Simulations Storybook: Supporting Young Children's Growing Understanding of Complex Systems (Short Paper)

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ספר סימולציות: תמיכת הצמיחה בידע של ילדים צעירים על אודות מערכות מורכבות (מאמר קצר)

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Abstract

This paper introduces Simulations Storybook (Levy & Sacks, 2022), an innovative educational design that uses digital storybooks embedded with computer models to support children's learning about complex systems. The study addresses changes in children's understanding of systems, the impact of system domain on learning, and how children interact with the Simulations Storybook featuring models of predator-prey relationships and epidemics. Using a mixed-methods design, the research analyzes data from pre- and posttest interviews with 15 kindergarteners and one child's interactions with the Simulations Storybook. The children's responses were coded for complex systems reasoning. Findings indicate that system domain influences children's use of using key systems-thinking concepts like level-transitions and interactions, though reading the Simulations Storybook did not increase children's use of these concepts. The case study participant showed interest and self-exploration with NetLogo (Wilensky, 1999) models. In the first session, "Feeding Rabbits," he focused on individual rabbit interactions, such as food holes made by the rabbits, without addressing broader system properties, like food availability. In the second session, "Sick Carrots," he adjusted the infection slider and began noticing group-level properties, like carrot populations and how their proximity influenced infection spread. This study highlights the potential of interactive models to promote systems-thinking.

Keywords: interactive simulations, educational technology, complex systems.
סימולציות, טכנולוגיות בחינוך, מערכות מורכבות.

This paper presents Simulations Storybook (Levy & Sacks, 2022), a digital storybook with simulations designed to teach children about complex systems, a central topic in science education

(NGSS, 2013). Technological advances have turned storybooks into interactive tools with varied success (Bus & Anstadt, 2021; Hoel & Jernes, 2024).

Literature Review

Computer simulations model scientific phenomena, aiding exploration of processes like molecules (Epstein, 2008). While research often focuses on adults and teens, young children remain underrepresented (Peppler et al., 2020).

Combining digital storybooks with simulations integrates storytelling and interactive learning, expanding their role in education (Hoel & Jernes, 2024). Prior studies have used storytelling with computational tools, like simulating bees or embedding programming (Danish et al., 2011; Horn et al., 2013). This study centers on complex systems—interactions where individual actions influence the whole, like ant colonies—focusing on physical and social systems.

Complex systems pose challenges due to misconceptions about control and causality (Hmelo-Silver & Pfeffer, 2004). Targeted interventions addressing system levels, interactions, and emergent processes can help (Jacobson, 2001; Wilensky & Resnick, 1999). This study examines predator-prey relationships and disease spread through a digital storybook.

Research questions:

1. Changes to systems-thinking: How do children's use of complex systems concepts change through interacting with the Simulations Storybook?
2. Impact of system domain on systems-thinking: How do their understanding differ between physical and social systems?
3. Simulations Storybook interaction characterization: What typifies their process of interacting with the storybook?

Method

A mixed-methods pretest-intervention-posttest design (Creswell, 2012) was used with semi-structured interviews. Fifteen Israeli kindergarteners (five females, M = 5.9 years, SD = 0.36) participated with IRB and Ministry of Education approvals.

One child was chosen for detailed analysis based on cooperation and verbosity. Each child completed six 20-minute sessions: two pretests on physical and social systems, two sessions with the storybook, and two posttests. Questions were validated in prior research (Sacks 2018), and video recordings captured screen activity and behavior.

The Simulations Storybook Design

Two NetLogo (Wilensky, 1999) agent-based models were embedded in a Hebrew story about a child caring for rabbits and growing carrots. The first model "Feeding Rabbits" (Figure 1), based on NetLogo's wolf-sheep predation model (Wilensky, 1997), simulates interactions between rabbits, carrots, and hay with simplified controls. The second model, "Sick Carrots" (Figure 2), inspired by NetLogo's disease model (Wilensky, 2005), introduces infected carrots, allowing children to adjust a "chance of getting sick" slider and observe disease spread.

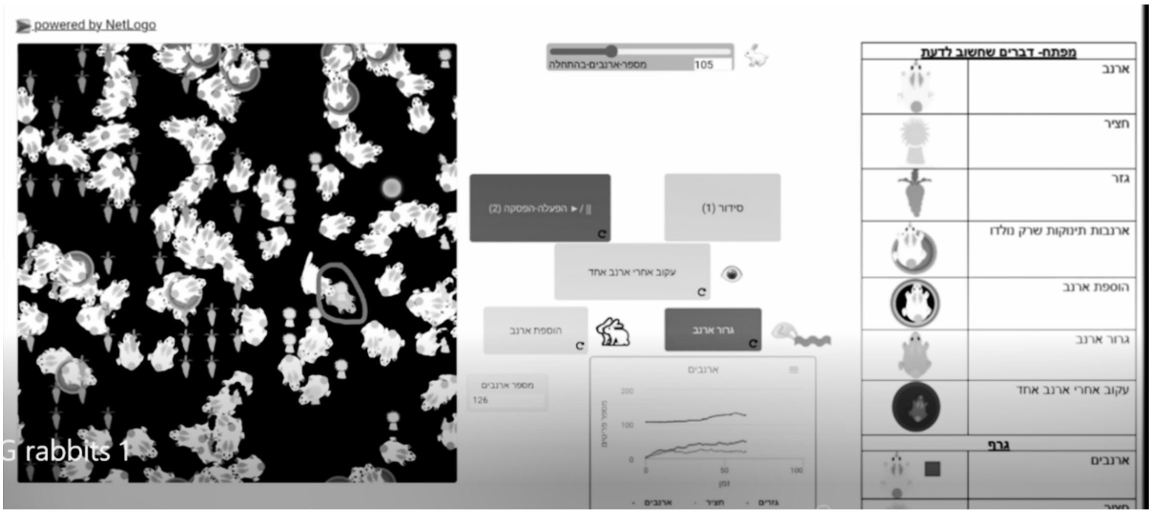

Figure 1. "Feeding Rabbits" (Levy & Sacks, 2022) simulation of rabbits eating carrots and hay.

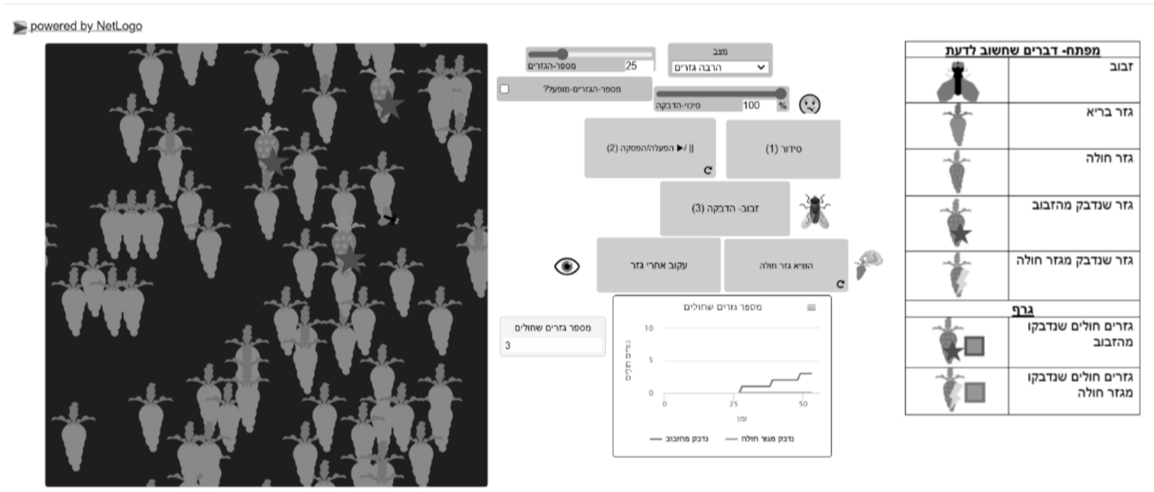

Figure 2. "Sick Carrots" (Levy & Sacks, 2022) simulation of the spread of disease.

Findings

RQ1: Changes to Systems-thinking

To evaluate changes in children's understanding of complex systems, the interviews' responses were segmented and analyzed. Each response segment was coded 1 or 0 for the presence of 12 system-thinking concepts (Table 1). The frequency of each concept was calculated, and a mean was computed for each test (Table 2). Mid-level concept frequency decreased from pre- to posttest, with no overall increase observed.

Table 1. Coding Table of System Concepts

Systems Concepts	**Example**
Level-Micro	*Hmm each [marble] collided with one marble. (Box task).*
Level-Macro	*Everyone just goes to the sides [of the yard]. (Scatter task).*
Levels-Transition	*Only the black [marble] moved everyone. (Box task).*
Emergence	*[Researcher: Canyou explain to me how they [the marables] are breaking down?]* *Hmmm I see they [the marbles] collide [into each other]and after that , they collide with the box and after that they start to break down.* *(Box task).*
Mid-level	*[Researcher: What behavior is there [of the sand grains?]* *Some [sand grains go] right, some [sand grains go left, some [sand grains go] backwards, and some [sand grains go] forward. (Sand task)*
Interactions	*They [the marbles] collide. (Box task).*
Parallel-Events	*No Example.*
Control	*Ask the kindergarten teacher [for permission]. (Room task.)*
Predictability	*No Example.*
Non-Linearity	*Hmm [the sand hill] was big and then [the sand hill] fell a little and then [the sand hill] became smaller. (Sand task).*
Equilibration	*That the pile [of sand] also falls down from the pipe and then [the pipe] drops another pile and another [pile of sand] and another [pile of sand] until [the sand hill] drops. (Sand task).*
Rates and Flows	*No Example.*

Table 2. Frequency of systems concepts in the children's pretest and posttest interviews

Domain	**Overall**		**Physical**		**Social**		**Significant domain differences**
Systems Concepts	**Pretest *M (SD)***	**Posttest *M (SD)***	**Pretest M (*SD*)**	**Posttest *M (SD)***	**Pretest *M (SD)***	**Posttest *M (SD)***	
Level-Micro	8.53 (2.39)	9.87 (2.42)	4.13 (1.51)	5.07 (2.02)	4.40 (1.92)	4.80 (1.47)	-
Level-Macro	9.53 (2.64)	9.53 (2.77)	5.53 (1.85)	5.00 (1.73)	3.80 (1.42)	4.53 (1.77)	Physical > Social

Domain	Overall		Physical		Social		Significant domain differences
Systems Concepts	**Pretest *M* (*SD*)**	**Posttest *M (SD)***	**Pretest M (*SD*)**	**Posttest *M (SD)***	**Pretest *M (SD)***	**Posttest *M* (*SD*)**	
Levels-Transition	2.47 (1.85)	2.40 (1.81)	0.73 (0.70)	1.00 (1.46)	1.73 (1.62)	1.40 (1.18)	Social > Physical
Emergence	0.07 (0.26)	0.07 (0.26)	0.07 (0.26)	0.07 (0.26)	0.00 (0.00)	0.00 (0.00)	-
Mid-level	0.93 (0.96)	0.33 (0.62) *	0.27 (0.59)	0.20 (0.41)	0.67 (0.90)	0.13 (0.35)*	-
Interactions	6.20 (3.59)	6.20 (4.16)	4.87 (2.85)	4.60 (1.77)	1.33 (1.35)	1.93 (2.82)	Physical > Social
Parallel-Events	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	-
Control	0.53 (0.92)	0.33 (0.72)	0.13 (0.35)	0.00 (0.00)	0.40 (0.91)	0.33 (0.72)	-
Predictability	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	-
Non-Linearity	1.73 (1.34)	0.93 (0.80)	1.07 (1.22)	0.27 (0.46)*	0.67 (0.62)	0.67 (0.72)	-
Equilibration	0.07 (0.26)	0.00 (0.00)	0.07 (0.26)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	-
Rates and Flows	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	-

Note to Table.

1. Statistical tests for significance were made using *paired t*-tests and using a series of mixed-effect Poisson-log regression models. Significant differences from pretest to posttest are marked on the posttest results with * signifying $p< .05$, and ** signifying $p<.01$.

RQ2: Impact of System Domain on Reasoning

Although no overall increase in systems concept use was observed, domain-specific analyses revealed notable patterns. Physical tasks prompted more macro-level references and articulation of micro-level interactions, while social tasks elicited more level-transitions. Mixed-effect Poisson-log regression showed significant predictors for system domain and macro-level use ($F(1, 116) = 6.21$, $p = .014$), level-transitions ($F(1, 116) = 4.88$, $p = .029$), and interaction use ($F(1, 116) = 27.22$, $p < .001$). Time (pretest vs. posttest) was not a significant predictor overall.

RQ3: Simulations Storybook Interaction Characterization

A case study of "Dan," a 6"2' year-old boy, illustrates a shift in focus across the two models in the storybook from individual rabbits in the first model to relating individual behaviors to group properties in the second. In Session 1 ("Feeding Rabbits"), Dan spent 24% of his time exploring 13 scenarios, focusing on individual rabbits and their interactions, like observing holes in the food where rabbits had eaten. However, he did not address broader system properties like population or food availability. In Session 2 ("Sick Carrots"), Dan spent 25% of his time exploring 28 scenarios. He adjusted the infection slider and began noticing group-level properties, like carrot populations and how the carrots' proximity influenced infection spread. An independent *t*-test revealed significantly longer exploration durations for "Feeding Rabbits" scenarios ($M = 82.0$ seconds/scenario, $SD = 37.1$) compared to "Sick Carrots" ($M = 18.3$ seconds/scenario, $SD = 16.2$), $t(14.19) = 5.93$, $p < .001$, Cohen's $d = 2.59$.

Discussion

For RQ1, no changes were observed in children's reasoning about systems after reading the Simulations Storybook, except for a decrease in mid-level construction from pre- to posttest. Regarding RQ2, domain differences revealed decreases in mid-level (social system) and non-linearity (physical system). Physical tasks prompted more macro-level references and micro-level interactions, while social tasks elicited more level-transitions.

The decrease in the making mid-level groupings, which decomposes systems by forming sub-groups, may have resulted from (1) as it's a simplification the children relied on it less over time when they needed it less with experience of the simulations; or (2) the storybook lacked object groupings to support its use. Non-linearity, the "butterfly-effect," is rarely used even by adults (Jacobson et al., 2011). Its limited use here aligns with prior research (Sacks, 2018), and the decline may be an experimental artifact, due to the small frequency value.

The third RQ examined one child's interactions with the storybook. The child conducted numerous explorations, varying model features and shifting from focusing on individual rabbits and carrots to recognizing group-level properties, like populations and individual rules, like how carrot proximity influenced infection. This shift reflects significant development in systems-thinking. The child spent more time on the earlier model, likely because it was more dynamic, included more populations, and appeared earlier in the sequence.

In conclusion, the Simulations Storybook enables children to explore and manipulate various system models, shifting their focus from individual entities to systemic properties—a hallmark of complexity-reasoning. However, this learning remains context-bound to the book and does not transfer to interview tasks. Future work will explore additional scaffolding to enhance learning. Despite this limitation, the children's extensive exploration of the book's simulations and their developing systems-thinking are promising.

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