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Children's Misconceptions as Barriers to Learning Stock-and-Flow Modeling

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Research has shown that people have difficulties understanding dynamic behavior. 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, 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.

INTRODUCTION

Research has shown that people's understanding of systems behavior is extremely poor (Booth-Sweeney & Sterman, 2000; Dorner, 1989; Resnick, 1994; Sterman, 1994). 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 (isee systems) 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 choose is to make dynamic processes visible and manipulable through physical interaction. Towards that end, we have developed System Blocks, a new hands-on modeling and simulation tool (Zuckerman & Resnick 2003). System Blocks were designed to provide 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 that equations might cause.

***Stock-and-Flow** continued on page 3*

THIS ISSUE AT A GLANCE

Updates…

Tucson

The best word to describe what is going on in southern Arizona with systems thinking in the schools is infection. The Catalina Foothills District, with generous support from the Waters Foundation, has been encouraging the use of systems thinking and dynamic modeling in the classroom and administration for about 15 years. More and more they are seeing the effects of their work spreading.

Bolstered by trainings in the Tucson Unified District, also supported by the Waters Foundation, that have been attended by teachers and administrators from throughout the Tucson area, the number of schools affected by teachers and administrators interested in the work is growing substantially. In addition, former employees of the Foothills District are turning up as advocates throughout the region and beyond (California, Texas and Colorado). It is exciting and heartening for all those who have been involved in the work to find old friends popping up and wanting to nurture the seeds where they are currently working. Infection is truly alive and well!

The current training being offered by the Waters Foundation group in Tucson is a 30-hour training, requiring a commitment on the part of the trainees as well as the trainers. The Waters group is finding that this sort of commitment, as well as the revised structure and content of the training, is sparking enthusiasm. They are offering two Level I trainings this summer and one again next school year, as well as a Level II training during the school year and in the summer of 2006. They are working hard to continue to incubate the infection.

If you would like more information about the work being done or the training opportunities available in the Tucson area, contact Tracy Benson (tsbenson@aol.com) or Joan Yates (jyates@cfsd.k12.az.us).

For information about Waters Foundation trainings in other parts of the country, see www.watersfoundation.org

EDITORIAL

As the school year draws to a close and the weather heats up (not necessarily quite yet in New England!), it is a good time to reflect on what we have accomplished over the past year and what still needs to be done. The respite of the summer gives us time to plan and become energized for next year.

A year ago, the CLE hosted our ST/DM conference out on the west coast at Skamania Lodge and enjoyed the energy and enthusiasm of those gathered there. At the same time the book, *The Shape of Change* debuted. It is now in its second printing and has been translated into Dutch.

There are various places where the infection model of spreading the ideas of ST/DM is taking hold (see the update on Tucson). The Waters Foundation has an increased emphasis on training this year. In the curricular area, Diana Fisher's two books, as well as *The Shape of Change,* have substantially improved the landscape. A glance back at the Essex meeting held in the summer of 2001 to look at the future of system dynamics in K-12 education is appropriate. The two necessary prongs to the efforts in system dynamics in K-12 were felt to be curriculum and training. Movement is being made on both those fronts.

Have a wonderful summer. Get ready for the 2006 ST/DM conference here in Massachusetts, and think hard and productively about what we should do next year and in the years to come to make systems citizens a majority in our world. We need them.

Take care,
Lees Stuntz (*stuntzln@clexchange.org*)

Learning Stock-and-Flow Modeling *continued from page 1*

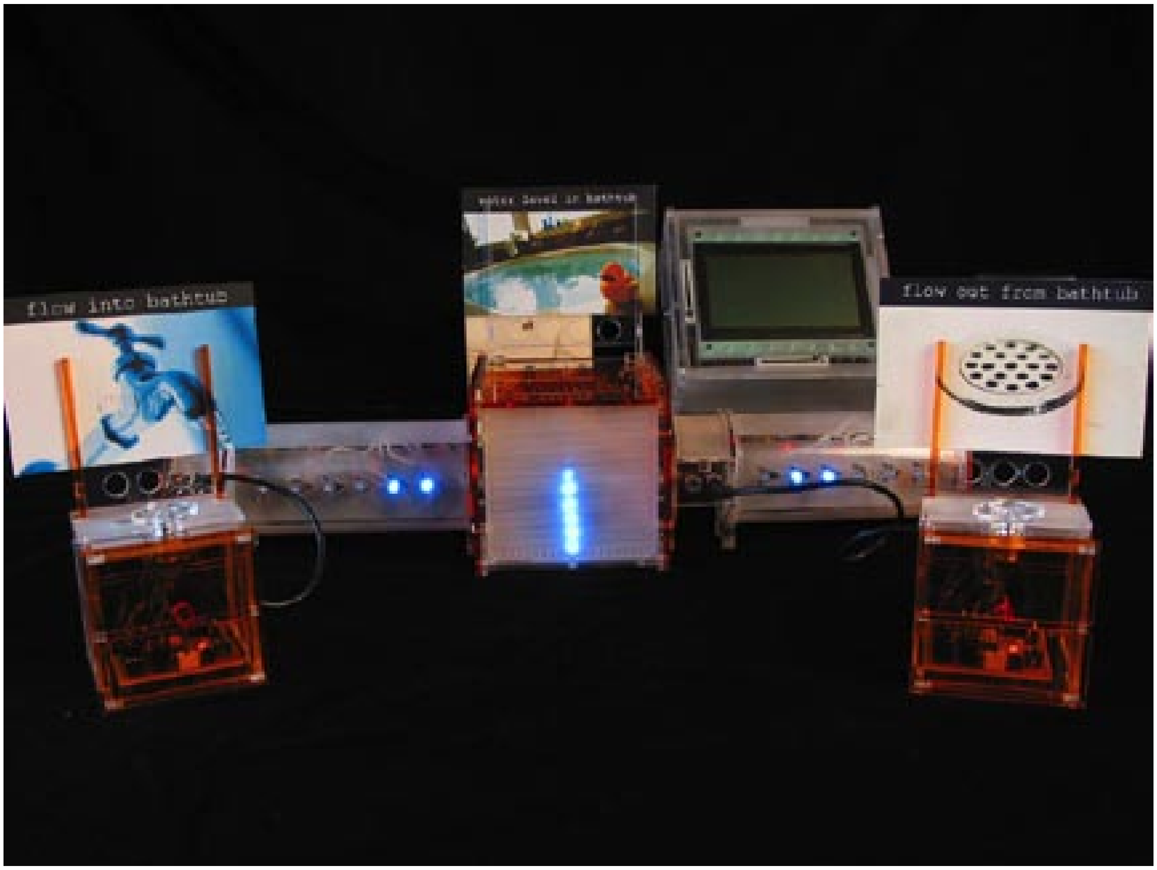

Figure 1. System Blocks simulating water flow through a bathtub

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 grade students show a tendency towards sequential processes, and how the interactive simulation and the visibility of the simulated processes enable 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.

EXTENDED EXAMPLE

Consider the dynamic system modeled in Figure 2 on page 4. Children participate in a “cookies store” activity at school, where they bake and sell cookies to the school's students. Some students bake the cookies at the school kitchen and pass them to a cookies basket, while other students sell the cookies to other students.

This system behavior can be modeled using System Blocks (see Figure 2). The inflow block represents the “baking cookies” rate, the stock block represents the “number of cookies in basket”, and the outflow block represents the “selling cookies” rate. When this model is simulated, students can play different scenarios and see how the system reacts.

Stock-and-Flow *continued on page 4*

Learning Stock-and-Flow Modeling *continued from page 3*

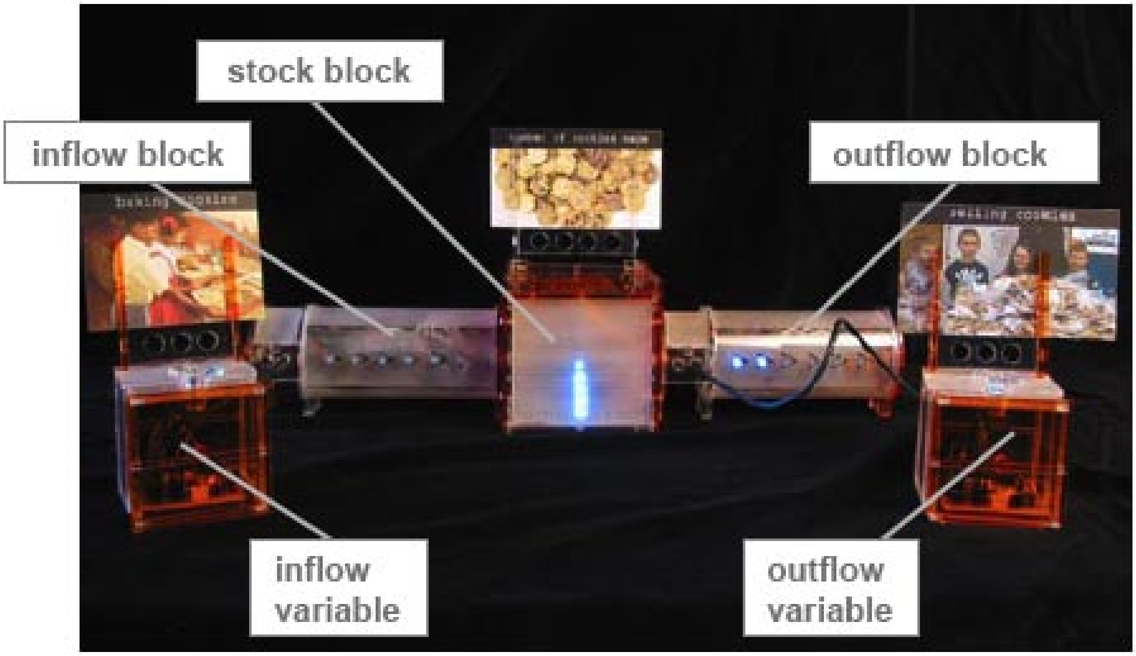

Figure 2. System Blocks simulating a "cookies store" example

For example, increasing the inflow rate by turning the dial on the inflow variable block (baking more cookies) will increase the stock (number of cookies in basket). Increasing the outflow rate by turning dial on the outflow variable block (selling more cookies) will decrease the stock (number of cookies in basket). Further tinkering with System Blocks enables students to quickly get to the next step, analyzing net-flow dynamics: If the inflow is set to a higher rate than the outflow, the stock will increase; If the outflow is set to a higher rate than the inflow, the stock will decrease; finally, if the inflow and outflow are set to exactly the same rate, the stock level will not change and the system will remain in a state of dynamic equilibrium. In our cookies store example, dynamic equilibrium means the number of cookies in the basket stays constant, while cookies are being baked and sold all the time.

The above scenario represents a generic system structure. Other simplified real-life examples that can fit this structure are a bank account balance, amount of homework left to do, pollution level in the atmosphere, and amount of calories in the body, to name a few.

If a stock represents "amount of calories in the body," then the inflow is "consuming calories" or "eating," and the outflow is "exercising." A person familiar with this generic structure would know that in order to decrease the amount of calories in the body and maintain a new balance one must pay attention to the inflow and outflow at the same time, and not focus on only one of them.

Building on this simple generic structure, consider the following next step: the students that bake the cookies want to make sure the cookies basket is always full. They watch the number of cookies in the basket, and they bake new cookies if this number decreases. This scenario describes a goal-seeking system. The goal is to keep the "actual number of cookies in basket" as close as possible to the "desired number of cookies in basket." The students are an integral part of the system. They monitor the goal (number of cookies in basket) and adjust the inflow (baking more cookies) based on the gap between the actual stock level and the desired level. In our study we have not modeled the time delay it takes to bake the cookies ("baking time"). System Blocks can model this time delay in the same way as any other stock & flow modeling tool, by adding an additional stock block for "number of cookies in oven" with a "cooking time" outflow.

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

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

Table 1: Overview of schools where study was performed

School students had no prior instruction in systems concepts.

The 5th grade 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, on page 6, lists some of the picture cards examples used during the sessions (both with and without positive feedback).

OBSERVATIONS

The students reacted positively towards System Blocks as a modeling interface:

"I like the blocks much more than working on the computer. With the computer, you click buttons and insert numbers and then a window opens and you see the result. With the blocks, I can see the flow, I can change this dial and see the lights move faster."

"I think the lights and the sound are very helpful. Also the graph is helpful, but I like the sound better. Starting with the lights, and then hearing the sound, and then seeing the graph worked great."

The simulation capabilities of System Blocks were essential to the students' iterative cycle of having a theory, testing it out, and revising the theory. This process of testing and revising confronted students with their own misconceptions time after time, and was effective in helping them use their own senses and observations to come up with a new theory. They did it quickly. It appeared as if they had no problem changing their theories. This is a core benefit of System Blocks. A simulation that can be operated by the student alone is critical to help students revise theories when they fail. Without a simulation tool, students could hold to their false theories, or drop them but adopt new false theories. In my activities with the students I repeatedly observed how System Blocks gives them a framework to test and revise their theories.

Stock-and-Flow *continued on page 6*

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Learning Stock-and-Flow Modeling *continued from page 5*

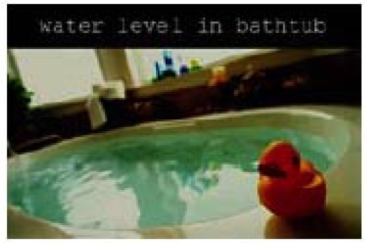
Inflow	Stock	Outflow
flow into bathtub 	water level in bathtub 	flow out from bathtub 
getting money 	amount of money saved 	spending money 
baking cookies 	number of cookies made 	eating cookies 
people get infected 	number of sick people 	healthy again 
hours per day spent watching TV 	interest in characters interest in characters	doing other things 
people join the trend people join the trend	number of people in the trend number of people in the trend	people leave the trend people leave the trend

Table 2: Examples of picture cards examples used during the sessions

During the sessions I asked the students to generate their own examples. I asked them to think of examples that match the system structure we simulated of inflow, stock, and outflow. In addition, I asked them to pick examples that relate to their own lives. Table 3 lists the examples generated by the Carlisle students, and table 4 the ones generated by the Baldwin students. Table 5 lists selected pictures of the Baldwin students' examples.

Student's gender	Inflow	Stock	Outflow
Male 1	Reading over a week	Books read	-no outflow
Male 2	How many minutes I read a day	Pages I have already read	-no outflow
Female 1	Getting books from library	# of books I have	Returning books
Female 2	Speed I am running	Total number of Min I ran. ***Later changed to***: Total yards	-no outflow
Male 3	Responsibility of me caring for my current pets	Total chances of me getting another pet	Grandma's health status

Table 3: Carlisle 5th graders personal examples for real-life systems

Student	Inflow	Stock	Outflow
Male 1	Getting a basketball	Practice	How good you are
Male 2	When I win games	How much I won	-no outflow
Female 1	Putting book in the shelf	Bookshelf is filled	Children take the books
Female 2	How much I dance	How much I get tired	How I feel after

Table 4: Baldwin 5th graders personal examples for real-life systems

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.

- ***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).

- ***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). This occurred more with the Carlisle students (the group with prior instruction).

- ***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. This 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). This occurred more with the Carlisle students (the group with prior instruction).

- ***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

Stock-and-Flow *continued on page 8*

Learning Stock-and-Flow Modeling *continued from page 7*

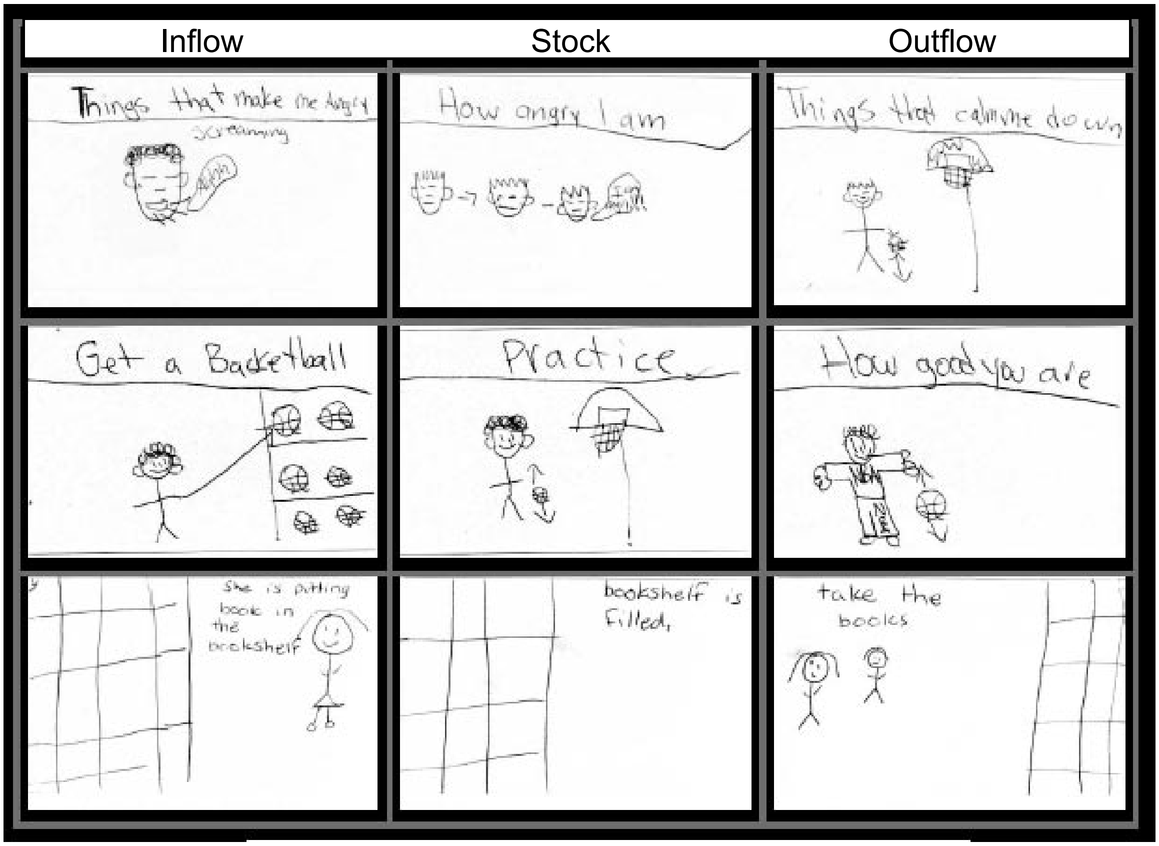


Table 5: Examples of drawings made by the Baldwin school students

assumed the system would stay in balance or not change. No differences were observed between the two student groups.

- ***Linear vs. curved***: students did not pay enough attention to the curvature of line graphs. They focused more on the direction of the graph (going up or down), and not so much on the curvature. From a mathematical (and real-life implications) point of view, there is a major difference between linear and curved growth (or decay). This problem night be addressed by improving the way line graphs are presented to students. Teachers can pay more attention to line curvature, using computer-generated graphs when possible, and emphasize the difference between straight and curved graphs. This inattention occurred more with the Carlisle students (the group with prior instruction).

DISCUSSION

Our findings are based on an exploratory study and a small sample, and should be regarded as such. We have showed that using System Blocks, both students with or without prior instruction in systems were capable of performing Stock & Flow modeling, simulation and analysis. Students were able to correctly map different real-life examples into Stock & Flow structures, and when errors were made, the interactive nature of System Blocks helped the students revise their models by themselves. 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 capable of learning feedback concepts (Zuckerman 2004). 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 systems 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 thinking sequentially rather than simultaneously. It seems that System Blocks might help to decrease the number of misconceptions with regards to net-flow dynamics and graph curvature, if used when these concepts are introduced to students for the first time.

System Blocks offer a delicate integration of tangible, physical representation and abstract, dynamic behavior. The blocks are tangible, but represent abstract entities. The picture cards serve as an intuitive way to create analogies, mapping the abstract entities with real-life examples. 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 structure 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 facilitators, and may have directly influenced 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 can be 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

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Listening to the Volcano: Conversations That Open Our Minds to New Possibilities

by David Hutchens, illustrated by Bobby Gombert

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Conversations to Spark Collaboration and Change

There is a common perception today that people are profoundly divided over the important issues that confront us. Social scientists increasingly cite intense polarities in politics and cultural values that are making it harder for us to get along and solve our problems. But despite the heightened rhetoric, we may not be as far apart as it appears on the surface. It could be that we are at odds, not because our concerns and desires are that different, but because the ways in which we express our views create barriers between us.

Listening to the Volcano: Conversations That Open Our Minds to New Possibilities, the new Learning Fable by Pegasus Communications, takes a fresh look at what many people are starting to grasp: that *how* we communicate is at least as important as *what* we have to say. Recognizing that good conversation can tap fresh sources of creativity and unleash the power of collective thinking, the book explores how productive communication can enable collaboration and positive action in the workplace and beyond.

Employing sly humor, zany illustrations, and the license of an imaginary world, *Listening to the Volcano* enables organizations struggling with sensitive issues to bypass defensiveness, engage in thoughtful inquiry, and open people's minds to innovative ideas. “By highlighting the importance of communication as the key vehicle for change, *Listening to the Volcano* offers an outstanding resource for managers who are serious about changing their company culture and level of performance,” says Chris V. Schena, vice president of the Motion & Power Control Division at Caterpillar Inc.

In this entertaining and provocative fable, rumblings from a long-dormant volcano provoke a crisis in the village of Smoldering Pines. Desperate to escape the impending flow of molten lava, the inhabitants meet to create a plan—and soon are at each other's throats. But led by Milo, a group of neighbors discovers a new way of talking and listening that leads to a surprising outcome. With its engaging use of metaphor and detailed discussion guide, *Listening to the Volcano* is a must-have resource for any organization interested in sparking generative thinking, improving decision-making, and creating effective action.

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by David Hutchens, illustrated by Bobby Gombert
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More information will be in the September *CLExchange*.

Process for submitting presentations for sessions:

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- **Mar. 1, 2006–**All authors will be notified of the status of their submission via e-mail.
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The conference will include the following topics:

- Tools for understanding and communicating in the classroom and in school administration.
- Training, both how to do it and training sessions for all levels from neophyte to experienced.
- Successive improvement–how have we done it, what are the markers of our failures and triumphs?
- Case studies approach–where has SD made a difference both in education and in the world?
- Many people enter systems education through various doors. How do we create paths from those doors? What paths have worked or have not worked?
- System Dynamics as a vehicle for collaboration and questioning.
- Tools for understanding.
- The future of SD/learner-centered learning in K-12. How can we contribute toward it?

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The list is not an overwhelmingly active one, so it will not burden your in-basket, unless there is a lively discussion going on. Our most recent one centered on the conceptual difference in a stock and a flow and why these are important concepts for students to understand. Bring your ideas and questions! Where else can you get answers from both experienced teachers and world-class system dynamics experts?

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