Children's Misconceptions as Barriers to the Learning of Systems Concepts

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1.1. Introduction

Research has shown that people have difficulties understanding dynamic behavior (Booth-Sweeney & Sterman, 2000; Dorner, 1989; Resnick, 1994; Sterman, 1994). In an attempt to better understand the nature of these difficulties, we have developed a new modeling tool and conducted an exploratory study with young children. The modeling tool, called System Blocks (Zuckerman & Resnick 2003), is a set of communicating plastic boxes with embedded computation that facilitates hands-on modeling and simulation of stock & flow structures. In the study, 5th grade students were asked to perform several assignments with System Blocks, dealing with concepts such as rates, accumulation, net-flow, and positive feedback. Our initial findings suggest there are common patterns in the way children think about dynamic behavior, which might account for some of the difficulties children as well as adults have when faced with dynamic behavior in general and stock & flow models in particular. These patterns include a tendency to prefer: quantity over process (stock over flow), sequential processes over simultaneous processes, and inflow over outflow.

Booth-Sweeney & Sterman showed that business school students have a poor level of understanding of stock & flow relationships and time delays. Dorner used computer simulations in his experiments and showed how poorly people perform when dealing with real life problems with interdependent features. He argued that people rely on a primary mechanism of "extrapolating from the moment" when dealing with temporal patterns. Resnick showed how people assume centralized control for patterns they see in the world, when in fact many phenomena are self-organizing, coordinated without a coordinator. Sterman listed the different barriers to learning that organizations face, including misperception of feedback, flawed cognitive maps of causal relations, and more. Sterman recommendations for improving the learning process include: eliciting participants' knowledge, using simulation tools, and improving scientific reasoning skills.

Existing stock & flow simulation tools such as Stella (HPS Inc.) and Vensim (Ventana Systems) are easy to use, but not easy enough to enable novices to model without training. Building on the body of work in constructionist research (Piaget, 1972; Papert 1980, 1991; Kafai and Resnick, 1996), the approach we took is to make dynamic processes visible and manipulable through physical interaction. System Blocks is a new hands-on modeling and simulation tool that provides an easier introduction to systems modeling and simulation. The blocks are physical, with knobs that enable real-time interaction with a running simulation. The dynamic behavior is represented using different mediums, including moving lights, sound, and a line graph. Special attention was given to create an "equation-less" modeling process, to prevent possible barriers to learning equations might cause.

Figure. 1. System Blocks simulating water flow through a bathtub.

We conducted an exploratory study with ten 5th grade students. These students used System Blocks to interact with core system concepts. We conducted one-on-one interviews with the students while they used System Blocks to model and simulate systems that relate to their own lives. We observed how the 5th graders show tendency towards sequential processes, and how the interactive simulation and the visibility of the simulated processes enabled them to recognize the simultaneous activity. In the same way, we observed how they interact and adapt their theories about concepts such as inflow, outflow, stock, net-flow, and positive feedback.
Based on our study we report on several misconceptions and tendencies, with regards to young children's understanding of systems concepts. In addition, we suggest two preliminary conclusions: (1) Multi-sensory representation of a system simulation can

help children understand key systems concepts; for example, sound helped the children recognize rate-of-change in an accumulation process. (2) An iterative process of modeling and simulation, performed by the children themselves, might help children revise their current conception of dynamic behavior and help them adapt new theories based on their simulation experience.

Our findings are based on an exploratory study and a small sample. Nevertheless, the patterns we observed can be helpful pointers to some of the difficulties children and adults might have when trying to learn about the behavior of systems. Further study should be conducted to examine the nature of these tendencies and to further suggest practical strategies that can help people develop richer understanding of systems concepts.

1.2. METHOD AND DATA ANALYSIS

We conducted our empirical study with 5th grade students at 2 different schools: the Carlisle Public School in Carlisle, MA and the Baldwin Public School in Cambridge, MA (see Table 1). The goals of the study were to evaluate System Blocks as a new modeling and simulation tool, to surface any misconceptions children might hold about dynamic behavior, and to investigate the potential of an interactive simulation environment as a method to overcome these misconceptions.
Our research approach was a qualitative one. We used a clinical interviews approach where an interviewer presents brief, standard tasks to the students, and then probes the students' understanding based upon their response to the tasks.

The two groups of 5th grade students differ in their prior instruction in systems concepts. The Carlisle Public School is part of the "Waters Foundation" program, where systems thinking concepts are introduced and used starting at elementary school. The Baldwin Public School students had no prior instruction in systems concepts.

Grade level	School name	socio-economic status	Prior instruction in systems concepts	Number of participants
5th grade	Carlisle	High	Prior instruction. Part of the "Waters Foundation" program. Familiarity with Stocks and Flows and Behavior Over Time Graphs.	5 students
5th grade	Baldwin	Mixed	No prior instruction.	5 students

Table. 1. Overview of the schools where the study was performed.
The 5th graders interviews were conducted in 2 one-on-one sessions of 45 minutes each. The interviews incorporated a standard set of probes but they were loosely

structured and designed to follow up on what the students said. The main activities in each interview were: (1) mapping of picture cards onto a simple inflow-stock-outflow structure. (2) Simulating the model and analyzing net-flow dynamics using moving lights and sound. (3) Analyzing net-flow dynamics using real-time line graph. (4) Analyzing models with simple positive-feedback loop. All sessions were videotaped for later analysis.

Table 2 lists some of the picture cards examples used during the sessions (both with and without positive feedback).

Inflow	**Stock**	**Outflow**
flow into bathtub 	water level in bathtub 	flow out from bathtub 
getting money 	amount of money saved 	spending money 
people get infected 	number of sick people 	healthy again 

Table. 2. Examples of picture cards used during the sessions.

1.3. OBSERVATIONS AND DISCUSSION

During the sessions we asked the students to generate their own examples. We asked them to think of examples that match the system structure we just simulated of inflow, stock, and outflow. In addition, we asked them to pick examples that relate to their own lives. Table 3 lists selected examples generated by the children.

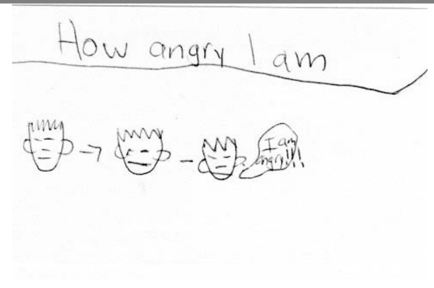
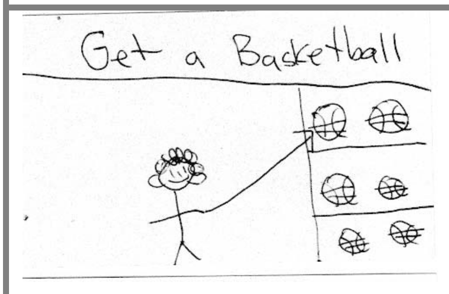
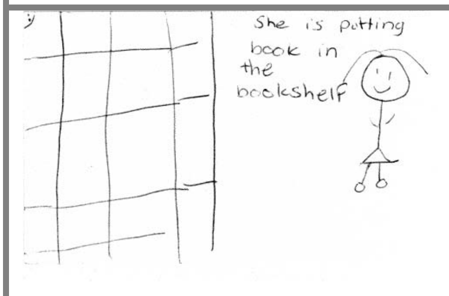
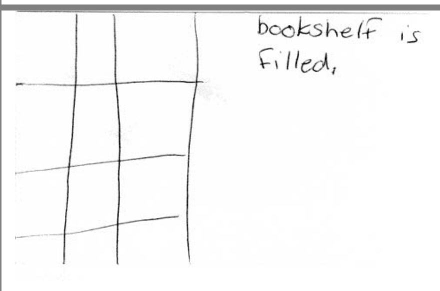
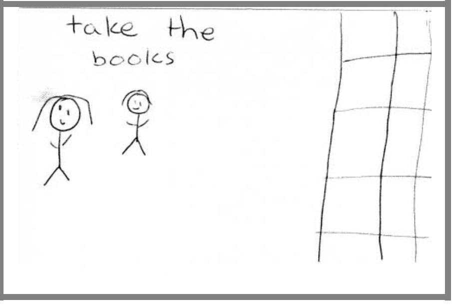
Inflow	Stock	Outflow
		
		
		

Table. 3. Examples of real-life systems generated and drawn by the children.

Throughout the sessions we observed several misconceptions and tendencies students held about dynamic behavior in general and systems concepts in particular. Our observations are based on an exploratory study with a small sample, but nevertheless, the patterns observed might serve as helpful pointers to some of the difficulties people have when trying to learn about systems concepts. There were surprising differences in the type of tendencies between the students with and without prior instruction.

System Blocks were effective in surfacing those tendencies with both groups of students.

1. **Sequentially over Simultaneously**: a tendency to think in a narrative way (beginning, middle, and end), A causes B then B causes C. Thinking about processes as if they happen one-at-a-time, rather than simultaneously. Occurred more with the Baldwin students (the group with no prior instruction).
2. **Quantity Over Process**: a tendency to favor quantity (something that can be counted) over process (an activity). When mapping real-life examples to Stock & Flow models, students that had this problem mixed the inflow (activity, process) with the stock (amount of something, quantity). Occurred more with the Carlisle students (the group with prior instruction).
3. **Inflow Over Outflow**: a tendency to give higher priority to the inflow rather than the outflow. When dealing with a problem, students with this tendency preferred to increase or decrease the inflow and did not pay enough attention to the outflow. Occurred more with the Carlisle students (the ones with prior instruction). When analyzing line graphs, students with this tendency connected the slope of the graph to the inflow, and completely ignored the influence of the outflow (the slope represents the net-flow, which is the difference between the inflow and the outflow). Occurred more with the Carlisle students (the group with prior instruction).
4. **Minor differences will not make a difference**: When minor differences exist between an inflow and an outflow, students ignored the change these differences would create over time, and assume the system would stay in balance or not change. No differences observed between the two student groups.

Students were able to correctly map different real-life examples into Stock & Flow structures, and when errors were made, a short simulation helped the students understand by themselves what might be the error and how to change it. In addition, students were able to map their own personal experiences to Stock & Flow structure. System Blocks were most effective in helping students understand the net-flow dynamics concept (that emphasizes simultaneous processes).

With regards to positive feedback, our observations suggest that 5th grade students are perfectly capable of learning feedback concepts. Further research should be done to prepare the relevant educational scaffolding to support learning of feedback concepts at a younger age.

Summarizing the misconceptions and tendencies, it seems that students with prior system thinking instruction had a tendency to favor inflow over outflow and quantity over process. On the other hand, they were faster to "shake off" the tendency for sequentially over simultaneously. It seems that System Blocks might help to decrease the number of misconceptions with regards to net-flow dynamics and graph shapes, if used when these concepts are introduced to students for the first time.

System Blocks offer a delicate bridge between concrete and abstract. The blocks are tangible, but represent abstract entities. The picture cards are clearly just an example, but nevertheless add concreteness to the modeling and simulation experience. When working with System Blocks, it is clear that the picture cards are only temporary representations. Still, the students had no problem shifting between different domains in a matter of minutes - from physical examples such as water flowing and cookies baked to emotional examples such as level of anger to social networks examples such as trends and diseases. In the same way that children build a castle from LEGO or wooden blocks and pretend it is a castle, they can pretend a box is a bathtub and blinking lights are flow of water.

In the interviews we played a key role as the facilitator, and could have directly influence the students' performance. We challenged the students and at the same time might have guided them. It is not clear if a student working independently can yield the same results. In a classroom environment, teachers would play the role of the facilitator. Teachers have a great deal of knowledge about their students' character, style of learning, and behavior in a group setting. Further study should be done to evaluate how effective System Blocks are in a small group setting with a teacher as the facilitator, working with the proper educational materials.

In this paper we showed how System Blocks provide students an opportunity to confront their misconceptions about dynamic behavior through a hands-on, interactive process of modeling and simulation. Many factors can be the cause for students' misconceptions and tendencies, including prior instruction, prior life experiences, the design of System Blocks interface or the specific examples we have used in our interviews. Nevertheless, our exploratory study suggests that one-on-one interaction with a student using an interactive simulation tool such as System Blocks can help students confront their current conceptions about dynamic behavior, and provide students an opportunity to revise their mental models towards a deeper understanding of systems concepts.

Acknowledgments

We would like to thank: Saeed Arida for the blocks' physical design. Ji Zhang, Timothy Brantley, and Brian Silverman for software and hardware support. Carlisle's and Baldwin's 5th grade students. Carlisle's SD mentors Rob Quaden and Alan Ticotsky. Baldwin's Technology Specialist Espedito Rivera.

This research could not have been done without the generous support of the LEGO Company, the MIT Media Lab's Center for Bits and Atoms (NSF CCR-0122419), Things That Think and Digital Life consortia.

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