Young Children's Representational Structures of Robots' Behaviors

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Abstract
Despite the fact that the sophisticated technologies are a substantial component of children's everyday environment, of the space within which they act, play and learn - the world of complex technological systems (their characteristics, and the knowledge and skills involved in operating, designing and programming them) is almost ignored in the preschool and elementary school curriculum. The study reported in this paper is part of a research plan embedded in the implementation of a comprehensive curriculum aiming to support the development of technological thinking in kindergartens, including knowledge and skills in areas such as design, the artifacts in our material culture, smart artifacts and robotic systems, or programming. This particular study aimed to address young children's (aged 5-8) perception of the adaptive behavior of a robot and the representational structures (or functioning schemes) they adopt to think about how its behaviors are generated and controlled. When children think about the robot's behavior, they may adopt different perspectives that translate into different representational structures, (e.g., one-time episodic representation; a script that can became a reusable routine; a universal representation such as a rule of behavior). The findings evidence the ability of young children engaged in programming to think in terms of abstract rules and to use these for programming and designing a robot's behavior.

Keywords
Robotics, representational structures, kindergarten, programmimg

Young Children's Representation of Robots' Behaviors

> A. (preschooler) says immediately after finishing to program the robot:
> *...I did it nicely. I had an idea. It wasn't easy. First, I got thinking, then I saw that it didn't help, then I knew that it would do it all the time and then it would get out of the maze. It's easy, I thought with the help of the robot suggesting an idea, and then I knew...*
>
> L. (first grader) adds while looking at the robot traveling on a black strip:
> *... How does it know how to turn around on this thing?? You (meaning the researcher) made it happen with a computer. But how does he know from the computer? The man is so small, so how can he see from the computer? The man inside this car (the robot). A little man, I can't see it. The man is smaller than a germ. He simply goes and sees what is written on the computer and moves it (the robot) ...*

These are just two examples (out of many) of kindergarten and first grade children reflections on a robot's behavior. A. describes the programming and debugging process, while L. tries to understand what is happening – why the robot behaves in the way it behaves. Both child's descriptions include anthropomorphic references to the robot. However, L. has difficulty at understanding that the autonomous behavior of the robot results from running code written by a programmer.

Young children are exposed to controlled technological systems from an early age – supermarket doors, programmable toys, smartphones, sophisticated appliances, or control systems embedded in many familiar devices in the environment. Young children play, try out, and learn to operate these systems as part of their daily lives. Given that sophisticated technologies are such a substantial component of children's everyday environment, of the space within which they act, play and learn - why the world of complex technological systems (their characteristics, and the knowledge and skills involved in operating, designing and programming them) is almost ignored in the preschool and elementary school curriculum?

With this overarching question in mind, we have developed, studied and implemented for more than a decade a comprehensive curricular intervention for kindergartens in Israel focusing on technological thinking skills and knowledge. Among the range of curricular strands and batteries of tasks implemented and examined, there are issues related to children's understanding of the structure and functioning of smart artifacts - the context of the study reported in this paper. The study addresses a specific aspect: young children's (aged 5-8) perception of the adaptive behavior of a robot and the representational-structures (or functioning schemes) they adopt to think about how its behaviors are generated and controlled.

A basic research assumption for the study was that when the children program the robot's behavior, they use different representational structures (e.g., one-time episodic representation; a script that can became a reusable routine; a universal and a-temporal representation such as a rule of behavior). The actual implementation of each representation obviously embeds differences in understanding the robot's functioning as well as in planning and programming strategies generating its behavior.
The main question examined in the study was: What are the representational-structures of control (i.e., episode, script, rule) used by young children (5-8 years) to represent a robot's adaptive behavior.

Background

Children's activities in a robotic environment imply acknowledging different types of behaviors of the system: from sporadic or one-time events (episodes), through reusable organized behavioral patterns (script), to time-independent behavioral patterns (e.g., rules) connecting between environmental conditions and robot's actions. A **script** is a generalized, temporally and spatially organized sequence of events about some common routine with a goal. Using a **script** is characteristic of preschoolers' thinking – for example, they create scripts when engaged in playing sociodramatic games (Mioduser, Levi & Talis, 2009) or in describing temporal events (Flavell, Miller, & Miller, 1993). Young children have difficulty in formulating the necessary proofs to examine a hypothesis, therefore have problems in drawing conclusions. Despite this, children can "draw" conclusions from actual observed data, obtained through active participation in its generation, e.g., a programming-and-program-running task.

Concerning **rules,** studies focusing on children's understanding of cause/effect relationships showed that children can distinguish a behavioral pattern in a robot's functioning and use these for predicting and planning its behavior (Siegler, 1986; Sobel, Tenenbaum, and Gopnik, 2004). While coping with a programming task, children will first look at the robot's functioning and describe it step by step in time, thus generating a script. However, the continuous use of scripts along different tasks leads to the perception of patterns and to the formulation of rules independent of time and expressing generally relationships between inputs and outputs (Mioduser, Levi & Talis, 2009). Using a rule is obviously different from using an episode or a script. Siegler (1986) describes four processes that occur when a new rule is learned:

- The ability to refer to and explain key variables.
- The ability to formulate a general rule.
- The ability to generalize to other contexts.
- Preserving the rule even after the intervention is over.

Research has shown that children perceive initially a robot's behavior as a one-time event – an episode. They focus on the robot's behavior while ignoring its interaction with the environment. Such focus on the robot's observable behavior is the basis of Papert's claim (1993) that the learner identifies herself with the behaving artifact and focuses on interpreting its behavior as a finite sequence of behavioral units. The study by Mioduser, Levi & Talis (2009) shows that episode-like descriptions of a robot's behavior were used when children were told to deal with complex tasks, or when they were confused and unable to understand complex patterns in robotic behavior.

It has been argued that children have more difficulties explaining the behavior of a robot than to program such behavior (Levi & Mioduser, 2007). However, evidence in the literature is not conclusive. There are studies emphasizing preschool children's difficulty in reasoning with rules, thus causing their use of scripts rather than rules to describe a robot's behavior (Flavell et al., 1993). In contrast, other studies show that experience with a facilitating robotic environment supports children's use of rules (Bers & Portsmore, 2005). Children who were only required to explain the robot's behavior used, as expected, more scripts and fewer rules to represent the robot's behavior, while children involved in programming were able to construct rules even if they could not express and describe completely their complexity (Mioduser, Levi & Talis, 2009). Hoyles, Noss, Adamson, and Lowe (2001) found that children aged seven to eight used a formulaic rule and a psychological explanation of a robot's behavior, but when involved in programming tasks, they described the events in terms of complete rules. Another study reinforces these conclusions indicating that the construction of rule-based behavior using a tangible-programming environment helps children stretch their cognitive skills (Mioduser, Levi, & Talis, 2009).

It is often seen in the literature that programming is a significant factor that encourages children's comprehension of rule-based behavior. In the study by Hong, Chijun, Xuemei, Shan, and Chongde (2005), children from three and a half to four and a half years old, had to use one rule: "If... then..." for one-dimensional tasks. For two-dimensional tasks, the children had to focus on two preconditions (i.e., "If... then... if... then..."). For three-dimensional tasks, the children had to focus on three preconditions. These situations obviously demand complex cognitive processes. The more dimensions, the more sophisticated the cognitive process involved indicating a development path. Most three-and--half year-olds could refer to a simple rule (If... then...). This reinforces earlier studies in which young children can only focus on one dimension. Another study that examined children's perspectives regarding artifacts (Siegler, 1986) indicates that young Children-Pre-scholars' can deduce complex explanations regarding behaving artifacts, but the number of rules they can connect by themselves with complex behavior is limited to one at a time. The conclusion that children can only concentrate on one dimension is thus strengthened further.

In cognitive complexity and control theory, complexity is measured by the number of levels in the rules. For example, three-year-old children can cope with the formalization of "If red, then...", "If blue, then..." But, if another dimension is added, such as "a car", This is already a very serious difficulty. The more complex the rule system, the more difficulty the children will have in relating to several dimensions. As children grow older (Maturity age), they can cope increasingly with several concurrent dimensions, and their cognitive ability consistently improves (Hong et al., 2005; Siegler, 1986).

The complexity level is an important component of the tasks in this study. When children are asked to explain a particular event or situation, they first act intuitively, and only later recognize a rule characterizing the artifact's behavior. Despite this, the two systems (intuitive and conscious) are at times integrated, and therefore children seldom need to maneuver their way between them. The experience-based reflection and inference system about real-world events develops earlier than the abstract and generalizable rule-based one. Children have everyday knowledge and they react based on their own experience (Levi & Mioduser, 2008). Moreover, very early children can use rules. Four years old can already use a rule construct ("if... then...") and to a limited extent, two combined rules ("If... then... and if... then...) to explain and/or generate an artifact's behavior.

In summary, there are different theories and evidence regarding children's ability to use rules regarding the behavior of a robot interacting with a changing environment. Piaget (1967), in his study regarding scientific causation, argues that young children will find it difficult to think abstractly. Later studies suggest that temporary structured events will be described more as a script than as abstract rules (Flavell et al., 1993). Current studies show that children can process and use knowledge acquired by observation and active participation in solving a task to predict, plan and construct rule structures to program a robot's behavior (Mioduser, Levi & Talis, 2009). Very few studies in the past have dealt with the issues of the importance of programming at an early age as a tool for learning and cognitive development.

This study attempts to examine the contribution of young children's involvement in programming processes to promote appropriate perceptions of behavior control representations. Our main research question was:

Which representational structures of control (e.g. script, episode, rule) young children (aged 5-8) use to represent the adapting robot's behavior, as a function of:

- Age group, discriminating between preschoolers and first graders.
- Complexity of the task, defined by the type and number of structural representations included, i.e., one rule, two rules, a rule and a routine.
- Type of involvement in performing the tasks, either as "explainers" or as "programmers" of the robot's behavior.

Methodology

Participants

Sixty-nine children participated in the study from 2 kindergartens and a school in a city of medium socioeconomic status in central Israel. Kindergartens in Israel are under the supervision of the Ministry of Education and are mandatory, starting at the age of five years old. They are mostly independent units and not part of schools. The participants' distribution was:

- 46 children aged 5- 6 years old, from two kindergartens,
- 23 children aged 6.5-7 years old, first graders.

Participants were divided into three groups by their involvement in performing the tasks: 23 **kindergarten** children "**programmers**" (they were asked to program the robot in the different tasks); 23 **kindergarten** children "**explainers**" and 23 **first grade** children "**explainers**" (requested to explain the robot's behavior in the different tasks).

Procedure

The study was conducted during eight months during the school year. The learning sessions were held during the preschool or school day. Children's performance and interviews were video-recorded. The observations were transcribed, and coding was carried out according to the categories determined for the study's variables.

Programming Environment

The robotic environment comprised a computer interface (Figure 1), a robot (built from Lego parts and the programmable brick), and a physical environment modified to meet the requirements of the various tasks. The programming interface used for this study, "Kinderbot", is a research and development tool created in the Science and Technology Education Center at Tel Aviv University (Talis, Levy & Mioduser, 1998). Programming is based on the use of icons allowing intuitive and simple definition of commands (e.g., single actions, sequences of actions, routines, rules) without requiring writing or reading code. A menu of the different programming modes appears on the right-hand side of the screen, each mode allowing to define the robot's navigation procedures in increasingly complex manner. Complexity increases from a mode resembling a remote control for the direct manipulation of the robot's actions, through modes allowing the construction of linear programs, to modes allowing to formulate conditional statements linking between incoming information (from the sensors) and outcomes or actions, in various rule formats (e.g., half a rule, a whole rule, routines -chunks of actions- and two interrelated rules). The rules are actually configurations of icons representing the inputs of the different sensors, and icons representing possible actions (the possible navigation directions for the robot) arranged in a matrix.

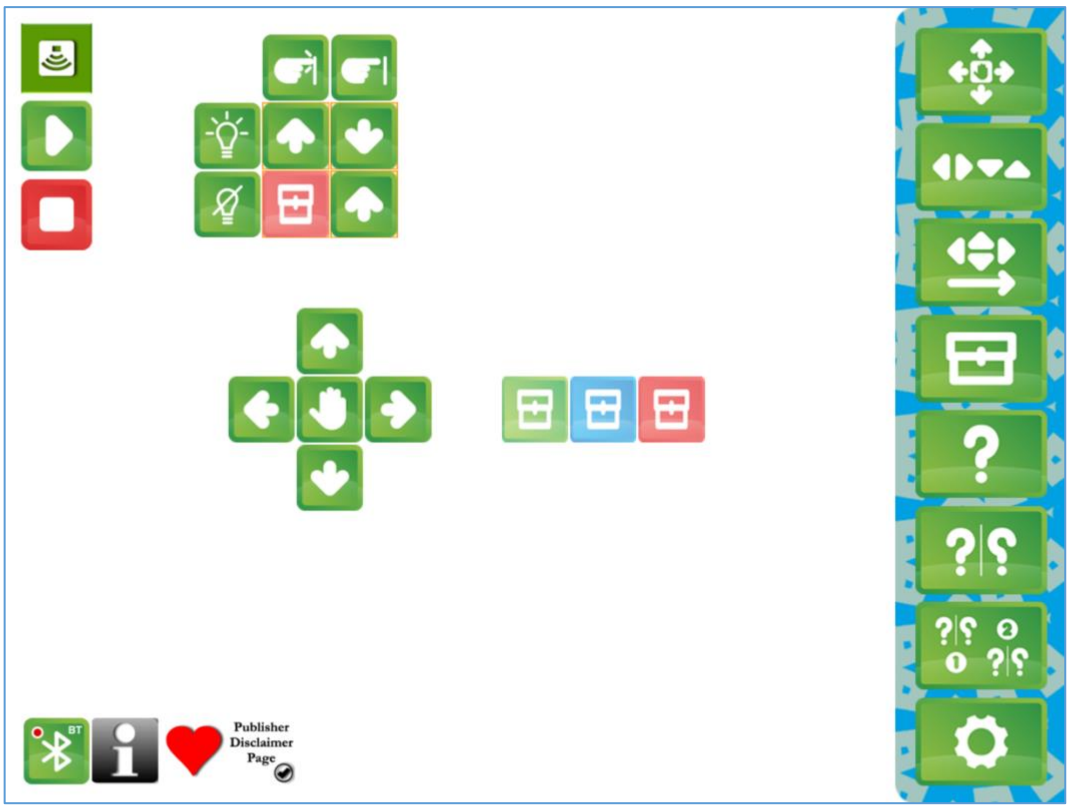

Figure 1: Kinderbot – the programming interface

Tasks

The children in this study performed three tasks of increasing complexity. The children in the "programming" group were required to plan and program the behavior of the robot. The children in the "explainers" group were asked to describe and explain the robot's observed behavior.

- One rule task: The Island. Frame story: the robot is on an island, and wanders in it without falling into the sea waters. The island is a black, elliptical surface, surrounded by a white surface. Robot's functioning: if the robot's light sensor detects darkness (the black color), it means that it stands within the island surface. If the sensor detects the white color the robot is now in the "sea area" and its path is corrected.

- Two rules task: The Bridge. Frame story: the robot must keep traveling on the bridge without falling into the raging waters. The environment is a white surface, with a black, winding, broad stripe in its center. Robot's functioning: if both light sensors detect the black color then the robot is on the bridge. If either the right or the left light sensor detects the white color, the robot is moving either to the right or to the left of the bridge (need to correct the path). If both light sensors detect the white color, then the robot is about to left the bridge – it should either stop or correct the path.
- Rule and routine: a maze with obstacles. Frame story: The robot must navigate a space avoiding obstacles, solid cubes scattered over it. Robot's functioning: Every time the robot hits an obstacle (touch sensor pressed), it runs a routine (several commands in succession) to escape it and continue its navigation.

Data analyses

The main unit of analysis were children's statements (verbal and enacted) as identified and coded following the transcription of the recordings of the programming and explanation sessions. Quantitative and qualitative analyses were performed on the data collected.
Aiming to answer the research questions the following comparisons were performed:

- The effect of the **type of involvement** in the tasks on **preschool** children's perception of the robot's behavior: programmers compared to explainers.
- The effect of the **type of involvement** in the tasks on children's perception of the robot's behavior, as **age-dependent**: preschool programmers compared to first grade explainers.
- The effect of **age** on children's **explanations** of the robot's behavior: preschool explainers compared to first grade explainers.

Descriptive statistical analyses as well as group comparison tests were applied to the data collected for all research variables.

Research Findings

Research question: Which representation structures of control (i.e. episode, script, rule) young children (aged 5-8) use to represent the robot's adaptive behavior?

This question was examined as a function of age group, complexity of the task and type of involvement in the task as described above. In the following we present quantitative as well as qualitative accounts of the analyses performed in the different comparison configurations.
Comparison between preschool programmers vs explainers, as a function of task complexity.
We analyzed children's statements to unveil the way they refer to each of the representation structures. Thinking in rules represent the highest level of thinking, understanding situations in which there is a cause and an expected outcome.

Data in Table 1 indicate significant difference in the use of representational structures between the preschool groups in all three tasks. The **programmers** used mainly rules while the **explainers** used

mainly episode and script structures to represent the robot's behavior. The distribution of statements among representation structures by age and group for all tasks is presented in Table 2. Data in Table 2 shows that among the **programmers** reference to rules was dominant for all tasks. Among the **explainers** there is a high frequency of statements focusing on the usage of a script description in Task 1 (approximately 75%), and a considerable increase in the use of rules as the complexity of the task increased (60-65%). As tasks increased in complexity, also the explainers were required to describe the robot's behavior using more sophisticated structures.
In the following, sample statements are presented, showing use of episodic description by the **explainers**:

A. (boy, aged 5, explainer): *"I saw the robot's eyes and then I knew where he would go to."*
E. (girl, aged 5, explainer): *"He goes around everywhere. He goes here and here and here and here"* (indicates circles inside the maze with her hand).
This was not the case with the **programmers** of the same age. There were no statements (for any task) describing the behavior as an episode. It seems that the design and programming

Table 1: Use of episodes, scripts and rules by preschool explainers and programmers

		Preschool programmers	Preschool explainers	t	p
Task 1	Mean	2.86	2.02	***9.03	0.0000
	Standard deviation	0.26	0.37		
Task 2	Mean	2.93	2.63	***3.55	0.0007
	Standard deviation	0.16	0.35		
Task 3	Mean	2.89	2.58	**2.74	0.0052
	Standard deviation	0.21	0.48		

Representation structures scores
1 - episode
2 - script
3 - rule
** p<0.01 *** p<0.001

Table 2: Distribution of statements (N=554) by use of representation structures, tasks, and activity (explainers or programmers) in the preschool group

	Rule		Script		Episode		Total	
	Preschool Programmers	Preschool Explainers	Preschool Programmers	Preschool Explainers	Preschool Programmers	Preschool Explainers	Preschool Programmers	Preschool Explainers
Task 1	94	10	12	53	0	8	106	71
	88.7%	14.1%	11.3%	74.6%	0.0%	11.3%	100%	100%
Task 2	80	67	10	32	0	4	90	103
	88.9%	65.0%	11.1%	31.1%	0.0%	3.9%	100%	100%
Task 3	93	46	14	26	0	5	107	77
	86.9%	59.7%	13.1%	33.8%	0.0%	6.5%	100%	100%

process requires, and facilitates, a broader view of the robot's functioning in terms of general and reusable rules.

Thinking about rules implies the capability to perceive the robot's behavior in terms of the causal relationship between a condition and an action ("If... then..." statements). Evidencing this perception, the programmers generated explanatory statements such as:

> K. (aged 5.8, a girl programmer): "*If you see black, left, and if you see white, then left too. He needs to go straight on the black. He is going on the black. And going around. Every time he gets to the white, he goes back to the black. Because I wrote to him that he should go straight on the black and turn right... That is left on the white.*"
>
> L. (aged 6, a boy programmer): "*The two eyes see black and he moves forward. When one eye sees white... Right or left? He goes back to his path. On the other side, he also goes back to the path. When both eyes see white he turns around.*"
>
> L. doesn't actually employ the wording, "If... then..." but his mode of expression show a clear perception of the robot's behavior in all possible conditions (i.e., on the path or outside the path either to the left or the right) using several rules. It is evident that he understands the rules and their effect upon the adaptive behavior of the robot.
>
> N. (aged 5.7, girl programmer): "*If he is free, then goes straight. And if he bumps into something, then a star (counts the steps back from the screen). And if he is free, straight forward. And then a star. It's hard... (Examines the robot). If he goes straight and gets stuck, then he goes here and here (moves the robot). When he bumps into something, he goes*

> *backwards and turns left. And dances like a star. He goes left, went backwards, and turned around until he got here (to the opening)* and left..."
>
> N. verbalizes the program. The task is very challenging and therefore N does a reflective process while planning. She understands the framework of rules and uses it to create a program with rules and a "withdrawing" routine (packed under an icon – the "star") due to which the robot manages to exit the maze.

The examples show that programmers understand the robot's behavior as a-temporal and repetitive process. The use of the words "all the time...", "goes back there...", "every time..." make it clear that the robot's behavior recurs whenever the defined condition is met.

Comparison between preschool programmers and first grade explainers as a function of task complexity.

Data in Table 3 shows that the performance of the **preschool-programmers** is significantly higher than that of the **first-grade-explainer**s, for all three tasks. Preschool programmers generated representations of the robot's behavior using rules, while the first-grade explainers used mainly script-based representations.

Results of the qualitative analyses summarized in the distribution of statements are presented in Table 4, supporting the quantitative observations. The main representational structure used by first-grade-explainers is the script for most tasks. In Tasks 2 and 3 the frequency of use of scripts is similar to the use of rules. These figures show that first graders understood the robot's behavior mostly as a repetitive pattern or sequence of actions, rather than as ad-hoc decision making pending on conditions.

A sample statement showing the use of a script among the first-grade-explainers:

> A. (aged 7.2) explains: "... *He began from here (indicates the start of the bridge) and from here (indicates the junction)."*

This does not apply to the preschool-programmers. They did not use any statements that indicate use of episodes or scripts to describe the robot's behavior while programming. They use rules more often than the first grader explainers.

Following is an example of the terminology used by the programmers for defining the rules that comprise the entire program required for the robot's functioning in the third task (in the form of a matrix of four condition-action pairs):

Table 3: Use of episodes, scripts and rules by preschool-programmers and first-grade-explainers

		Preschool programmers	First grade explainers	t	p
Task 1	Mean	2.86	1.97	***7.38	0.0000
	Standard deviation	0.26	0.52		
Task 2	Mean	2.93	1.94	***7.02	0.0000
	Standard deviation	0.16	0.65		
Task 3	Mean	2.89	2.01	***5.76	0.0000
	Standard deviation	0.21	0.71		

Representation structures scores
1 - episode
2 - script
3 - rule
*** p<0.001

Table 4: Distribution of statements (N=605) by use of representation structures, tasks, and activity-type (explainers or programmers) in the preschool-programmers and first-grade-explainers groups

	Rule		Script		Episode		Total	
	Preschool Programmers	First grade Explainers	Preschool Programmers	First grade Explainers	Preschool Programmers	First grade Explainers	Preschool Programmers	First grade Explainers
Task 1	94	14	12	38	0	8	106	60
	88.7%	23.3%	11.3%	63.3%	0.0%	13.3%	100%	100%
Task 2	80	31	10	38	0	22	90	91
	88.9%	34.1%	11.1%	41.8%	0.0%	24.2%	100%	100%
Task 3	93	63	14	56	0	32	107	151
	86.9%	41.7%	13.1%	37.1%	0.0%	21.2%	100%	100%

> Y. (aged 5.7, programmer): "*If the two eyes see black, he will go straight on. If they both see white, it will go backwards. If one eye sees white and the other black, then right. And the second side – left. If one eye sees white and it turns and goes to the black...*"

The wording by Y. unveils a highly sophisticated capability to cope in concrete terms with four Boolean configurations of the values incoming from two sensors, i.e., sensors a <u>and</u> b "see" white;

sensor a “sees’ white and sensor b black (a and not-b); sensor a “sees” black and b white (not-a and b); both sensors “see” black (neither a nor b). Kindergarten programmers used mainly rules, either while programming or while explaining the robot’s behavior.

Comparison between preschool-explainers and first-grade-explainers as a function of task complexity.

Table 5 compares between the two groups of explainers regarding the representation structures used by the children. Significant difference between the groups was observed in Tasks 2 and 3. It can be seen that the preschool-explainers used significantly higher representation structures in their explanations –i.e., scripts and rules– than their peers first graders. The research literature indicates that reasoning based on cause and effect, or reasoning according to rules, is not characteristic of preschool children’s reasoning. It could have been expected that specifically among the first graders –average age of 7– their explanations would comprise a significant number of representation structures based on reasoning according to rules. However, analysis of their statements shed light on their frequent use of episodic and script-like structures in their explanations.

Table 5: Use of episodes, scripts and rules by preschool-explainers and first-grade-explainers

		Preschool explainers	First grade explainers	t	p
Task 1	Mean	2.02	1.97	0.35	0.7295
	Standard deviation	0.37	0.52		
Task 2	Mean	2.63	1.94	***4.44	0.0001
	Standard deviation	0.35	0.65		
Task 3	Mean	2.58	2.01	**3.17	0.0028
	Standard deviation	0.48	0.71		

Representation structures scores
1 - episode
2 - script
3 - rule

** $p<0.01$ *** $p<0.001$

Table 6 shows the representational structures used by participants in both groups of explainers. About 20% of first graders’ statements indicated the use of episodes, whereas only about 7% of preschooler’s statements refer to an episodic description. The first graders’ use of episodes increases when required to cope with more complex tasks, or when they got confused observing the robot’s behavior and were unable to notice a particular pattern characterizing it.

The findings indicate an increase in the first graders' use of rules – from 23% for Task 1 to 41% for Task 3. The trend is similar with preschoolers – from 14% for Task 1 to 60% for Task 3. In this complex task, the robot's behavior triggered explanations based on the formulation of rules, particularly among the preschoolers.

Table 6: Distribution of statements (N=553) by use of representation structures, tasks, and activity-type (explainers or programmers) in the preschool-explainers and first-grade-explainers groups

	Rule		Script		Episode		Total	
	Preschool Explainers	First grade Explainers	Preschool Explainers	First grade Explainers	Preschool Explainers	First grade Explainers	Preschool Explainers	First grade Explainers
Task 1	10	14	53	38	8	8	71	60
	14.1%	23.3%	74.6%	63.3%	11.3%	13.3%	100%	100%
Task 2	67	31	32	38	4	22	103	91
	65.0%	34.1%	31.1%	41.8%	3.9%	24.2%	100%	100%
Task 3	46	63	26	56	5	32	77	151
	59.7%	41.7%	33.8%	37.1%	6.5%	21.2%	100%	100%

Examples of statements showing use **of rules** among first graders and preschoolers:

> A. (aged 5.7, a boy preschooler): "*On black, he needs to go on the black, right, and stop when the eyes see white. And if one eye went, then he goes back. The eyes see white, one sees white and one sees black, and then it turns to the black.*"
>
> Y. (aged 7.4, a boy first grader): "*You wrote to him if you bumped into something. Then don't stay in the same place. Go back to some other place. And if you bump into something. Then go to another place. If you don't bump into something, then great!*"

It seems that both the first graders and preschoolers are able to generalize and generate abstract descriptions while explaining the robot's behavior. They are able to refer to cause and effect situations when they see the complex behavior of the robot, which is not perceived necessarily as a repetitive pattern. However, at the same time, in Task 3 we observed more frequent usage of the rule representation structure among preschoolers - 60% as opposed to only 41% among first graders (we should note that these are findings by two groups of "explainers", who were not actively involved in programming – we will expand on these findings in the discussion section).
We should note that for the explainers' groups, both preschoolers and first graders, data analyzed showed an increase in the use of the more sophisticated structure -rule- as task complexity increased. Tasks 2 and 3 complexity was evident - use of two rules in task 2 (meaning an increase in

variables' value configurations) and a routine plus a rule in task 3 (requiring definition of the routine and its integration as the "action part" in the rule). These tasks demanded a more thoughtful reflection even for the non-programmers, in order to generate satisfactory explanations of the robot's complex behavior. Within the explainers, we found more frequent use of the rule construct among the preschoolers – the interpretation of this particular finding will be presented in the discussion section.

Overall summary of our observations

Summarizing our quantitative and qualitative observations, the study findings indicate that:

- Programmers seem to perceive the robot as a system, and even more – as a rule-based system.
- First-grade-explainers mostly understood the robot's behavior in terms of a temporal sequence of actions – expressed either as episodic or script-like explanations.
- In contrast, preschool-explainers demonstrated higher understanding than their peer first grade explainers, using rules significantly as part of their explanations.

Discussion

> N., a preschooler: *"That **if** he doesn't touch, **then** he won't dance. And **if** he touches, **then** he will dance"*

The ability to understand, generate and apply condition-action constructs by young children has been a matter of research for a while, not solely connected with robot programming (Mioduser, Levi & Talis, 2009). Studies show inconclusive evidence regarding children's ability to form rules in general, and in relation to a robot's behavior in a changing environment in particular. Piaget (1967) argues in his studies on scientific causation that preschool children have difficulty in perceiving abstract cause/effect relationships in the physical environment. In a series of studies conducted by us for several years, we aim to examine the effect of children's actual involvement in planning and programming an artifact's functioning on their understanding of complex adaptive behaviors and the abstract constructs underlaying it.

The findings of this study showed that **preschoolers who program** the robot are able to grasp the complexity of the observed/expected behaviors of the robotic device and formulate it in the form of a-temporal and general rules. We found that they do not use "episodes" at all to represent the behaviors, and use "scripts" minimally (see data in Tables 3 and 4). The use of rules among the **programmers** is dominant for all tasks – both easy and difficult. The differences with the other research groups were significant for all tasks implemented (data in Table 3).

The planning and programing processes demanded form the children to develop a broad vision of the robot's behavior, to identify regularities and repetitive chunks of action, and to formulate all these in the form of general rules of behavior rather than ad-hoc linear episodic descriptions. Although many studies have shown that preschool children have difficulties in using a coding interface that demands formalization of the rules, i.e., defining If...Then... constructs, this study reinforces our previous findings showing a different picture: Children can use abstract tools to program a robot's actions and even explain its behavior in terms of an abstract rule or even two interacting rules (Levi, & Mioduser, 2008).

Regarding the first graders explanations

Examining the representation structures used by the first graders', we found that they use "episodes" more than the preschoolers. The question that arises is what brings first graders to use the situation specific and linear representation as construct to describe the robot's behavior, despite their developmental advantage over the preschoolers. Moreover, the first graders' use of episodes increased when they were required to cope with a complex task or when confused and unable to pay attention to particular patterns characterizing the robot's behavior. It appears that they focus on the robot, noticing its actions each at a time, while ignoring the environment traits within which it is acting – thus ignoring cause-effect relationships. We suggest two possible explanations for the older children's performance.

The first explanation relates to the schooling/curricular acculturation processes. Existing research provides evidence on the contribution of actual experimentation with technologies and involvement in performing technological tasks to the understanding and learning of concepts and skills related to the artificial world. However, school curricula usually encourage more traditionally academic learning than active involvement in experimentation, doing, and constructing processes than kindergarten curricula. Kindergarten curricula comprises learning environments and tasks aimed to encourage children to become involved in creative processes, to cope with complex processes, to ask questions and look for answers, while offering ample space for exert curiosity and learn by doing and constructing. In contrast in school curricula there is a decrease in tasks involving manipulation of objects, working with building kits or implementing solutions for open ended real-world problems (e.g., not structured into the learning materials in use). Perhaps, the focus on structured tasks leading systematically to the attainment of pre-established goals (e.g. concepts, skills, "right answers") characterizing most learning processes at school, makes difficult for the children to explore unstructured situations related to objects and systems in the world, and to generate appropriate insights and abstract explanations concerning their complex behavior. Ways of thinking extensively supported by the flexible, experimentation-based and open-minded kindergarten's curricula and learning culture gets gradually replaced by the structured, academic-oriented and "right-processes"- "right-answers" curricula and learning culture in school. Obviously, maturation and developmental changes between the two age-level groups do exist, but these alone do not warrant higher level perceptions and understanding of the observed phenomenon – in this case robots' behaviors. Along similar lines of explanation, previous research stresses the role of developmental paths, experience and pedagogical approaches on children's perceptions and thinking about complex problems and designed objects in the environment (e.g., Ebel, Hanus & Call, 2019; German & Defeiter, 2000).

Following the above, our second explanation relates specifically to the effect of being involved in constructing the robot's behavior on children's development and consolidation of rule-generation and inductive reasoning skills. In a previous study, we examined kindergarten children's ability to distill abstract rules while programming a robot's complex behavior (Mioduser, Levi & Talis, 2009). We discussed there the situation faced by the young programmers in which the abstract rules governing the robot's behavior are embedded in a concrete physical object acting in response to environmental features. The robot's behavior can be manipulated, observed, programmed and debugged in endless iterations. *"This is the realm of thinking processes we refer to as the realm of ''concrete-abstractions'', in which recurring cycles intertwining the symbolic and the concrete are exercised by the child while abstracting schemas for understanding the robot's behavior."* (pp. 32). First graders, who did not go through the rule-construction process in all its faces but were asked only to describe the robot's behavior, were not able to unveil the deep a-temporal and general structures underlaying the robot's adaptive behavior.

The results of this study strengthen our previous observations on the connection between young children's involvement in programming and cognitive gains concerning their understanding of the complex functioning of artifacts. Within the concrete-abstractions realm, children at a young age are able to explore complex processes, discover regularities and formulate these using formal descriptions. The support of a developmentally appropriate coding environment is crucial.
In our current and planned research, we aim to deepen our understanding of children's coping with more sophisticated robot behaviors (e.g. the use of routines or procedures embedded in the rules, or the use of several interacting rules). Our goal is to gain a better understanding of children's inductive and rule thinking when facing dynamic adaptive processes – so common in real world events.

The conclusions of this study are consistent with the conclusions of other studies conducted by us in recent years examining the importance of young children's experience in programming processes (Spektor-Precel & Mioduser, 2015; Rave, 2017).

At the implementation level, we have already integrated the knowledge gained in the development of learning environments and experiences for kindergarten children, as well as teacher training activities. We continue to develop the KiderBot programming language and environment which is already in use in kindergartens in Israel.

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