Using Computer-based Modelling for Primary Science Learning and Assessment

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ABSTRACT

Computer-based modeling is not just a means for students to learn important scientific knowledge and skills, but also a technique to assess student understandings of science. A software tool called Model-It allows young students to create their own models so that their learning becomes more interactive and engaged. However, there is a mismatch between how students learn and how they are assessed if conventional paper-administered tests are used. This paper argues for alternative assessments to be better aligned with curriculum and instruction.

Forty 4th grade students in a local Singapore school participated in a science inquiry activity that involved learning with modeling as an alternative assessment. The students individually created models of food webs to illustrate their understanding of energy flows and photosynthesis. A scoring rubric based on four criteria ("focus and structure", "accuracy", "completeness" and "functionality") was used to evaluate the models, with the modeling scores being compared to student scores of the school's paper-based assessments of science learning. In addition, 18 students were interviewed about their understanding of models and modeling. The data is currently being analyzed and the findings of this study and potential implications for educational assessments will be presented in this paper. (200 words)

Introduction

> "Assessing student knowledge and educational outcomes is not as straightforward as measuring height or weight; the attributes to be measured are mental representations and processes that are not outwardly visible. Thus, an assessment is a tool designed to observe students' behavior and produce data that can be used to draw reasonable inferences about what students know (Pellegrino, 2003)."

How to design assessment tools that reflect students' understanding in order to inform instruction is a great challenge for educators. Pellegrino, Chudowsky and Glaser (2001) and their National Research Council committee proposed an assessment triangle that identified three key elements underlying any assessment (Figure 1). The first element is a model of *cognition* and learning in a domain; the second element, *observation*, are tasks or situations that prompt students to say, do, or create something to demonstrate knowledge and skills; and the third element is *interpretation*, which is a process for making sense of the evidence (Pellegrino, Chudowsky, & Glaser, 2001).

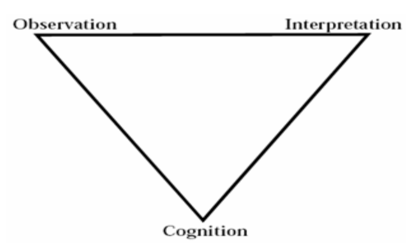


Figure 1. The assessment triangle (Pellegrino, Chudowsky, & Glaser, 2001, p. 44)

Introducing systemic thinking and modeling in primary science curricula is aligned with the requirement in Singapore's primary science syllabus (http://www.moe.gov.sg/cpdd/doc/Science_Pri.pdf). Using computer-based modeling as an assessment tool fits the stated framework well. The exploratory study reported here is part of a larger project. We used a computer-based modeling program called Model-It as an alternative assessment tool for fourth grade science students. For *cognition,* or the learning outcome, that we assess is students' understanding of energy flow, photosynthesis, and food chain. The *observations* are individual student models, their performance in traditional exam, and their understanding of models and modeling captured by interviews. Our *interpretation* is based on our analysis using rubrics. The following questions guided this study: First, can a computer-based modeling be used as an alternative assessment tool for young students? Second, what are the characteristics of 4th Grade students' initial models?

Literature Review

Constructing, testing, and revising models (as part of modeling) is central to scientists' daily practices (Clement, 2000; Latour, 1987; Magnani, Nersessian, & Thagard, 1999). Engaging students in modeling has the premises for connecting school science to real science (National Research Council, 2000) in order for them to understand science and the nature of science (J. Gobert, Snyder, & Houghton, 2002; Schwarz & White, 2005). One of the suggestions from Project 2061 (AAAS, 1990) is that in pre-college classrooms, mathematical models and computer simulations should be used in studying evidence from different resources in order to form a scientific understanding of the universe.

A model is "a conceptual representation of something, described verbally, visually, or quantitatively" (Jonassen, 2005). The process of building, test, and revising models is called modeling. With ubiquitous computing power, computer-based modeling provides great potential for students to construct and manipulate their models (Stratford, 1997). The models become external representations of their understanding of science phenomena. They allow students to make their thinking visible and receive feedback from others (Gordin & Pea, 1995). Engaging students in scientific practices through modeling provides a context for students to construct knowledge and to integrate content, inquiry and epistemological understanding of science (Clement, 2000; J. D. Gobert & Buckley, 2000; Penner, 2001). Grosslight and colleagues (1991) classified student understanding of models and modeling into three levels. At level 1, students believe that there is a 1:1 correspondence between models and reality. For example, models are toys or small incomplete copies of actual objects. A model is correct when it is of the same appearance as the real thing. At level 2, students understand that models are representations of real world objects or events rather than representations of ideas; and a model's main purpose is communication rather than for exploring ideas. Only experts satisfy level 3 understanding. They consider models to be multiple; are thinking tools; and can be purposefully manipulated by the modeler to suit his/her epistemological needs.

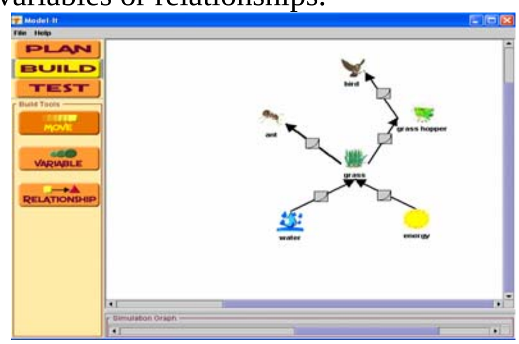
Using computer-based modeling for learning and assessment satisfies formative assessment situation which are authentic simulations rich in contextual details (Wiggins, 1992). The details of student understanding cannot be captured by traditional paper and pencil tests. Therefore, we propose using computer-based modeling as an alternative assessment to student learning outcomes. Meanwhile, computer-based modeling can become a form of formative assessment if we intend to use the results to inform teaching and change instruction plan accordingly. On the other hand, we do not exclude traditional paper and pencil tests as other forms of assessment, such as concept mapping because experts are able to represent their knowledge in different ways (Jonassen, 2005).

Methods

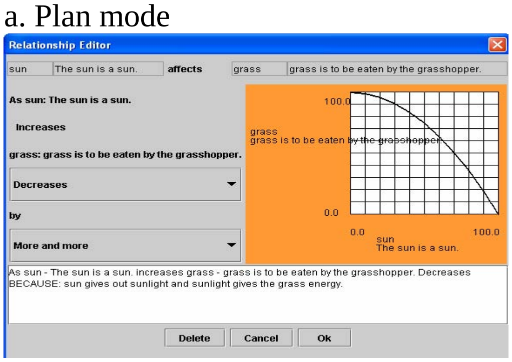
The computer-based modeling software: Model-It

The modeling tool used in this study, Model-It, was developed by the Center for Highly Interactive Computing in Education (http://hi-ce.org) at the University of Michigan (Jackson, Krajcik, & Soloway, 1999; Metcalf et al., 2000). Model-It does not require sophisticated mathematic skills and supports mainly qualitative model building. Figures 1 a-d illustrate the three modes (Plan, Build and Test) in Model-It that sequence the modeling process. In the Plan mode (Fig. 1a), a user creates, defines, and describes objects (e.g., stream, plants and people) and specifies qualitative or quantitative variables that are associated with specific objects (e.g., the water temperature of the stream and the number of people). Next, in the Build mode (Fig. 1b and 1c), the user builds causal or relational links between the variables that are presented by both verbal description and graphic representations. An example of a typical relationship in verbal representation is as follows: As the BIRD: the number of birds increases, WORMS: the number of worms decreases because more birds will eat more worms. For data visualization, in the Test Mode (Fig. 1d), Model-It provides meters and graphs to the user to view and change variable values. A meter and a colored graph line correspond to a variable. As students test their models they can change the values of independent variables and immediately see the effects on dependent variables from both meters and graphs. If the simulation does not run the way the user expected it, Model-It allows the user to move back to the Plan or the Build mode to revise objects, variables or relationships.

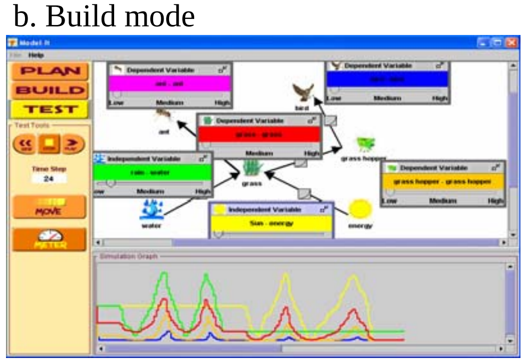
a. Plan mode



b. Build mode



c. Relationship editor



d. Test mode

Figure 1: The various modes of Model-IT

Participants and context

Forty 4th grade students from a neighborhood school in Singapore participated in the study towards the end of the school year 2004. Their teacher who has five years of teaching experience completed teaching the science syllabus to the class and the students had just taken their 4th grade final school examinations. The teacher reported that for teaching she had followed closely to the science textbook *My Pals are Here: Science* developed by Federal Publication, Singapore, and the students had learned the topic 'photosynthesis and food chain'.

For the study, we first spent fifty minutes introducing the basic concepts of objects, variables, and relationships to the students and also demonstrating the use of Model-It to create a simple model for the query on "What affects the air quality around us?" Students then individually created their models of "food webs". To facilitate students with this more difficult task, the researcher showed students a simple food web with two branches of food chains. The models created by students were collected. An earlier investigation to establish students' understanding of models and modeling was done by interviewing a sample of eighteen students before introducing Model-It. The students were selected based on their science achievement level and gender. Three achievement groups - high, medium, and low - consisting of 6 students each were formed, and each group with an equal mix of boys and girls.

The interview questions include the following:

- Student background information (their names and experience with using computers).
- The nature of models, such as "What is a model?" "What are the types of models?" "What are the characteristics of models?"
- The nature of modeling, such as "How to make a model?" and "What is in a model?"
- The evaluation of models, such as "How to decide whether a model is good?" and "What are the criteria for deciding whether a model is good?"
- The purpose/utility of models, such as "What are the purposes of having a model for a scientist or for you as a student?" "Can we have multiple models and why?"

Data analysis

The modeling work of the 18 target students formed the main source for data analysis in this study. Their created models were replicated in a textual format (see example in Appendix I) with two screenshots of the plan and build mode, respectively. The replicated models included the model components (i.e. objects, variables, and relationships) and the inputs that students made.

Students' models were analyzed using a scoring rubric (see Table 1). Four criteria were specified, namely "focus and structure", "accuracy", "completeness" and "functionality" and with three descriptor bands of performance quality – "good", "fair" and "poor". A model with a clear *focus* means that a student has highlighted the major variable(s) in the model in terms of what they were asked to model. A model with a clear *structure* shows identifiable pattern of variable grouping in terms of certain criteria. For a model around water quality, putting "water quality" variable in the middle of a model with all the variables that affect water quality on the top of the model layout, and all the variables that water quality affects at the bottom was considered a model with good structure. *Accuracy* describes to what extent a model's objects, variable names, descriptions and initial values as well as relationships and their "because statements" revealed understanding that was commonly accepted. One consideration for the accuracy criteria was how many errors students made in their models (Singer, Krajcik, and Marx, 2000). Some possible errors that students might made with variables are: inappropriate object association (a variable was not a measurable trait of the object), duplication (multiple variables represented identical traits) and off-focus (a variable was not related to the purpose of the model). Errors made with relationships are: directional errors (relationship illustrated a cause and effect relationship that was reversed), direction of effect errors (relationship illustrated an increasing effect when the appropriate relationship was decreasing and vice verse), and illogical connection (the variables paired in the relationship were not related). *Completeness* describes whether students filled in all the required fields such as the articulation boxes and to what extent a model had included the major components of a phenomenon. *Functionality* refers to what extent a model reflected the real phenomenon in regard to its driving question or focus.

To ensure reliability in scoring, two raters rated the students' models independently. Overall there was good inter-rater reliability. When a 2-point score difference was observed between the two raters, the affected student's work was reassessed to establish a final score to be assigned.

Table 1. Rubrics for Scoring Students' Models

	Focus and structure	Completeness	Accuracy	Functionality (coherence)
Good (5)	A model related to energy or the source of energy is identified and it is a web instead of a chain	Plants, plant eaters, and meat eaters are all present; all details of a model's components (i.e. objects, variables, and relationships) are complete	Valid variable names; details of a model's components are aligned with commonly accepted science knowledge	A model coherently and conceptually represents the science phenomenon
Fair (3)	It is a food chain or some branches are not valid	Plants, plant eaters, and meat eaters are all present; details of a model's components (i.e. objects, variables, and relationships) are partially complete	Valid variable names; details of a model's components are basically aligned with commonly accepted science knowledge	In general, a model coherently and conceptually represents a science phenomenon
Poor (1)	It is a food chain without conceptually identifiable focus (e.g. energy flow or photosynthesis)	Plants, plant eaters, and meat eaters are all present; details of a model's components (i.e. objects, variables, and relationships) are incomplete	Not valid variable names; some details of a model's components are not aligned with commonly accepted science knowledge or are trivial given the focus	A model does not represent a science phenomenon that exists

Results

Analysis of the student interview data showed that the students were basically at a "level 1" understanding of models and modeling (Grosslight, Unger, Jay, & Smith, 1991). They were not able to explain the idea of a model but when the interviewer presented them with some starting ideas they were able to link objects like toy cars and toy airplanes as models. These results indicate the students' belief of a 1:1 correspondence between models and reality. The students did not know the terms "variable" and "relationship" in the context of science. They responded with a “No” to most of the interview questions. Only a few students who had prior encounters with scientific models, such as a DNA model or a diagraph of water cycle, could explain the idea of models as showing how something looks like but they were still not able indicate the use of scientific models for explaining and exploration ideas.

Table 2 shows the raters’ assessment of students’ models. We observed that, in general, students were able to create a model that sounds reasonable given the amount of time they had for learning how to use the modeling program and related concepts. Only 5 out of 18 students scored lower than 12 points, which is considered as the “passing” score of having a reasonable model. It is a positive sign that students were able to create their models after a short demonstration. The scaffolding in Model-It (Metcalf, Krajcik, & Soloway, 2000) should have helped students to complete their models. Basically, students were able to identify objects that are relevant to the phenomena although we have also put the images of some irrelevant objects in the picture panel.

Table 2. Students’ Obtained Scores For Their Created Models

Student Name	Ability Grouping	Gender	Obtained Scores***				
			Focus and structure	Completeness	Accuracy	Functionality (Coherence)	Total points
Tan Hua Ping	H*	F	4/3	4/5	5/4	5/4	18/16
Derek Lee	H	M	1/1	2/3	3/3	3/3	*9/10*
Joy Tan*	H	F	5/5	5/4	3/4	5/5	18/18
Gail Mei Hui	H	F	3/4	3/2	3/4	3/4	12/14
Teoh Shao Jun	H	M	5/5	5/5	3/4	5/5	18/19
Haziq Ben	H	M	2/3	2/2	2/1	1/1	*7/7*
Ng Ling	M	F	0/1	1/1	2/2	1/1	*4/5*
Charles Tay	M	M	5/5	4/3	3/4	4/5	16/17
Chee Hou Liang	M	F	5/4	4/3	3/4	4/3	16/14
Julia Ong	M	F	4/3	4/4	3/4	4/4	15/14
Dean Goh	M	M	3/4	¾	3/4	3/3	12/15
Erik Tan	M	M	3/3	½	1/2	3/2	*8/9*
Siti Suppiah	L	F	1/2	4/3	1/2	1/2	7/9
Nick Wong	L	M	4/3	3/2	3/2	3/3	13/10
Thiam Jin Hua	L	F	4/3	5/4	3/4	4/4	*16/15*
Mary Choo	L	F	3/2	4/4	3/4	3/3	13/13
Tan Jia Yang	L	M	He created an off-topic model with low quality				
Wei Zhao	L	M	3/3	3/3	2/3	3/4	11/13

* All student names are pseudonyms; **H= High; M=Medium; L=Low; *** Scores assigned by the two raters BH/LH (a maximum possible score of 5 points was used for each criterion)

Some preliminary findings and observations of students’ modeling work include:

- Only four out of the eighteen students were able to provide valid variable names although their overall models were understandable. A valid variable name indicates a measurable trait of an object that has a range of values. For example, for object **AIR** one variable is **temperature** which has a range of values “high, medium, and low”.
- Some students gave descriptions of variables as variable names – this may indicate that they still lacked knowledge in the use of the modeling program.
- For “degree of changes” in a relationship, six out of the eighteen students used the default degree of change “about the same” – this may indicate students’ focus in just

exploring the software but not customizing the "degree of change" to make the model more accurate. A lack of supporting data to use for making choices in the "because statement" may be another reason.

- Although the modeling task was for a "food web", six out of the eighteen models were focused on "food chain" (example as shown in Figure 2). This result indicates that the students showed understanding of food chain but not food web although both concepts had been taught in their science syllabus. This also shows the potential of a computer application like Model-It to help students better visualize their scientific thinking and make connections between ideas.
- Another puzzling finding is a mismatch between student achievement level and the quality of their models. Below are some examples:
    1. Derek Lee (High achiever, Male)— *9/10* (average score 9.5)
    2. Haziq Ben (High achiever, Male), —*7/7*(average score 7)
    3. Ng Ling (Medium achiever, Female) –*4/5* (average score 4.5)
    4. Thiam Jin Hua (Low achiever, Female)— *16/15* (average score 15.5)

One possible reason for the mismatch is that teachers did not differentiate student achievement levels in a distinct way. For example the "low achievers" were not the students with lowest achievements. The teacher did acknowledge this when being asked. Secondly, there is a fundamental mismatch between the skills being assessed through our modeling activities (typically involve higher-level systematic thinking) and the school exams prior to our study (predominantly test the students in domain-specific facts and concepts); the latter's results, however, were served as the basis for the teachers to categorize their students into the three achievement levels. Finally, some "low achievers" were actually more IT-savvy and could be quickly accustomed to such software environments while some "high achievers" might not have the same competency.

Discussion and implication

This study has been our first attempt to use a modeling program as an alternative tool for the assessment of student understanding of a science phenomenon. Since the notions of models and modeling are very new to fourth graders, it is not surprising that students had difficulties in using the software properly to express their understanding. Some of the quality issues might be due to the familiarity to the modeling software. The results from this study have also shown that it could become a good "pre-test" for student understanding of the modeling program. However, it also looks promising to use modeling as an alternative assessment tool given the fact that most students were able to create reasonable models after the fifty-minute demonstration.

Understanding variables and relationships has been a challenge for the young students. In the follow-up curriculum units, we have designed student investigations such as "What affects germination and plant growth?" and "What affects the rate of evaporation?" which we hope to help students to make sense of variables and relationships.

Since even the "low" achievers were able to create models of high quality, we expect the modeling program will be able to foster student reasoning skills and content understanding at all levels, including those low achievers.

In summary, we have presented an exploratory study that applied a computer-based modeling program in a Singapore neighborhood school at primary four level. The results are both encouraging and challenging for us to design learning experience for young students to benefit from using computer-based modeling for science learning. The results have helped researchers in our subsequent curriculum development and implementation for modeling integrated instruction and learning. The computer application also holds promise as a tool for delivering alternative assessment – one not involving paper-based testing.

Acknowledgement

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Appendix I: An exemplar of a student's model of a food web

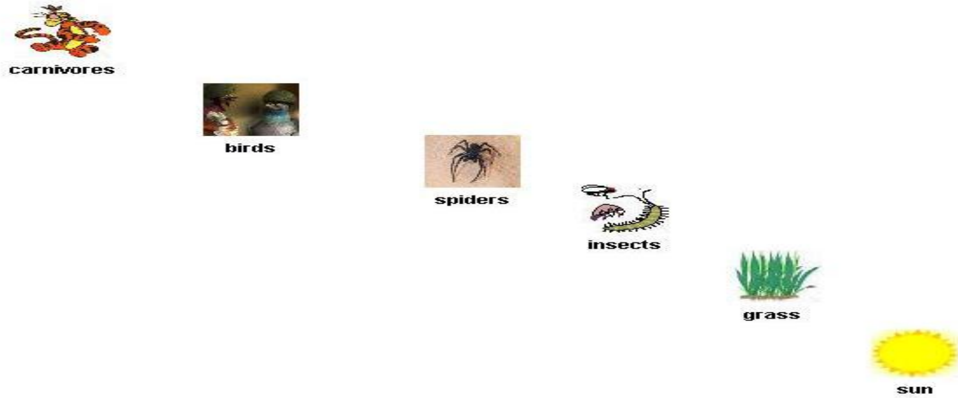

Figure 2. Student's Plan Mode of a "food web"

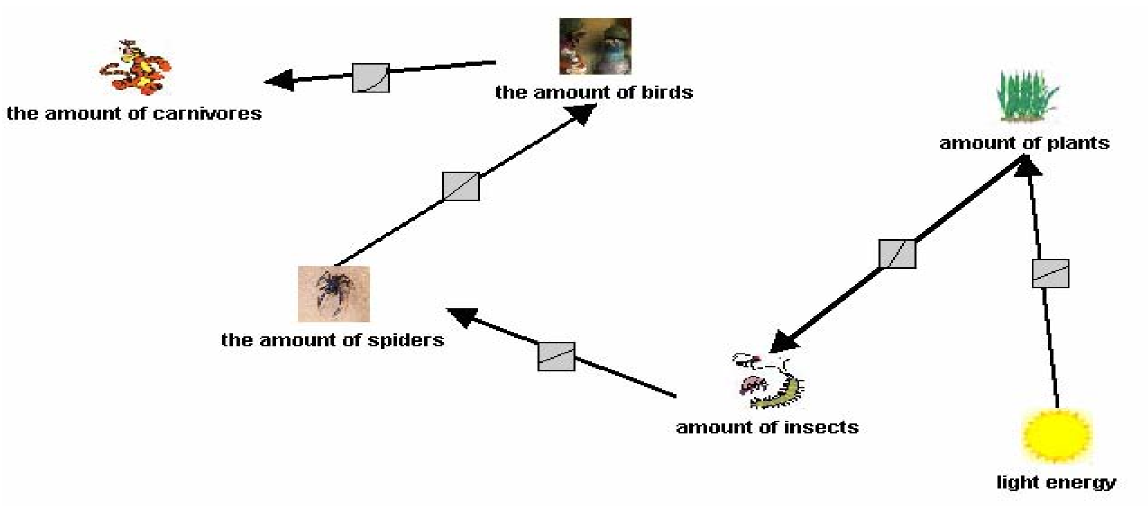

Figure 3. Student's Build Mode of a "food web"

Objects
Sun: gives out light energy
Grass: use light energy from the sun to make food
Insects: eat the grass and get the energy stored in the plants
Spiders: eat the insects and get the energy
Birds: eat the spiders and get the energy
Carnivores: eat the birds and get the energy

Variables
SUN–light energy (*high):* the sun gives off much sunlight
GRASS – amount of plants (*Medium):* the more plants the more starch(madefrom the light energy)
INSECTS–amount of insects (*Between High and Medium and Low*): the more insects the more birds

SPIDERS–the amount of spiders (*Between Medium and Low):* the more spiders the more birds
BIRDS–the amount of birds (*Between Medium and Low)* the more birds the more carnivores.
CARNIVORES–the amount of carnivores (High, medium, *Low*): *(no description)*

Relationships
As sun - light energy increases grass - amount of plants Increases (a little) BECAUSE: they need light energy to make food
As grass - amount of plants increases insects - amount of insects Increases (a lot) BECAUSE: insects are herbivores
As insects - amount of insects increases spiders - the amount of spiders Increases (a little) BECAUSE: spiders eat some insects
As spiders - the amount of spiders increases birds - the amount of birds increases (about the same) BECAUSE: birds eat spiders
As birds - the amount of birds increases carnivores - the amount of carnivores Increases (more and more) BECAUSE: carnivores eat meat