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Supporting scientific modeling through curriculum-based making in elementary school science classes

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ABSTRACT

Our work investigates how Making may be used in the context of scientific modeling in formal elementary school science classes. This paper presents an investigation of fourth- and fifth-grade students engaging in Making activities to create simulation, concept-process, and illustrative models in the science classroom. Based on video analyses of the Making-based class sessions, a generalized process model was developed for each type of science model. In addition, cross-cutting themes were found in Making-based science modeling: first, there are two loops that intersect and interact with each other (modeling for Making and modeling for Science content), and they interrelate in various ways depending on science model type; and second, showcasing Making products (sharing with peers, teachers, or helpers) is a primary factor that determines students' overall engagement with science in the activity. We suggest that Making-based science kit and lesson design needs to support students to showcase their Making output, on top of science-related reflections, and to consider the balance between Making and science activity. We conclude that Making has the potential to support the development of scientific model thinking in the elementary science classroom, but much further research is needed in this area.

1. 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 most classrooms worldwide are '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 amongst 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.

In this paper, we investigate how Making may have a role in the modern classroom to support scientific modeling. How do students engage with scientific modeling through the hands-on construction of interactive models of their science, and in so doing, engage in learning science topics that are in line with their school's curriculum? 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 of interest.

Our research engaged 4th and 5th grade students over two school years of science classes. These grades are an important turning point in many educational systems, for example, in the United States when schools typically transition toward the implementation of formal science curricula and testing. Developmentally, they fall into the *Concrete Operational Phase* [3,4] where children begin moving beyond concrete modes of thinking to develop stronger abstractions. While some have raised questions concerning the rigidity of developmental staging [5,6], most agree that general developmental progression does take place in the child, and the progression correlates generally with biological age [6,7]. It is critical thus that students at this level begin to get a grasp of the role of models in science. This paper focuses on students engaging in Making-based curricula using three different types of models: simulation models, concept-process models, and illustrative models. Following, we provide an overview of the use of models in the learning of science, describe our study, and present our findings from qualitative video-based analyses, and discuss their relevance with respect to Making-based science learning in elementary education.

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2. Models and modeling in science learning

2.1. Background

Scientific models are essentially representations of 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 an entire system by narrowing the focus to specific factors [8–10]. As described by Chamizo [11], "models (m) are partial for the world (M)". The visual nature of models have been shown to free up working memory load [12] as one thinks about the phenomenon in focus. When scientific models are expressed formally (e.g. through mathematical formula, computation, causal diagrams), they can be used to make predictions, test data, and generate new understanding [13]. Research in the use of models and modeling to teach science is known as the 'model-based view (MBV) of science' [14].

Harrison and Treagust [8] identify ten different types of models. Analogical models, also referred to as expressed models [15,16] can take various forms ranging from the visual (e.g., 2D diagrams or illustrations), physical or concrete (e.g., 3D structures), to the symbolic or mathematical, and verbal [11,17,18]. We focus on three types of analogical models in our research: (i) *Illustrative models*, which are equivalent to Harrison and Treagust's 'maps, diagrams and tables' that represent "patterns, pathways and relationships" typically in 2D form, e.g., blood circulation; (ii) *Concept-Process models*, which represent the process of a science phenomenon, e.g., oxidation; and (iii) *Simulation or facsimile models* that are dynamic models representing the complex process of a phenomenon such that one can see its performance and effects, e.g., global warming.

Models are a central focus in the 5th and 6th grade science curriculum. For example, the 5th grade science curriculum for Texas [19] states that students should know that "models of objects and events are tools for understanding the natural world and can show how systems work". The students are expected to "draw or develop a model that represents how something works or looks that cannot be seen such as how a soda dispensing machine works". The Next Generation Science Standards [20] also list 'systems and system models' as one of the key cross-cutting concepts that students should be familiar with in the 5th grade (e.g., "A system can be described in terms of its components and their interactions").

Prior research has shown that the use of models in science education helps students to gain better understanding of science concepts [21,22]. Gobert [23], for instance, presents case study evidence of 5th grade students constructing a simple static diagrammatic illustrative model of plate tectonics and then later correcting the model to include concepts such as movement of magma and convection currents escaping from the Earth's core. Her findings highlight the importance of students accepting errors in original interpretations and believing that models can be altered to account for new factors in the science. A meta-level knowledge of model thinking is also important. Gobert and Discenna [24] administered an Epistemology Questionnaire to gauge the level of 9th grade students' understanding of the purpose of models. They found no significant difference between the quality of the diagrammatic illustrative models of those who expressed a higher level of scientific understanding, compared to those with a lower level of understanding. However, they did find that students who demonstrated greater understanding of the purpose of models were better able to apply their knowledge expressed in the model (e.g., plate tectonics) toward the understanding of complex associated causal mechanisms (e.g., convection), while also demonstrating stronger knowledge transfer to new contexts (e.g., continental and ocean plates). This demonstrates the importance of students learning more than just how to construct and assemble physical models. If that is the stopping point of their level of understanding, they will miss the opportunity to apply the knowledge demonstrated in the models toward constructing new knowledge and testing theory to better understand complex dynamic processes and relationships [25].

2.2. Problems with model-based learning

Multiple challenges have been identified in the use of models in science education, notably a: (i) *lack of exploration and reflection:* Clement [26] 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 [27]. However, Justi and Gilbert [28] 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 [8,9,26,29,30]. Shwarz et al. [13] 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 [13]; 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 [13]. Thus, they become concerned with memorizing models, and rarely understand the illustrative and explanatory purpose behind models, nor the necessity of multiple models [31].

2.3. Methods of teaching science modeling

Numerous methods and approaches have been proposed to support model-based learning in elementary and middle school science. The MARS project [32–34] 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. Such computational models engage the student's spatial reasoning abilities that include spatial visualization, orientation, and relations [35]. Others have investigated the use of *textual and graphical computer programming environments* in the classroom as modeling tools for scientific phenomena [36–39], showing that the type of programming environment affects how children engage in model-based reasoning and computational thinking. In Louca's work [36] for instance, students modeled different scientific phenomena (buoyancy, accelerated motion, etc.). The study showed that children who employed a system that hid the complexities of programming through a direct manipulation program interface had more difficulty discussing the phenomena they modeled than children who used a harder-to-learn LOGO programming language. Wilkerson-Jerde et al. [40] studied the differences in students' science modeling practices using *drawing, animation, and simulation*. Their in-depth qualitative analysis showed that the representational forms afforded by the three different media (drawings emphasize *components and relationships*; animation emphasizes *process*; and computational simulations encode *rules and causal interactions*) led the students to move through design modeling cycles from 'messing about' to actually 'digging in'.

3. Making for learning

Making has been broadly defined as "the use of technological resources to build something of interest" [41]. Work in Making can be seen as encompassing most commonly three main technological areas: (i) Electronics; (ii) 3D digital fabrication; and (iii) Programming or computation. Rode et al. [42] for example detail a case study of ten children, ages 8 to 10, who engaged in an e-textiles project that involved both electronics and computation. The children made 'monsters' with fabric and conductive thread in an elementary after-school computer club. The children used the LilyPad Arduino and the *ArduBlock* block-based programming environment to control the electronics (e.g., turning LEDs on and off) in their monsters. We posit that Making may help the child in scientific modeling for at least two reasons:

The use of Making for science learning falls within an area called 'learning-by-design', whereby learning happens "by engaging in design-and-build challenges culminating in the production of an 'artifact' that represents underlying understanding" [43,44]. The physicality benefit of learning-by-design can be seen most clearly when contrasted with methods that have used pure programming and simulation environments to support students in science (e.g., [36]). In such environments, either children program aspects of a graphical science model, or they are given a pre-programmed model that they can manipulate by changing the variables. In the former case, the model is built through code, while in the latter, code is used to vary the simulated output. In Making, students construct the model themselves using materials (e.g., cardboard and motors) and use code manipulation to effect changes in the physical model operation (e.g., to make the motor spin faster). Physicality brings in all the benefits of embodied cognition (e.g., [45]), constructionism [46] and tinkerability [47] to affect the child's desire and ability to explore the science model, and the child's understanding of the effects of variable manipulations.

We are not aware of any research so far that looks at how Making may interact with scientific model thinking, especially for younger children. Our research aims to fill in this gap in the literature, and asks the following question: *How do elementary school children engage in Making for scientific modeling in the formal science classroom?*

4. Study description

The data analyzed in this paper came from a two-year study, whereby 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 two school years and the two grades, there were 9 simulation Making activities done, 9 concept-process Making activities, and 6 illustrative Making activities. The science class lasted 45 min for 4th grade and 1.5 h for 5th grade. The class structure for both grades 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 interactive model and perform the associated science activities. All students provided verbal assent to participate, and parents signed consent forms for video and audio data collection prior to the beginning of each school year. All procedures were approved by the Texas A&M Institutional Review Board. During all study sessions, at least two helpers, who are mostly undergraduate students, are present in the classroom to assist with any logistics and classroom management issues.

The curriculum-based Making kits and activities were developed using an approach that engaged the science teachers of each

Fig. 1. Simulation kit of earthquake.

grade and a design team brainstorming on how electronics and arts and craft may be used to satisfy partially or fully the learning goals of the science topic in question. Aspects that were considered during the design process of the kits 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. A high-level description of the Making kit design process can be found in Chu et al. [48]. For our current investigation, we selected the Making projects done that were the most representative of each of the three types of models of interest in year 1, and the most representative in year 2 of the study. Thus in total, two of each type of model were selected across grades 4 and 5 and years 1 and 2.

4.1. Simulation models

Year 1: The 'Earthquake' Making kit: The 4th grade curriculum unit covered for this kit 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 Fig. 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

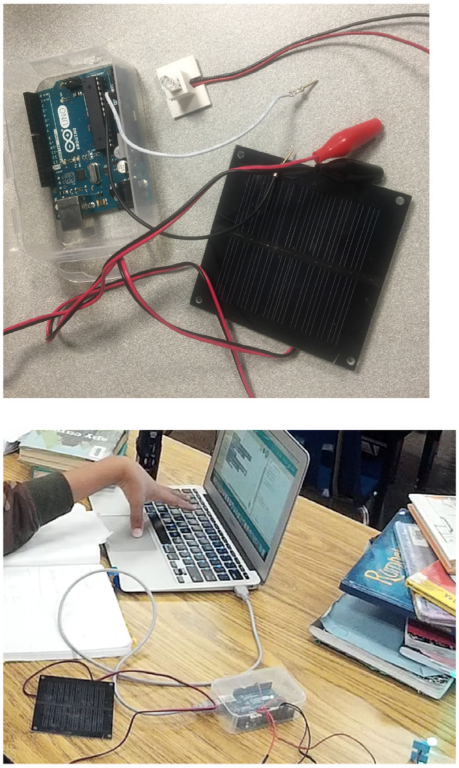
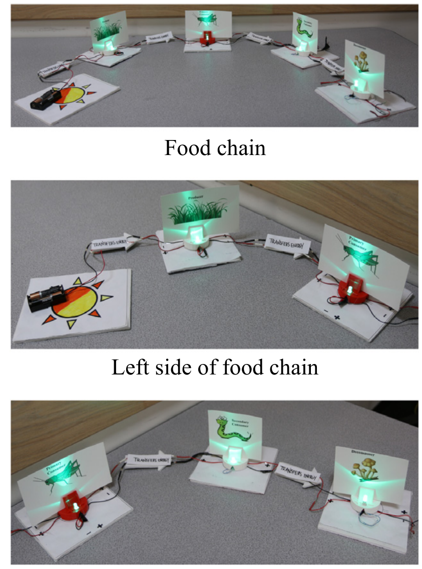


Fig. 2. Simulation kit for solar energy.



Food chain

Left side of food chain

Right side of food chain

Fig. 3. Concept-process kit for food chain—Year 1.

wooden dowel rods that support the foam board. When the motors are activated, the vibrations 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.

Year 2: The 'Solar Energy' Making kit: The 5th grade curriculum for this model was *Earth and Space: Alternative Forms of Energy*. Students were expected to be able to understand that solar energy (light) is a renewable resource. The Making-based model for learning this objective consisted of a solar panel that was connected to an LED and an Arduino (see Fig. 2 top). The lights in the room ceiling were used to represent the sun. The goal of the activity was for students to build a simple program in the *Ardublockly* programming environment (Fig. 2 bottom) using *if-then* statements (the template for the code was given to the students), and input different values into the program to determine how much light the solar panel sensor would need in order to power on an LED.

4.2. Concept-process models

Year 1: The 'Food Chain' kit: The 4th grade curriculum unit for this kit was *Organisms and Environments: Food Chains*. Students were expected to understand that energy originates from the sun, is used by producers to create their own food, and is transferred through a food chain and food web to consumers and decomposers. The Making-based model to show the logical food chain (see Fig. 3) 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 contained integrated holders for LEDs, a battery to represent the sun, and foam board arrows embedded with a pair of wires 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.

Year 2: The 'Food-Chain' kit: Similar to the food chain kit in year 1, the 4th grade activity for the food chain curriculum unit asked students to model their understanding of the flow of energy from the sun to various producers, consumers, and decomposers. However, in this project, the Making-based activity consisted of LEDs, pictures of producers, consumers, and decomposers, Arduinos and laptops (see Fig. 4). Students first wrote a story about their food chain, and then were tasked with programing the 'wait time' for their LEDs (how long the LED remains on) to match their story as it was read aloud. For example, when the student is talking about the grasshopper (consumer), the LED representing the grasshopper should be illuminated; when the student moves on to the hawk, the LED representing the hawk should be illuminated, and so on.

4.3. Illustrative models

Year 1: The 'Water Cycle' kit: The 4th grade curriculum unit for this kit 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 to form liquid water droplets, creating clouds. The Making-based model to illustrate the water cycle (see Fig. 5) 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 on the graphic, placing the LEDs on the foam board drawing at locations of the students' choice, and building the circuit to make the LEDs light up.

Year 2: The 'Properties of Soil' kit: The curriculum for this model was *Earth and Space: Examining Properties of Soil*. Students were expected to be able to examine characteristics of soil, including color and texture, capacity to retain water, and ability to support growth of plants. The types of soil used were loam, silt, sand, and clay. After the students spent several class periods examining each soil, the Making-based activity included LEDs, batteries, and switches, which the students used to correctly place their LEDs in a chart that represented each soil's capacity to retain water (see Fig. 6). Connecting the LED, switch, and battery correctly would allow it to light up during a quiz at the end of the session.

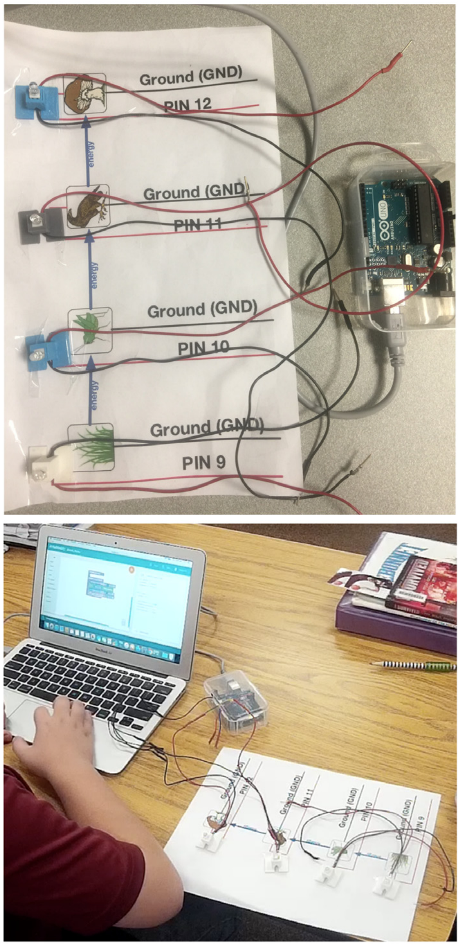


Fig. 4. Concept-process kit for food chain—Year 2.

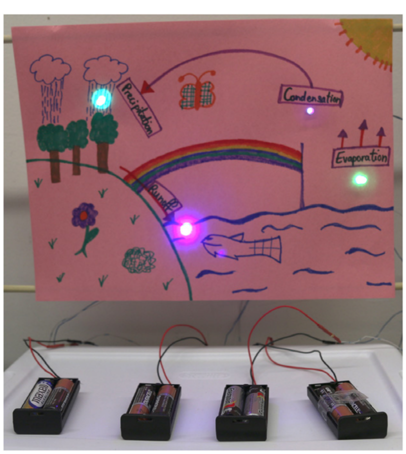


Fig. 5. Illustrative kit for water cycle.

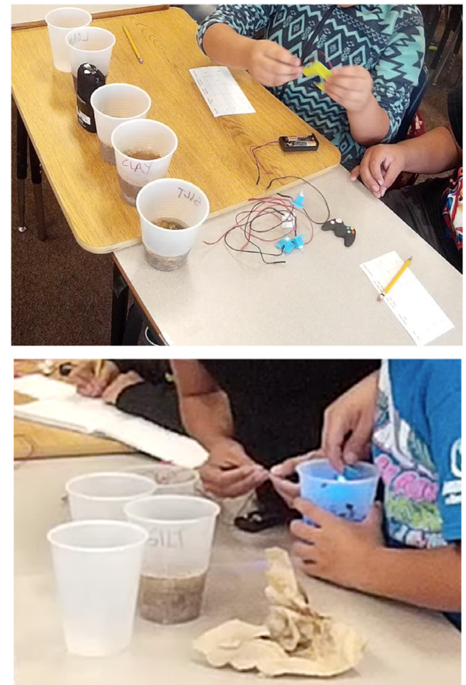


Fig. 6. Illustrative kit for properties of soil.

5. Data collection and analysis

All class sessions of the study were audio and video recorded. Each table in the classroom, typically sitting two to four students, was recorded by one dedicated camera on a tripod and an audio recorder placed in the middle of the table. Two to four tables were chosen for analysis for each focus kit/activity, resulting in selected data of 48 students (16 students or 8 student-pairs per model type). None of the students were the same across the various sessions. The six Making activities to be analyzed were distributed among four coders. For each Making activity, the assigned coder was given the video and audio recordings for the tables for each of the five days that the study lasted for that Making activity. The analysis process was conducted as follows: (1) For each video, the coders performed a basic first-cycle coding [49], 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.). Multiple passes of coding were done for each video, each time focusing on one particular child (e.g., four passes if there were four students per table in a particular video); (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 [49] whereby the descriptive codes were abstracted out to key phrases that captured the essence of the activity being performed by the child, e.g., ‘M1 connects up red wire to Arduino’ and ‘M1 switches wire to pin 9’ would both be coded as ‘Connecting circuit’; (4) One coder then constructed a generalized process model for each science model type by synthesizing the activity flows for all the 8 student-pairs analyzed per model type; and (5) Finally, the coder performed a round of thematic coding by comparing and contrasting first- and second-level codes to generate themes.

6. Study findings

6.1. Generalized process models

Simulation science models: The simulation models analyzed were the ‘earthquake’ and the ‘solar energy’ kits. The science model for the ‘earthquake’ kit was that the movement of tectonic plates

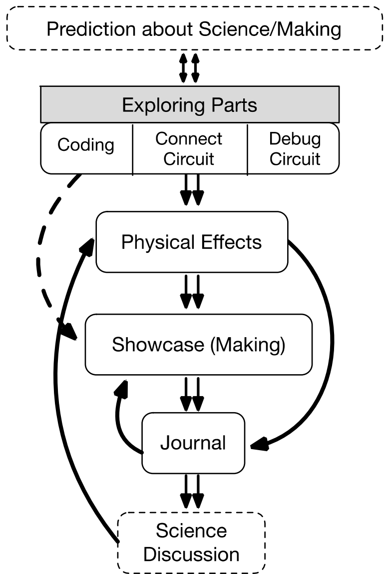


Fig. 7. Process model for simulation science modeling.

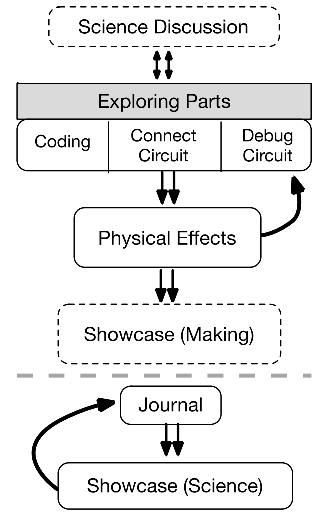


Fig. 8. Process model for concept-process science modeling.

result in the shaking of the earth that causes houses to collapse. The science model for the 'solar energy' kit was that a certain amount of energy from the sun is needed to power a device. Students built models to simulate these processes. The generalized process model for simulation science models is shown in Fig. 7. Engagement typically began with an initial discussion about the science either led by the teacher or among the students themselves. This involved predictions that integrated science and Making, e.g., "how many circuits do you think need to be connected before it falls apart?"

Students then began by either exploring Making parts (e.g., examining the solar panel) or engaging in Making by connecting up circuits, debugging circuits, and coding (if needed for activity). They then observed the physical effects produced, e.g., lighting up of the LED, collapsing of the houses. Students showcased the effects or sometimes their code itself to others (helpers, teachers, peers). The showcase of their Making was followed by journaling. Writings in their journals detailed the science model, e.g., "the earthquake caused the houses to fall". This was typically followed by a post-science-related discussion that integrated Making and the science, either led by the teacher (e.g., "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"), or catalyzed by the students themselves (e.g., a student asking whether the solar panel can power their laptops).

Concept-process science models: The concept-process models analyzed were the 'food chain' kits. The science model was that energy is transferred from producers to consumers to decomposers. The generalized process model for concept-process kits is shown in Fig. 8. Two approaches were seen. In the first approach, the students focused on getting the science concept right first (e.g., placing elements in order of logic of transfer of energy) through discussion and referencing of the Making components (e.g., moving bubble diagrams in correct order, pointing), and then moved on to Making. Essentially, they used the structure of the food chain to guide them into knowing the order of the wire connections, or the logic of their code. For example, one pair determined that the battery as the sun should be on one end and the 'decomposer' LED on the opposite end. Making functioned as a mark of completing the activity, e.g., having the LEDs light up in the correct sequence was an affirmation of their success. One problem that arose with this approach 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.

In the second approach, there was no science discussion initially. The students focused on Making first without thinking about the science concepts. Since the Making was more complex than their electronics/computational level of knowledge, they needed to constantly ask for help. In both approaches however, science reflections after Making if done, was a separate loop of journaling and showcasing what they wrote about the food chain in their journal, unlike for simulation models whereby journaling interacted with showcasing of their Making.

Illustrative science models: The illustrative science models analyzed were the 'water cycle' and 'soil properties' kits. The emphasis of the science model for the former was that the water cycle consists of multiple processes including precipitation, condensation, evaporation, etc., and the science model for the latter was that different kinds of soils have properties that vary in terms of texture, color, water retention, etc. The generalized process model for illustrative science modeling is shown in Fig. 9. For all groups, engagement with the illustrative model kits started with the students exploring the non-Making materials given for the activity (e.g., soils, cups, coloring). This was followed by sharing what one has done or found out with others, and noting it down in the journal. This cycle was distinct from the Making cycle of exploring parts and interacting with circuits, checking the physical effects (e.g., seeing whether the LED placement is as desired), and optionally sharing the interactive products with peers, helpers or the teacher depending on the project.

6.2. Cross-cutting themes

Theme 1: Layers of modeling for science: Irrespective of model types, we found that there are two loops that intersect and interact with each other in Making-based science modeling. A common underlying pattern of activity underlined all the Making kits. Modeling for Making included behaviors consisting of exploring parts, coding, connecting circuit, debugging circuit, exploring physical

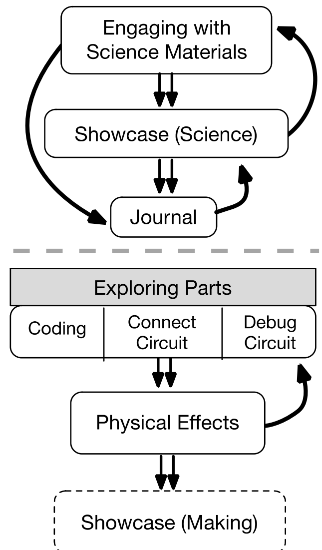


Fig. 9. Process model for illustrative science modeling.

effects, and showcasing. Modeling for science content included behaviors including journaling, discussion with peers, showcase, exploring materials, and teacher-led Q&A. Differences among the generalized process models of the three science model types were in terms of the sequencing order of the Making and Science loops, and extent to and way in which the two loops interacted.

For instance, for simulation models, science interacts intimately with Making in the actual parts used and physical effects (e.g., angle of solar panel, number of motors used, seeing how the plates separate). One can think of it as 'Making = Science'. For illustrative models, Making essentially becomes an expression of the student's knowledge (e.g., LED indication of the correct soil properties, placement of LED at water cycle processes for emphasis), after the student has already given at least some thought to the science first, essentially 'Science >Making'. The interaction of Making and science in concept-process models is ambiguous. Making may or may not interact with science aspects at all depending on the approach taken by the student. One can think of it as 'Science <>Making'. If they do interact, Making can possibly act as a scaffold for the science or vice versa.

Theme 2: Significance of showcase: An interesting theme that emerged was the importance of showcasing in terms of both Making and science reflections. We use the term 'showcase' here to refer to any kind of sharing by the student, e.g., showing off her work to a friend, asking a helper to look at her work, the teacher reviewing her work, a formal presentation of her work to the class, etc. While science reflections were most of the time given a (formal or informal) avenue for showcase, Making output was not always showcased. When the teacher did not set up formal presentations involving Making, many students found avenues for showcasing their Making successes and products such as by pulling a friend over to their table, announcing loudly to the class, or asking the teacher to come over. However, we observed that whenever Making showcase did not happen in one way or another, retraction behaviors occurred and the child decreased engagement or completely failed to engage in science reflections subsequently. That may not be problematic for cases when the Making loop takes place after the Science loop, in which case the child still gains in terms of science learning. But in cases when the Science loop typically takes place after the Making loop or the two loops take place in parallel or alternately, the child may never engage in science reflections at all.

A stark scenario example was in the class session using the 'food chain' (Year 2) kit. Darius (name changed for anonymity) spent a good amount of time coding the LEDs such that they went on and off "like Christmas lights" in the food chain sequence. He managed to make it work as he wanted and called the teacher over twice to look at his product. When the teacher finally came to his table, he looked at his partner's science journal but not at Darius's LEDs. His artifact did not draw the attention of other students either who were busy working on their own circuit or journal, and his partner did not mention anything about his accomplishment. Thereafter, Darius disengaged completely from the activity and refused to write down or draw anything in his science journal. This suggests that Making-based science kits and activities need to factor in the need for showcase in their designs.

7. Discussion and conclusion

Our study explored how Making interacts with engaging students in science modeling in 4th and 5th grade science classes. We deployed Making kits as probes that covered simulation, concept-process and illustrative analogical science models. Generally, all the three science model types led to similar student behaviors. We were surprised that a generalized process model could be constructed across all our analyzed cases. The process models may provide a foundation for researchers to begin thinking about the role of Making in the science classroom. We described two key themes of observed interactions and possible effects that may inform the design of educational Making kits to be used in formal contexts.

We suggest that the following two factors be taken into consideration in the area of Making-based science learning: (i) 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 productive for an adult who already has fluency with Making. An exception is if the science model is intimately related with the Making as in the simulation models whereby Making is needed to see the effects of the science phenomenon to be learned. The science-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; and

(ii) A second factor is the *level of Making complexity or amount of Making and the degree of science activity*. While one would expect that the higher the complexity of the Making or the more Making a kit contains, the less time for the amount of science activity. However, Making and science relate in different ways. One can be used to catalyze the other by motivating the child to engage in the other, or to scaffold the other by helping the child in performing in the other, or to equalize contributions in the activity by offering students on the team each a different role to play. A delicate balance is needed in the design not only of the Making kit but also of the overall Making-based science activity in the classroom.

The limitations of this study are that first it is certainly tied to the specific designs of the curriculum-based Making kits that we used as probes, which may have somehow led to biases in certain findings. Second, we did not account for students' baseline experience with Making or starting level of understanding of the science concepts in our video-based analysis. Although we have no reason to believe that Making knowledge varied widely among the students analyzed since they all entered into our Maker program at the same time, differing baseline experiences may have affected their behaviors. Nevertheless, these limitations do not diminish the value of our findings that attempted to abstract out behaviors and potential qualitative effects.

Future work involves the analysis of more cases from our collected dataset of videos; investigating how to operationalize the simulation, concept-process 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.

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