A Physical Interface for System Dynamics Simulation

Oren Zuckerman and Mitchel Resnick
MIT Media Laboratory, 20 Ames Street E15-020, Cambridge MA 02139 USA
{orenz, mres} @ media.mit.edu

ABSTRACT

We present the System Blocks, a new physical interactive system that makes it easier for kids to explore dynamic systems. A set of computationally enhanced children blocks, made of wood and electronics, the System Blocks can assist K-12 educators to teach the complex concepts of system dynamics and causalities. System dynamics and system thinking are methods for studying the world around us. They deal with understanding how complex systems change over time, and how structure influences behavior. In this paper we will show how the System Blocks enable young children (as early as four years old) to create and interact with systems that simulate real-life dynamic behavior such as a bank account; population growth; or the delicate equilibrium of an ecosystem. The System Blocks gives young children a hands-on environment to learn about complex behavior and encourage new ways of thinking.

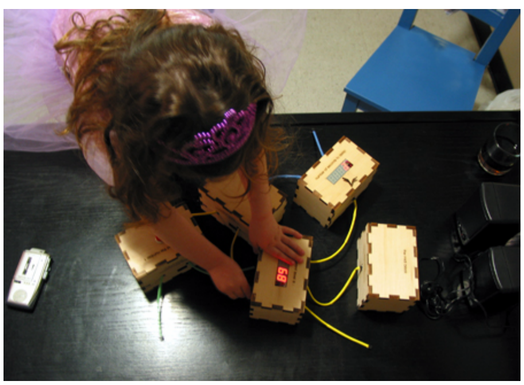

Figure 1: A four-year-old girl plays with the System Blocks

Keywords

System dynamics, System thinking, Digital manipulatives, Toys, Construction kit, Simulation, Education

INTRODUCTION

Jay Forrester, who pioneered the system dynamics field, showed there are common underlying principles of systems [2], such as feedback loops, time delays, levels and rates. The system dynamics 'language' developed by Forrester and the system dynamics group at MIT has been used in the last 20 years to model systems in a variety of different fields, such as business, economics, public policy, environment and social systems. Forrester and later Peter Senge [8] have argued that system dynamics is essential to understand the world around us. Furthermore, they emphasize that learning 'the deeper lesson' can be done only by training our Mental Models using computer simulations of dynamic systems.

Researchers have found that interaction with the physical world is a critical factor in the development of a child's mental model. A particularly notable example is Froebel's collection of twenty gifts [1], and Montessori's materials, each carefully designed to enhance learning of important concepts through physical manipulation (concepts such as shape and number). Seymour Papert [5], building on the work of Piaget, has shown how children can refine their mental models of the world through constructive processes.

RELATED WORK

There are several software-based simulation environments for dynamic systems such as Stella, Vensim, Model-It, and StarLogo. The System Blocks contribution is the physical interface and a simplified set of principles.

The Tangible Media Group at MIT Media Lab has done pioneering work in the field of tangible interfaces. They introduced a new approach for interacting with system dynamics models, using the 'Sensetable' tabletop display surface [6]. The System Blocks is different in the constructionist approach that enables creation of new models and in the overall design approach of embedding new systemic behavior inside the physical blocks rather than projecting it from standard system dynamics software.

Our group (Lifelong Kindergarten) at MIT Media Laboratory has previously introduced a collection of digital manipulatives [7] – computationally augmented versions of blocks, beads, balls, and badges. The 'blocks' are programmed from a personal computer and used to create robotic toys or kinetic sculptures. By contrast kids don't program the individual System Blocks, but rather create behaviors by connecting System Blocks together.

Previous work has been done on 'physical programming' interfaces for kids, such as the Electronic Duplo Blocks [9] and the Tangible programming bricks [3], but none has focused on dynamic systems simulation.

IMPLEMENTATION

To adapt the system dynamics principles to a K-12 audience and to the limitations of a physical interface, the following six types of blocks were created: **The Sender** – when clicked sends out the number 'one' through the output cables; **The Accumulator** – receives input from the

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'plus' port or the 'minus' port, adds or subtracts it from the accumulated level, and sends the level through the output cables; **The Delay** – receives input, holds it for X seconds and sends it through the output cables; **The Multiplier** – receives input, multiply it by X and sends it through the output cables; **The Converter** – receives input, ignores it and sends out the number 'one' through the output cables. **The MIDI** – receives input and plays the MIDI note associated with the input value (0 – 127).

The Delay and Multiplier blocks have knobs that enable interaction with the block's property. Each block has input ports and output cables. Each block may be connected to several blocks or back to itself. Blocks can be connected in different arrangements, forming different systems.

The System Blocks were prototyped using Bass wood and the Tower System – an electronics toolkit for prototyping tangible user interfaces, developed at MIT Media Lab [4].

Scenarios – Feedback loops

Feedback loops are a system dynamics core principle, and a complex one to understand, especially for children. From the different scenarios System Blocks can simulate, in this paper we will emphasize feedback behavior:

Scenario 1 – Reinforcing feedback loop. Consider the blocks arrangement in figure 2. The Sender starts the process. One click on the Sender button sends the number (1) to the Accumulator 'plus' port, which changes its level from (0) to (1). The Accumulator sends its level (1) to the next blocks – the MIDI and the Delay. The MIDI, through the speakers, plays the note associated with the number (1), and the Delay holds the value for 2 seconds and then sends it to the next block. The converter receives (1), ignores it and sends out (1) - back to the Accumulator 'plus' port which adds it to its current level (1 + 1 = 2), and sends out the current level (2) to the MIDI and Delay, and so on.

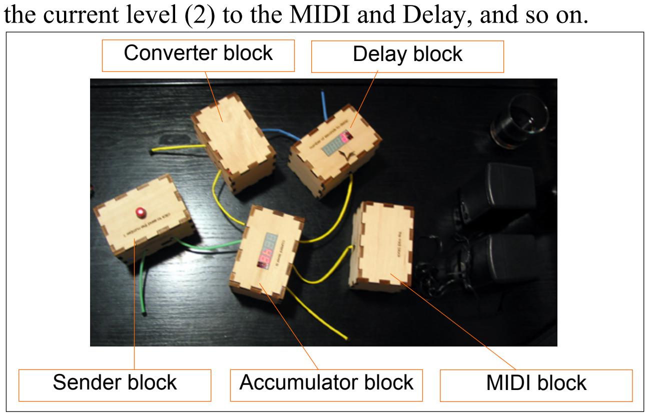

Figure 2: A 'reinforcing' or 'positive' feedback loop simulation

The resulted behavior is linear growth (1, 2, 3, 4, 5…), displayed on the Accumulator internal display and played by the MIDI block (notes playing a scale going up). Note that removing the Converter block from this arrangement will simulate geometric growth (1, 2, 4, 8, 16, 32…). **Scenario 2 – Balancing feedback loop**. Consider the same arrangement in figure 2 with the following changes: replace the Converter block with the Multiplier block (set to multiply by 2); and connect the 3rd output cable of the Accumulator to a Converter and back to the Accumulator 'minus' port. In this arrangement there are two loops going out from the Accumulator and back to itself, one loop pushing the level up ('plus' port) and the other bringing it down ('minus' port). The resulted behavior is oscillation (1, 0, 2, 1, 0, 4, 3, 2, 8, 7, 6, 16, 15, 14…). Using the Delay time knob, the oscillating behavior can be fine-tuned.

EVALUATION

The evaluation of the System Blocks took place with four children, 4, 6, 10 and 13 years old. Each child played with the blocks for 45 minutes in his/her home environment. We tested four different scenarios with each child, in growing complexity, and asked them to explain what each block is doing, what is the behavior of every arrangement, and if it bring to mind any phenomenon from their lives. All children understood the function of the blocks and enjoyed making different arrangements. The younger children understood the principle behind the Accumulator, but were confused when time delays were added. The older children figured out time delays and after some exploration understood the principle of feedback processes.

FURTHER INVESTIGATION

Careful studies should be done on the actual learning done with the blocks, defining the appropriate age range, comparing the learning done with the System Blocks to software-based system dynamics simulation tools and improving the blocks' design to simplify understanding.

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