-driven [2], educators are reluctant to employ Making in the classroom and favor 'instructionism' to meet accountability goals and tests. Such challenges among others result in Making-oriented activities and kits being designed for and tested mostly in workshops and after-school programs, rather than in the classroom where formal learning actually takes place.

In this paper, we investigate whether and how Making may have a role in the modern classroom to teach scientific model thinking. Can Making provide the means by which students construct interactive models of their science, and in so doing, engage in learning science topics that are in line with their school's curriculum and the meta-level scientific model thinking? For our investigation, we adopt the approach of deploying prototype probes of designed curriculum-based science Making kits and activities in the classroom, and analyzing the students' engagement process to uncover themes that will inform the next iteration of the Making kits.

Our research engaged 3rd, 4th, and 5th grade students over a school year of science classes. These grades are when schools typically transition toward formal science curriculum. Developmentally, they fall into the *Concrete Operational Phase* [3, 4] where children transition from concrete modes of thinking to develop stronger abstractions. It is critical that students at this level begin to get a grasp of the role of models in science. This paper focuses on the 4th grade students engaging in Making-based curricula of three different types of models: simulation models, concept-relation models, and illustrative models. Following, we overview the use of models in the learning of science, describe our study, and present our findings.

Models in Science Learning

Scientific models are devices that represent systems of phenomena whose complex dynamics and causal relationships among factors may otherwise be abstract and not readily visible. Models are often designed to be simpler explanations and visualizations of the entire system that narrow down the focus to specific factors [5, 6], and their visual nature frees up working memory load [7]. When scientific models are expressed formally (e.g. through mathematics, computation, causal diagrams), they can be used to make predictions, test data, and generate new understanding [8].

Models come in many different forms [9]. We focus on three types of analogical models that contain visual, physical, symbolic, and verbal characteristics: Simulation models, conceptual models, and illustrative models. *Simulation or facsimile models* represent the process of a phenomenon such that one can see its performance and effects. *Concept-relation models* represent a phenomenon with an emphasis on the logic behind the concept itself, for instance showing cause-and-effect relationships. *Illustrative models* aim to depict the composition and process of the phenomenon in visual form.

Models are a central focus in the elementary or primary school science curriculum. For example, a 5th grade science curriculum in the US [10] states that students

should know that “models of objects and events are tools for understanding the natural world and can show how systems work”.

Multiple challenges have been identified in the use of models in science education, notably a: *i) lack of exploration and reflection:* Clement [11] characterizes modeling in science learning as one that moves the student from preconceptions to a target model, indicating that inquiry is critical for science models to be effective [12]. However, Justi and Gilbert [13] report that science teachers sometimes maintain the view that there is one correct model that must be presented to the students, rather than students working to discover and explore aspects of the model; *ii) lack of student motivation:* When multiple models are used in teaching, students become impatient [5, 6, 11, 14, 15]. Shwarz et al [8] further state that one of the challenges is “in giving students a real sense of audience for their models.” If students see models as instruments for them to communicate science concepts, they may be more willing to invest effort to understand and explore the models [8]; and *iii) a lack of sense of empowerment:* Students are often convinced that they are only making the models for the teacher, as a means to assess their learning [8]. Thus, they become concerned with memorizing models, and rarely understand the illustrative and explanatory purpose behind models, nor the necessity of multiple models [16].

Numerous methods and approaches have been proposed to embody, support and improve the effectiveness of model-based learning in elementary and middle school science. The MARS project [17-19] demonstrated the ability of 6th grade students to make and test predictions by running dynamic *interactive simulation models*. To understand mass, for example, students can use the model view in the application to *see* density differences. We are not aware of any research so far that looks at how Making may support scientific model thinking, especially for younger children.

Our research thus aims to fill in this gap in the literature, and asks the following question: *How may Making support scientific model thinking in elementary school students in the formal science classroom?*

Study Description

The data analyzed in this paper came from a year-long study, whereby 3rd, 4th and 5th grade students engaged in Making activities in their science classrooms for six non-consecutive weeks throughout the school year, with each week addressing a different science topic. Throughout the school year and the three grades, there were 22 simulation Making activities done, 4 concept-relation Making activities, and 6 illustrative Making activities. The class structure generally consisted of the following protocol: 1) a lecture on the science topic was given by the teacher; 2) the model to be created was described by a Maker instructor; 3) students were given the appropriate Making kit materials; and 4) the students worked in pairs to make the model and perform the associated science activities. All students provided verbal assent to participate, and parents signed consent forms prior to video and audio data collection. All procedures were approved by the Institutional Review Board.

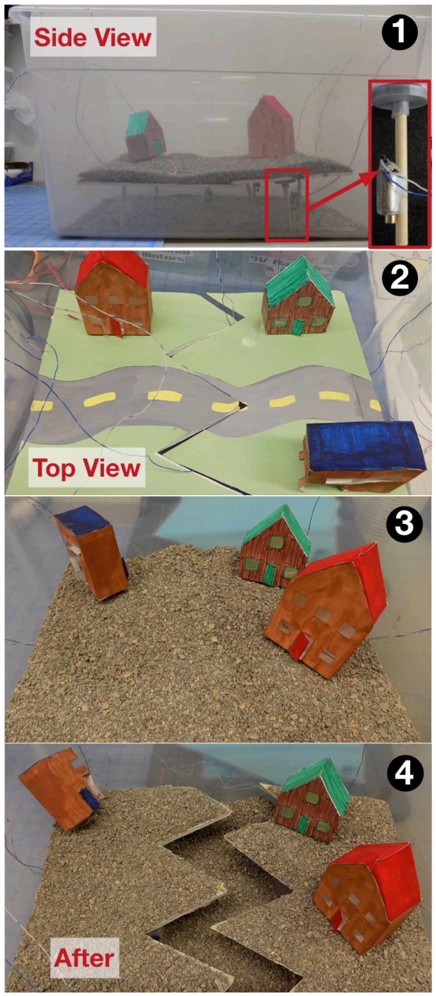


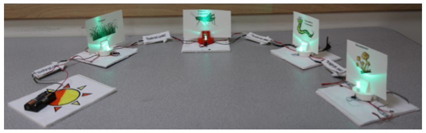
Figure 1. Simulation model of earthquake

The curriculum-based Making kits and activities were developed using an approach that engaged the science teachers of each grade and a design team brainstorming on how electronics and arts and craft may be used to satisfy at least part of the learning goal of the science topic in question. Aspects that were considered during the design process included the motor and cognitive abilities of the children, their level of previous knowledge on the topic, technical feasibility, etc. We do not describe the design process in detail here, as this paper focuses on how the students engage science models through Making in the classroom. For our current investigation, we selected the Making project performed in the 4th grade that was most representative of each of the 3 types of models of interest:

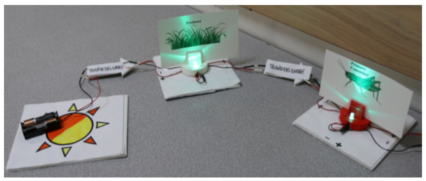
The 'Earthquake' Simulation Model: The curriculum unit covered for the chosen model was *Earth and Space: Rapid Changes*. The learning goal specified that students should understand that Earth consists of natural resources and its surface is constantly changing. One example of a rapid change in the Earth's surface is an earthquake. The Making-based model designed to simulate an earthquake (see Figure 1) consisted of a piece of foam board that was cut in half on a jagged line to represent tectonic plates. Kitty litter was spread on the plates to act as soil. Vibrating motors were taped directly underneath the surface of the tectonic plates and onto the wooden dowel rods underneath the tectonic plate surface such that their vibration when activated would cause the tectonic plates to collapse. The activity for each student pair was to create origami houses to represent a village at the spot where the earthquake would take place and to connect up the circuit of the vibrating motors.

The 'Food Chain' Conceptual Relation Model: The curriculum unit for the chosen model was *Organisms and Environments: Food Chains*. Students were expected to describe that the flow of energy derived from the sun and used by producers to create their own food is transferred through a food chain and food web to consumers and decomposers. The Making-based model to show the logical food chain (see Figure 2) consisted of pre-printed cards of the various organisms involved (e.g., plants, insects, reptiles, fungi) that are placed in custom-designed card slots that had holders for LEDs, a battery to represent the sun, and arrows cut out of foam board with wires attached that represent the energy transfer at each step of the food chain model. Connecting the battery (sun), wires (energy transfer arrows), and LEDs (organisms) correctly results in the LEDs lighting up. The activity for each student pair was to form the food chain and light it up.

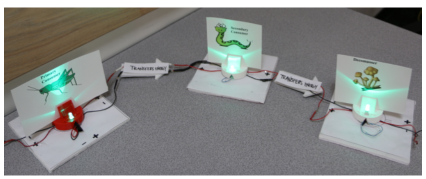
The 'Water Cycle' Illustrative Model: The curriculum unit for the chosen model was *Matter and Energy: Water Cycle*. The student is expected to identify the phases of the water cycle caused by heating and cooling, such as liquid water evaporating by the heat from the sun and condensation of water vapor forming liquid water, creating clouds. The Making-based model to illustrate the water cycle (see Figure 3) consisted of lighted dioramas of the water cycle using foam board, LEDs, and electric circuits. The activity for each student pair consisted of drawing a water cycle illustration, labeling the different processes within, placing the LEDs on the foam board drawing at spotst of the students' choice, and building the circuit to make the LEDs light up.



Food chain



Left side of food chain



Right side of food chain

Figure 2. Concept-relation model of a food chain

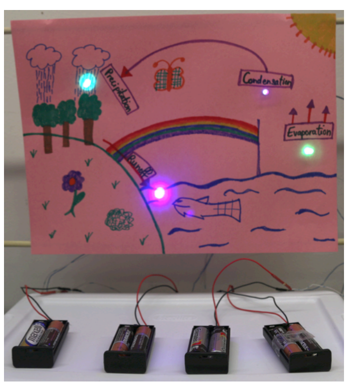


Figure 3 Illustrative model of water cycle

Data Collection and Analysis

All sessions of the study were audio and video recorded. Each table in the classroom, typically sitting 4 students, was recorded by one dedicated camera on a tripod and an audio recorder placed in the middle of the table. Two tables were randomly chosen for analysis for each focus activity, resulting in selected data of 24 students (3 Making activities X 2 tables X 4 students). The video and audio recordings for the tables for each of the 5 days that the study lasted were identified and distributed among 3 coders. The analysis process was conducted as follows: 1) Each coder was assigned a Making activity, and performed a basic first-cycle coding [20] on the videos, whereby descriptive codes are assigned to video segments to describe the content (i.e., explicit happenings and identifiable behavior units, e.g., M1 connects up red wire) of each segment, and relevant speech transcribed with timestamps. The coders focused on the actual Making process itself for this coding (as opposed to other parts of the class such as setting up materials, lectures by the teacher, etc.). Four passes of coding were done for each video, each time focusing on one particular child (since there were 4 students per table); 2) The 3 coders met several times to establish a common ground understanding for the types and granularity of codes during the first-cycle coding process; 3) Each of the coders then performed a second-cycle coding whereby the descriptive codes were classfied into categories that related to any aspect of model thinking, and the categories were labeled. All of the 3 coders were familiar with the literature review that was done on science models and presented earlier in this paper; 4) One coder performed a last round of coding to integrate the categories into themes.

Study Findings

We present below a discourse integrating the key themes that emerged from our video analysis under two main umbrella:

i) Students' articulation of science model thinking

Concept-relation 'food chain' model: Two approaches were seen in terms of Making-based model thinking. In one approach, the children pair focused on building the circuits first without thinking about the science concepts. Since the circuit was more complex than their electronics level of knowledge, they had little progress and needed to constantly ask for help. In the second approach, the children pair focused on getting the science concept right first (placing elements in order of logic of transfer of energy, seeking feedback from peers and instructors, swapping elements around if needed), and then moved on to building the LED circuits. Essentially, they used the structure of the food chain to guide them into knowing the order of the wire connections. For e.g., one pair determined that the battery as the sun should be on one end and the 'decomposer' LED on the opposite end. In this second approach, building the circuits simply functioned as a mark of completing the activity – having the LEDs light up were an affirmation of their success.

One problem that arose with this second approach, however, is that arrows representing the transfer of energy were neglected or forgotten in the subsequent building of the circuits. The students attempted to connect each element directly to each other. Their state of mind was that they had already placed the elements in the correct order physically, and did not think that another representational device is needed for the transfer

of energy. They found out about the relevance of the arrows only when they were building the circuits, which required wire connections.

Illustrative 'water cycle' model: The tension between Making and science concept was not seen in the illustrative model, since the activity clearly dictated the science concept to be clarified first (drawing of the water cycle illustration), before the Making activity could take place (inserting and connecting up the LED circuits into the illustration). However, students' mental models of the science phenomenon were seen in the aesthetic details and creative freedom that the Making activity allowed. For example, in one pair, a girl drew the sun pink, and the partner wanted her to redo the sun drawing to be "the real sun" which is yellow in her mind. Students also debated on the type of elements to draw (e.g., what type of water body to draw – lake, pond, sea, etc.), and where (e.g., water has to be underneath the sun), as well as how to use the LEDs to creatively emphasize different things in their drawings.

Simulation 'earthquake' model: The science concept and the Making was tightly coupled in the earthquake activity. Contrary to the concept-relation model activity, this was done mainly through the teacher who engaged the students in thinking about how the power or number of the vibrating motors whose circuits they were connecting represented the strength of the earthquake: "what that does is simulate what a small earthquake will do, and then more power and more power, and then you get to see finally what a big earthquake, what consequences that will create for your ground." More time was spent during this session with the class discussing aspects of earthquake (e.g., Richter Scale, gradations of earthquakes, locations of earthquakes), given the lower complexity of Making required as compared to the two other cases analyzed.

ii) Sense of ownership

The flexibility afforded by the *concept-relation 'food chain' model* Making activity (e.g., free arrangement of elements) helped mostly the students' articulation of their mental model). For the *illustrative 'water cycle' model* activity on the other hand, the flexibility of the Making activity provided the students with a strong sense of ownership. The students added elements not necessarily within the scope of the science concept in their water cycle illustration, e.g., butterflies, flowers, sharks in water, acorns on tree, stars. Many instances of a child pointing to certain parts of the drawing and saying "I did that" were seen. Sense of ownership in *simulation 'earthquake' model* came from a combination of Making, the science concept articulation, and artistic personalization details. The students revealed a strong sense of ownership of the causal change that resulted from the collapse of the houses they made in the earthquake model from the vibrating motors.

Discussion and Conclusion

In our study, we found that there are numerous factors to consider in how Making may support the development of scientific model thinking in the formal classroom context. Specifically, one has to consider *using Making as either the means or the end*. The approach of the science concept guiding Making appeared to work the best, notably because the child's Making knowledge is still premature. Using Making knowledge to guide science concepts understanding may be more feasible for an adult who already has fluency with Making. The science concept-guiding-Making approach also

seemed to allow Making to support scientific concepts that are more abstract in nature, e.g., the arrows in the food chain model.

A second factor is the use of either electronics/technology or arts and craft to allow for creative freedom in Making of the science model. Making generally necessitates for at least some allowance be made for creativity. One has to consider whether and how to capitalize on only arts and craft, technology, or both (e.g., drawing adornments and LED placements in the water cycle model) to allow that in the students' construction of science models.

And a third factor is the level of Making complexity and the degree of science concepts discussion. While it is logical that the higher the complexity of the Making, the less time for the amount of science discussion, and thus that lower Making complexity is desired, one has to consider how to still integrate elements of personalization details in the Making so as to deliver a sense of ownership in the students for the model. This is especially important given that electronics Making tend to be a complex activity for children, and making it less complex to fit both the child's abilities and within the class time period may remove the empowering elements necessary to maintain student interest in science modeling. In our earthquake model, we achieved that by combining origami houses with the motor circuits.

Our initial findings show that Making has the potential to attenuate some of the key problems with teaching scientific model thinking in the classroom, such as the lack of student reflection, motivation and empowerment. However, many factors have to be considered in the design of the curriculum-based Making kits and activities, including the role of Making, allowance for creative freedom, and the level of Making complexity.

The limitations of this study is that it is certainly tied to the specific designs of the curriculum-based Making kits that we used as probes, and the findings may thus be limited in terms of generalizability. Nevertheless, we believe that our analysis of the students' experience throughout the activities revealed factors that serve to enhance our understanding of designing for Making in the elemenary/primary school classroom.

Future work involves the analysis of more cases from our collected dataset of videos; investigating how to operationalize the simulation, concept-relation and illustrative types of science models into other specific designs of Making kits and activities; and studying curriculum-based Making with respect to other types of science models.

Acknowledgements

This research has been supported by NSF Grant: "Strategies: Making the Maker: A Pathway to STEM for Elementary School Students," DRL-1433770. We thank all the children and teachers who participated in the study.

References

1. Halverson, E.R. and K.M. Sheridan, *The Maker Movement in Education.* Harvard Educational Review, 2014. **84**(4): p. 495-504.
2. Dougherty, D., *The Maker Mindset*, in *Design, Make, Play: Growing the Next Generation of STEM Innovators*, M. Honey and D.E. Kanter, Editors. 2013, Routledge. p. 7-11.
3. Piaget, J., *The language and thought of the child (1923)*. 1973, New York: World.

4. Adey, P. and M. Shayer, *Accelerating the development of formal thinking in middle and high school students.* Journal of Research in Science Teaching, 2006. **27**(3): p. 267-285.

5. Harrison, A.G. and D.F. Treagust, *A typology of school science models.* International Journal of Science Education, 2000. **22**(9): p. 1011-1026.

6. Ingham, A.M. and J.K. Gilbert, *The use of analogue models by students of chemistry at higher education level.* International Journal of Science Education, 1991. **13**(2): p. 193-202.

7. Gobert, J.D. and J.J. Clement, *Effects of student-generated diagrams versus student-generated summaries on conceptual understanding of causal and dynamic knowledge in plate tectonics.* Journal of research in science teaching, 1999. **36**(1): p. 39-53.

8. Schwarz, C.V., et al., *Developing a learning progression for scientific modeling: Making scientific modeling accessible and meaningful for learners.* Journal of Research in Science Teaching, 2009. **46**(6): p. 632-654.

9. Chamizo, J.A., *A new definition of models and modeling in chemistry's teaching.* Science & Education, 2013. **22**(7): p. 1613-1632.

10. Texas Education Agency (TEA). *§112.16. Science, Grade 5, Beginning with School Year 2010-2011.* STAAR: State of Texas Assessments of Academic Readiness 2015 [cited 2016 March 21st]; Available from: http://tea.texas.gov/WorkArea/linkit.aspx?LinkIdentifier=id&ItemID=25769822641&libID=25769822740.

11. Clement, J., *Model based learning as a key research area for science education.* International Journal of Science Education, 2000. **22**(9): p. 1041-1053.

12. Buckley, B.C., *Interactive multimedia and model-based learning in biology.* International journal of science education, 2000. **22**(9): p. 895-935.

13. Justi, R.S. and J.K. Gilbert, *Science teachers' knowledge about and attitudes towards the use of models and modelling in learning science.* International Journal of science education, 2002. **24**(12): p. 1273-1292.

14. Coll, R.K. and D.F. Treagust, *Learners' mental models of chemical bonding.* Research in Science Education, 2001. **31**(3): p. 357-382.

15. Harrison, A.G. and D.F. Treagust, *Secondary students' mental models of atoms and molecules: Implications for teaching chemistry.* Science education, 1996. **80**(5): p. 509-534.

16. Justi, R. and J. Gilbert, *History and philosophy of science through models: some challenges in the case of'the atom'.* International Journal of Science Education, 2000. **22**(9): p. 993-1009.

17. Raghavan, K. and R. Glaser, *Model–based analysis and reasoning in science: the MARS curriculum.* Science Education, 1995. **79**(1): p. 37-61.

18. Raghavan, K., M.L. Sartoris, and R. Glaser, *Impact of the MARS curriculum: The mass unit.* Science Education, 1998. **82**(1): p. 53-91.

19. Raghaven, K., M. Sartoris, and R. Glaser, *Why does it go up? The impact of the MARS curriculum as revealed through changes in student explanations of a helium ballon.* Journal of Research in Science Teaching, 1998. **35**(5): p. 547-567.

20. Saldaña, J., *The coding manual for qualitative researchers*. 2nd ed. 2012: Sage.