When is a Tree a Process? Influences on Student Representations of Process in "Low Floor" Qualitative Modeling Tasks

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Abstract: Many learning tasks, including computer supported modeling, require students to learn and use some kind of structured representational system. In order to use any such system, students must make a match between the perceived world and the representational elements given. There is interplay between student conceptions and the representational ontology, with the ontology guiding student conceptualization of the problem at hand, but also with student ideas about the meaning of the representational elements influencing their use. Beyond individual elements, students should be able to combine these elements into a cohesive whole which works as an explanation of system behavior. This involves the development of an understanding of the rules and syntax of the representational system, as well as an understanding of why it is important to follow it. This study describes student use of the idea of process as a basic level modeling entity in several computer-based modeling tasks. In this study, I found when given the choice to use a modeling entity representing processes in models, they do so but sometimes in ways that conflate process with other entities in the system or the outcomes of the process. In addition, students frequently do not explicitly model the processes' influences on the other entities in the model. I offer several conjectures as to why having to do with the students' orientation to modeling as a representational task and conceptualization of the representational system.

Introduction

Engaging in modeling is one way for students to begin to make sense of scientific phenomena and to think about systems similar to the ways in which scientists do (Penner, 2001). Benefits of engaging students in modeling in science have been discussed extensively elsewhere. (Stratford, 1997, Jackson et. al, 1996, Miller & Brough, 1991, Mandinach & Cline, 1989, Ogborn, 1996.) However, there has been less work looking at how students engage in modeling as a representational task. Computer supported modeling involves the use of a structured representational system. These systems can be very powerful once learned. (Other examples of structured representational systems include mathematical notation, musical notation, or programming languages.) The power of a structured representational system comes in large part from its structure and consistency. This facilitates interpretation and comparison of the representations, allows them to be combined with each other and enables runnability or other computational feedback. However, this very structure may make learning and using a new representational system difficult. Any given system of representational elements for modeling necessarily must make some cuts through reality, creating an ontology of ideas and relations that are allowable, and a syntax of how to combine them. The underlying assumptions behind such ontological and semantic decisions may be oblique to student conceptions or they may rely on formal knowledge that the student does not possess.

In the Vmodel project (Forbus et. al, 2000, 2001, Carney et. al 2002) we are designing a modeling system for young students who may have little or no experience with modeling or use of other formal representational systems. A major design question of the Vmodel project as a whole is whether it is possible to supply students with a "low floor" modeling formalism. This formalism should be easily usable, but will also allow students the benefits of using a formal representational system.

In this paper, I look at student use of a single component of the Vmodel notational system, the idea of physical process. In the Vmodel system, process is an important member of a suite of basic modeling elements with which students can build models. The Vmodel formalism is based on ideas of Qualitative Process (QP) Theory (Forbus, 1984). In QP Theory, causal relationships are modeled as direct influences between processes and the quantifiable attributes (parameters) of other entities. The centrality of process in QP theory is intended to make contact with notions of causality in naive mental models of science phenomena. (Forbus & Gentner, 1986). In

Vmodel, it is possible for students to model processes as entities which influence change parameters, rather than drawing mathematical relationships directly between parameters.

Given the centrality of process to this formalism it is important to consider how students conceptualize and use the process entity in their models. Student use of the process entity has thus far been different from the intents of the designers in several ways. I detail some of these differences and offer some conjectures for why that may be and what design implications this may have. Beyond the Vmodel project, this work is important to the larger modeling community as a case study in how students interact with one element as situated within a given representational system in the course of making models.

Design

Visually, the modeling ontology is divided into two different basic representational forms: boxes, which represent basic entities and their describers and arrows, which represent relations among them. Students assemble their models from these elements.

The four basic object types are *thing, substance, multiple thing,* and *process*. These basic entity types can be localized to the phenomenon being modeled with instance-specific natural language labels. Other (rounded) boxes represent types of attributes or parameters can be used to describe the basic objects in Vmodel.

Figure 1. Two basic objects and a parameter, with instance-specific labels

Arrows are used to relate objects to attributes or parameters, show configuration relationships (e.g. y *contains* x) or show causal relationships among entities. The labels for arrows are fixed. Students do not pick a domain specific label for them. There is an intended syntax of relations between entity types and relationship types. For example, a *thing* can be contained by another *thing*, but not by a *rate* or *level*. Followed correctly, this syntax should allow students to create models which are explicit and consistent enough to enable comparisons and computational feedback on their meanings. In the current version of Vmodel, however, there is no computational feedback beyond rudimentary coaching described below.

Intended use of the process entity

Each process entity should represent a single process at work in the system being modeled, and be named for that process. Processes can be described as other entities can (for example, processes can have *rate*s as parameters). Influences of processes on parameters of other model entities are shown using arrows labeled *increases* or *decreases*. In Vmodel, an “affects” link is also available to students as a placeholder for instances when they are unsure of how the process affects the parameter. Although it is possible for a process to exist independent of something which does it, if a student wishes to indicate agency, he or she may do so by using a *does* or *can-do* relationship. Finally, students can indicate the conditions under which processes are active. This can be done with the controller links, *requires*, *prevents* and *controls*. These links can connect a process to relationships or entities which enable or prevent a process from happening. An expanded vocabulary for non-causal relationships among entities allows preconditions to be specified.

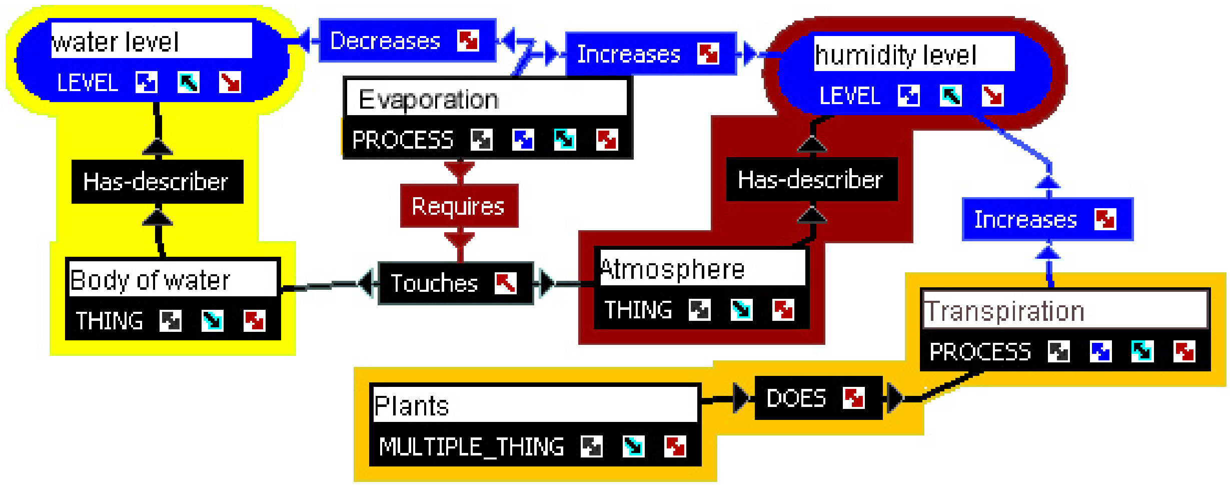

Figure 2. Process entities used as intended in a partial model. At center, the *process* evaporation is affecting parameters of body of water (water level) and atmosphere (humidity level). The precondition for that relationship (atmosphere in contact with body of water) is shown with a *requires* link. In the bottom right, the process transpiration is shown in an agency relationship with plants.

<u>Supports for students understanding and use of the process entity</u>

Students were given pre-modeling instruction about the meaning and use of each kind of modeling element, including the process entity. In addition, within the software is a help directory in which students can access hypertext about the meaning and use of each modeling element and an example of it as ideally used. There are also aids for students in understanding the intended modeling syntax. At the bottom of each kind of box are color-coded glyphs indicating the type and directionality of allowed input and output arrows for that entity type. Also, an interactive coach in the upper right hand corner of the screen smiles, looks puzzled or frowns depending on the syntax of the student models. This coach was implemented halfway through this study.

THE PROCESS ENTITY AS USED BY STUDENTS

This study considers student use of process in models made during the first whole classroom trial of the Vmodel software. This study was undertaken in a seventh grade classroom in a public primary school in a Chicago. The classroom was chosen because the teacher had extensive experience with project based science and educational technology and was open to piloting new software and curricula in her classroom. Models made in the context of classroom activity and also in a clinical interview setting were considered.

In the classroom portion of this study, students made models as part of a project based science unit on Mars colonization. Students were asked to consider what should be present in a Mars colony in order to keep a group of colonists comfortably alive for two years. Small groups were asked to conjecture which what might be included in an "ecodome" and model their interactions. Aside from the supports outlined above, students were given few formal criteria as to what to include in their models or how to show interactions. Working in groups of 2-4, students had three class periods to work on their models. Model syntax coaching was implemented between the second and third draft of these models.

Student use of process in classroom models

Of eight models created by students as a part of their class work, students used the process entity thirteen times in their first draft models. On average there were 1.6 processes/model, and around 20% of all basic objects were processes. In final drafts, students used the process entity eight times. On average there was one process/model. Ten percent of basic objects were processes. Some models contained multiple processes and some contained none.

<u>Specifying what a process is: Naming the process entity</u>

One clue to how students conceptualize processes can be gained by looking at what names students put into the process boxes in their models. Students used the name of a process and that alone only two thirds of the time.

In the other instances, students put the names of non-processes or multiple entities in process boxes. In these cases, they generally labeled the process entity with one of two things: the thing which does the process or the outcome of the process. Some students would use these naming schemes (process, outcome and agent) interchangeably within the same model. Also fairly frequent in naming processes was use of the name of the process in addition to either the agent or the object of the process, as in "Trixie eats" or "eats food". In several cases students labeled other modeling entities such as attributes or multiple things with the names of processes.

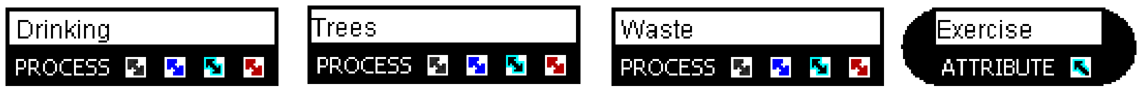

Figure 3. Examples of student use naming of processes in Vmodel models. From left: process as process, agent as process, outcome as process, and an attribute labeled with the name of a process [1]

Agency relationships

A little over half of all processes were connected to an agent using the does or can-do link.

Processes in functional roles

Surprisingly, only three of the processes included by students in the first modeling task were linked to other entities using any kind of causal relationship. Most (71%) of the processes were representational dead ends, with no relationships of any kind coming from them to other modeling entities. That is not to say that the student models were without notions of system or functional relations among entities. Students often modeled relationships directly between other high level entities. This was sometimes done even when a relevant process had been included elsewhere in the model. Often the meanings of these "shortcuts" were apparent to an observer, even though the students did not follow modeling syntax.

Figure 4. A modeling "shortcut" with no process

Students also implied processes by including the "does" relationship directly between an entity and something that might be affected by a process.

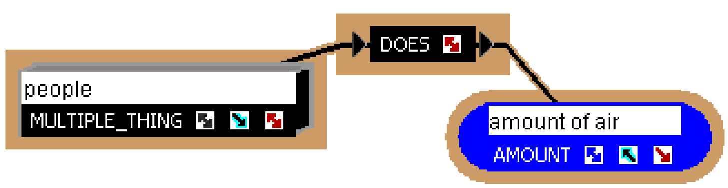

Figure 5. A relationship in which some process acting on amount of air is implied

Influence of classroom and on line helps:

Students rarely consulted the help documentation, and largely ignored the color-coding syntax cues on boxes. When a syntax coach which would frown or look puzzled at student syntax was introduced, students changed some of the relationships between processes and other entities, but changes made were minimal. Feedback from the coach did not engender careful consideration of the help documentation or other aids.

Discussion of the use of process in classroom models

The large proportion of processes which had no influence on anything else in the model is striking, especially in light of the designers' intentions about process as central to representing causality. This begs the question of why processes with no functional role were included at all.

One interpretation is that students included processes merely to provide additional information about other entities in the way that an attribute or other describer would. This interpretation is strengthened by the observation that students included functional relationships directly between the other basic entities in their models, even when relevant processes were included in the models. This is consistent with preliminary work showing that when students are given loose constraints and asked to represent systems, their representations are often centered on entities (Carney & Kalathil, 2000). If students conceive of entities as the locus of the model, then a reasonable role for the process entity is to provide additional information about the entity. In addition, students sometimes explicitly used processes as modifiers, either by using an attribute entity with the name of a process in it, or by using the *has-describer* link to connect a process to another modeling entity. One student modeled processes as attributes, but also included other processes modeled as processes in the same model. His distinction among them was that processes were things engaged in automatically, while attributes are processes that different people engaged in to different extent. Therefore these were attributes because they might be used to distinguish people from each other.

Student misunderstanding of the modeling syntax also may affect their use of the process entity. I draw a relationship between conflations within the representation of the process itself and lack of explication of the process' relationships with other parameters. If the description of the process includes its outcomes, there may be no reason in a student's mind to model explicitly the outcome as an assembly of modeling elements.

Another likely interpretation for the relative scarcity of processes in student models could be due to the nature of the assignment and student content knowledge. Students were asked to think about what should entities be in the dome and how they might interact. Nowhere in the task was process explicitly called for. In addition, students may not have had much understanding of which processes might be at work in this ecosystem or how they worked.

Student use of process in the clinical interview

With the idea that students might not think processes were central to their models in mind, members of the Vmodel development team engaged seven students in a clinical interview-based modeling task. This second task focused students much more explicitly on processes and their influences by including processes and their consequences explicitly in the description of a phenomenon to be modeled. Students were given a paragraph about an elephant's weight loss, asked to make a model that showed why it was happening. The paragraph reads as follows:

> At the zoo, the weight of Trixie the elephant is decreasing. Trixie eats fruit and nuts and leaves. Eating food usually increases Trixie's weight, and decreases the food. We've noticed that Trixie only eats when Jim the zookeeper is singing, but Jim doesn't sing very long each day. We think that might be the reason that Trixie is loosing weight.

Students used the process entity much more frequently in this task. There were nineteen uses of the process entity in the seven models completed. Sixty-six percent of basic objects in interview models were processes.

Naming the process box

Processes were more central to student models in the clinical interview task. But students were more likely to conflate them with other elements in their models. Thirty one percent of all processes modeled were conflated with other entities. These included conflations of process with agent, process and outcome and even preconditions in their naming of the process boxes. In one case the student put so much into her process box that she only needed three other entities to complete the entire model.

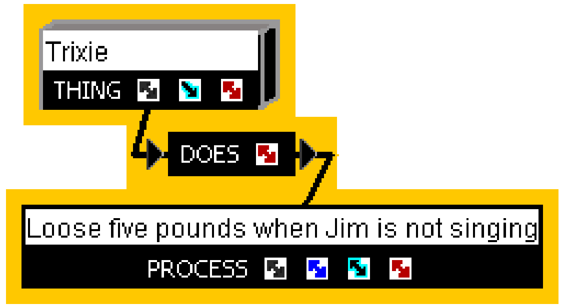

Figure 6. A multiple conflation. This student includes condition, influence and object of the process in her process box label.

Agency relationships

Student included agency relationships for all but three processes in this task. Processes were done by either Jim or Trixie, the main actors in the paragraph.

Processes in functional roles

In this task, processes were more likely to be modeled as things which had bearing on the central problem, the weight gain of the elephant. All students represented some subset of eating, loosing weight and singing as processes. Other ideas that might have influence on weight were also modeled as processes. Several students modeled "not singing" as a process, and one student modeled "silence" as a process, reasoning that if the elephant only ate when Jim was singing, then silence or not singing has causal consequences. The ways in which these processes had consequences, though, were not always modeled explicitly. Almost half of the processes in the interview models (47%) were representational dead ends, with no relationships from them to other entities in the model, not even Trixie's weight. Four of the seven students modeled weight explicitly as a parameter of Trixie the elephant but only one connected a process to the weight, and that was in response to an interviewer question.

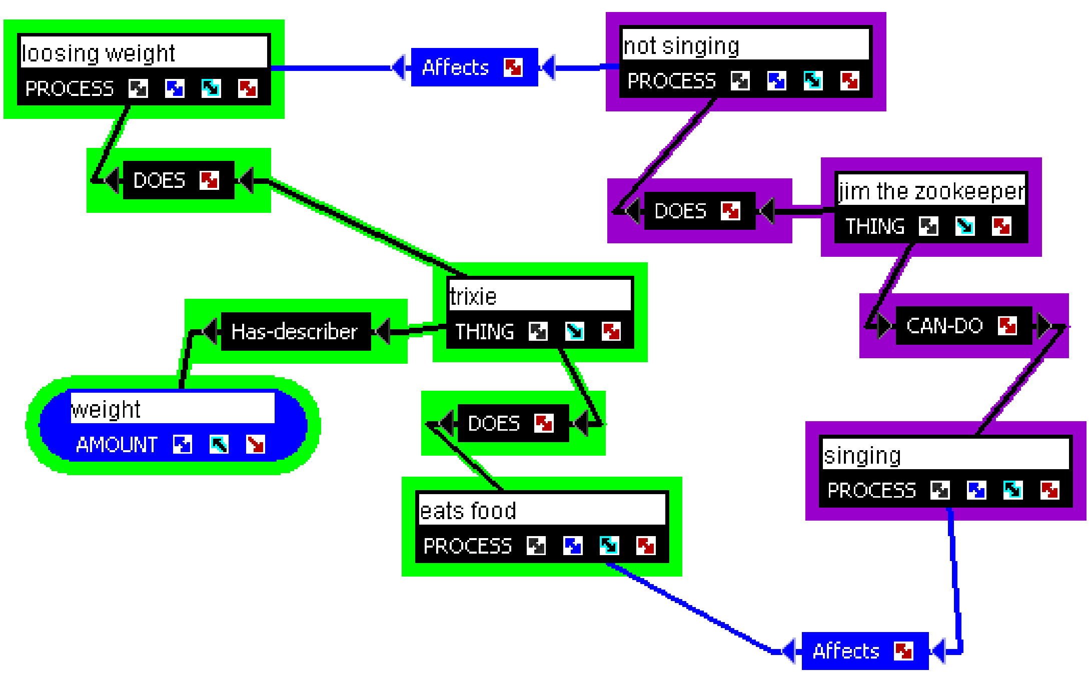

Figure 7: In this student model two processes ("loosing weight" and "eating") have no explicated relationship with weight. The idea of weight is also part of "loosing weight" conflation. Note the process "not singing" which is modeled as influencing "loosing weight."

During the clinical interview task students were allowed to continue modeling until they declared they were finished or until approximately thirty minutes had passed. Most finished before time. They were asked whether they considered their models to be complete and satisfactory explanations of why the elephant was loosing weight. All students expressed satisfaction with their models, although some indicated they would have added more information with more time. Largely the students would have added detail, such as the kinds of food eaten.

Discussion:

Computer supported modeling is one of many kinds of learning tasks which involves students in the use of a structured representational system. In learning and using such a system, students must negotiate a fit between the representational elements at hand and their conceptions of the phenomenon being represented. Beyond this, however, students must understand the use of representational elements so they may combine these elements into a cohesive whole. This whole must be sufficiently specific as to account for causality and syntactically the same as other models to ensure computational feedback and comparisons of models

These studies seem to demonstrate that the process entity does make contact with student conceptions and is easily usable as a component in their representations of systems. Students regularly included at least one process in their models, and the processes included were not irrelevant to the systems being modeled, although how central they were to the model's causal story seemed to vary according to task context. When students were given material to model in which the interactions of processes were central, they used processes more centrally in their models. These processes did have bearing on the phenomenon being modeled. Students were less successful, however in being explicit about how processes affect parameters in their models, and in separating processes from entities which affect or are affected by them and detailing those relationships using the model syntax given.

Implications:

Students were able to use the Vmodel ontology to represent their ideas and expressed satisfaction with their models as explanatory constructs. It is only in consideration of the designers' intent to move students towards explicitness and syntactical consistency in the model that student use of the process element becomes problematic. While students were able to use process as a representational element, it is less clear that they were using it as a modeling element. Beyond agency and description relationships, students often did not explicitly represent relationships between processes and other entities. This, combined with the multiple meanings that students ascribe to *process* seems to indicate a lack of student understanding of the process entity's fit into the larger modeling picture.

Development of the ability to use a modeling formalism is not a one-way street. Student preconceptions influence use of modeling elements, but the ontological distinctions and semantics of a modeling system should come to influence student use of the modeling elements as well. Had they understood the syntax better would they have been more consistent in their construal of the nature of processes and more explicit about their relationships among them and other modeling entities? It is clear that students largely ignored instruction and coaching as to the syntax of their models. This may indicate a design tension in our work. By designing the individual elements for usability, have we circumvented the students' motivation to learn the modeling syntax? This study also seems to point to the nature of task as central to student conceptualization and use of the modeling entities. When the task context was changed from a high level system overview to one in which the explanation of a specific change was called for, students used processes in ways that were closer to designers' intents, though they still made many of the same modeling errors they had in the previous task.

Designers of a low floor modeling system must consider that by giving students entities that might be usable on an individual element basis, they have only done part of their work. We as designers must consider how to help students to make models that are more consistent and explicit in their representation of system components and their relationships. But we also must help students to understand why that is a necessary or valuable thing to do.

Endnotes:

[1] All examples are taken directly from student models, although many have been taken out of larger student models, or redrawn to save space.

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