KINDERGARTEN CHILDREN'S PERCEPTION OF ROBOTIC CONTROL RULES

David, Mioduser, Sharona-Tal Levy, Vadim Talis

Tel-Aviv University, School of Education, Ramat-Aviv, 69978, ISRAEL

miodu@post.tau.ac.il

Research concerning young children's perception and learning of technological systems is sparse. Different studies show that children categorize artifacts by function, perceive causal relations in technological mechanisms, and are aware of the importance of the "insides" of artifacts for their functioning very early in their lives (e.g., Kemler Nelson et al, 1995; Simons & Keil, 1995). In attempting to explain this early understanding, researchers point out the large amount of knowledge already accumulated by young children (a) from the very fact they are immersed in a technology-saturated environment; (b) because of the many interactive encounters with such systems; (c) from the relatively greater attention children allocate to dynamic phenomena and processes, such as the functioning of artifacts. Today, controlled technological systems (e.g. remote-controlled television sets or automatic doors and faucets) have become pervasive in everyday life - hence, the importance of studying young children's perceptions of the structure and function of controlled systems (Ackerman, 1991; Papert, 1993).

It is possible to represent control knowledge, using different representations such as flowcharts, state-spaces, scripts or rules (Levin & Mioduser, 1996). Among other features, these constructs differ from each other by being either time-dependent or time-independent representations of the control process. Developmentally, scripts (time-dependent) are earliest to emerge. For example, children tend to structure objects in space according to temporal features of particular events (e.g., buying at the grocery store). However, rules or productions are considered powerful constructs for representing control and systems' adaptive behavior. Research knowledge about young children's perception and ability to design controlled systems using rules is yet weak and unstructured. It is suggested that in the domain of technology, children can operate at more mature levels of understanding (Piaget, 1956). Therefore, we conducted a study in which we have examined the "rule-thinking" of young children and its development in a real-world constructive environment - a computer-controlled robot, traversing a modifiable terrain.

In the study conducted our main purposes were to examine young children's understanding of, and ability to program, the behavior of a robot in terms of control rules. In this paper we will report on our findings regarding the first goal, namely children's understanding and perception of the functioning of a robot in tasks of different levels of complexity. These perceptions were examined in terms of (a) the perspective taken by the children in their explanations (i.e. psychological or technological); (b) the complexity level of the explanations (e.g., half rule, complete rule; interrelated rules); (c) the type of constructs used by the children (e.g., episode, script, rule); and (d) the effect of reflective dialogue on children's explanations.

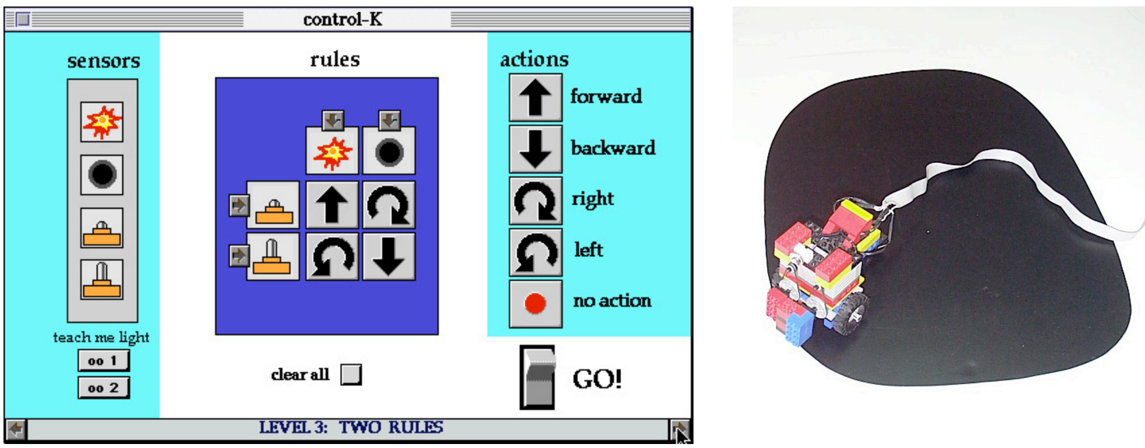
METHOD

The sample included six children, 3 boys and 3 girls, selected randomly out of 60 children in a public school in the Israeli city of Rishon-LeZion. Their ages spanned 5y4m- 6y0m. Due to technical difficulties with part of the data, this report refers to five children.

Instruments

Two sets of instruments have been developed. One is a computerized control environment, designed to scaffold the children's learning process. This environment includes a computer interface, a physical robot and modifiable scenes for the robot's movement according to the various tasks. A key component of the environment is a visual iconic interface for defining the control rules in a simple and intuitive fashion (Figure 1).

Figure 1: Sample screen of the computer control environment - configuration for level 3 tasks (two interrelated rules), and setting for the "island" task.



The second is a series of tasks using this learning environment to define the robot control rules. Examples of tasks are: "Teach the robot how to move freely in an obstacles field" or "Teach the robot to traverse a winding bridge, without falling off". Both environment and tasks were designed as a progression of increasing complexity. The operational definition of rule complexity is its number of condition-action pairs. Half a rule is one condition-action pair, i.e. 'when the robot sees a light it turns away' (the shy robot, if the sensor faces forward). One rule contains two pairs, i.e.: 'when the touch sensor is pressed the robot turns, when the touch sensor is not pressed the robot moves forward in a straight line' (the runaway top, if the touch sensor faces up). Two unrelated rules have 4 condition-action pairs, organized in two independent rules. For example, 'When the light sensor sees black the robot turns, when the light sensor sees white the robot goes straight; when the touch sensor is pressed its buzzer goes on, when the touch sensor is not pressed, its buzzer is off' (the screeching seeker of dark). The final level of complexity is that of two inter-related rules. For example: 'when light sensor 1 sees white and light sensor 2 sees white stop; when light sensor 1 sees white and light sensor 2 sees black, turn to the left; when light sensor 1 sees black and light sensor 2 sees white, turn to the right; when light sensor1 sees black and light sensor 2 sees black, go forward' (crossing a dark bridge on a white river, if the two sensors are pointing down).

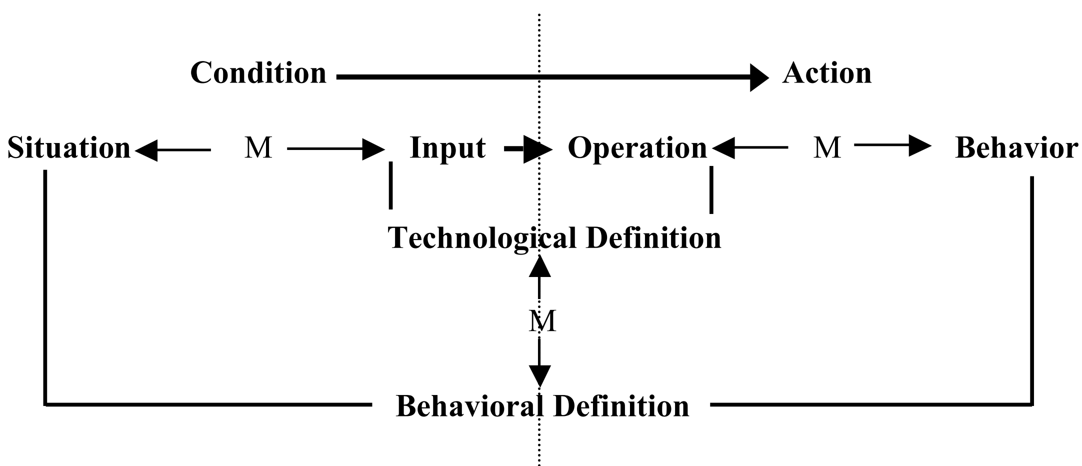
Procedure

The study lasted five 20-45 minute sessions, spaced one week apart. Data were collected by videotaping the sessions. The children worked and were interviewed individually. Each session focused on one stage in the rule-complexity progression. A typical session included two parts: a description task, where the children were presented with a given robot behavior, and a construction task, where they were asked to program the robot with control rules to produce a particular behavior. In the description tasks (on which this paper focuses), the children were asked to describe the robot's behavior. Two types of questioning followed (neither of these instructional nor teaching interventions). One type is 'jump-starting': the same question is asked in different forms, encouraging description and re-description, which usually enrich the initial version. The second type is a 'decomposing' intervention. When differentiation is not made - in the robot's actions or its relevant environment conditions - different questions aimed at separating them out are asked. The questioning is referred to in this paper as "intervention", and its effect on the children's descriptions is discussed.

Data analysis framework

The children's descriptions and definitions of the robot's behavior were analyzed using as framework the conceptual model of the rule structure shown in Fig. 2. An important aspect for the understanding of how technological systems work is the ability to bridge between two levels of descriptions: (1) that of the behavior of the system, or what it is doing when interacting with its environment (behavioral or psychological perspective), and (2) that of the technological building blocks whose interaction with each other and the environment produce the system's particular behavior (technological perspective).

Figure 2: Framework for the analysis of the rules perceptions in behavioral and technological terms, and the mapping (M) scheme among their components.



The model discriminates between behavioral and technological definitions and maps out the relationships between them. A first discrimination is made between the condition and the action parts of the rule. Both components may be perceived and referred to in behavioral as well as in technological terms. For example, a given situation to which the robot should respond (condition part) may be described as "looking for a bridge " (a behavioral condition), or as "when its light sensor senses the bridge's color" (a technological description). We assume similar modalities for the action component of the rule. Moreover, we assume a mapping process among behavioral/technological perceptions of both the rule components, as well as the whole set of rules, determining the device's overall functioning. This model does not distinguish between different ways of describing the events: from a timeline account of sporadic episodes, a temporal pattern of repeating behaviors (a script) or a time-independent description of interacting rules. These will be related to separately.

Variables

The study's independent variables were the complexity level of the tasks (1/2 rule, complete rule, 2 independent rules, 2 interrelated rules), and adult intervention. As for the dependent variables, the children's performance was analyzed in terms of : (a) the perspective taken by the children in their explanations (i.e. psychological or technological); (b) the complexity level of the explanations (e.g., half rule, complete rule; interrelated rules); (c) the type of constructs used by the children (e.g., event, script, rule); and (d) the effect of the intervention on children's explanations.

RESULTS

Perspective taken by the children

For most tasks, the initial description of most children were behavioral or psychological (Table 1), for example: "*he looks all the time for food*", or "he does not understand what is white". However, with supporting intervention, all children generated technological descriptions (e.g., "*on the white* [area] *he turns and then goes forward*"). This gradual shift can be seen within each task. As a particular task evolves, description moves from focusing on simple behaviors (one condition-action pair) to the consideration of a compound of a number of behaviors (functional chunks), as well as of relevant contextual information. This process does not happen to a child independent of interaction with an adult. Most children provided more complex descriptions when an adult intervened and helped them decompose the situation at hand. After the behavioral description has been sufficiently defined, the technological description arises, while preserving the original target behaviors. With experience in the learning environment, the technological description is easier to achieve. As the tasks are more advanced and complex, technological descriptions are more frequent. Children's explanations shifted from psychological to technological in about 65% of their descriptions along all tasks, and from technological to psychological only in 7% of their descriptions.

Table 1: perspective taken in describing a robot's behavior in different tasks

tasks	**1/2 rule**		**Complete rule**		**2 independent rules**		**2 interrelated rules**	
	initial	intervent.	initial	intervent.	initial	intervent.	initial	intervent.
S1	t	c	c	t	p	t	t	t
S2	-	t	p	t	p	t	p	t
S3	p	t	p	c	t	t	p	t
S4	t	t	p	t	p	t	p	t
S5	-	t	p	t	-	t	p	t

t= technological description / p= psychological description / c= combined description

Level of complexity of explanations

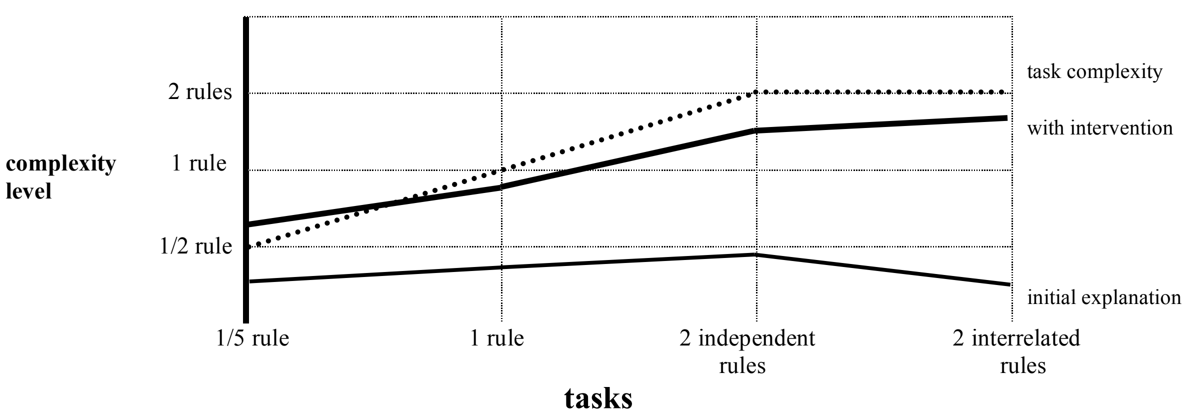
Without intervention, children's ability to describe the robot's behavior in terms of its complexity (i.e., number and configuration of the rules) was poor (Table 2). With less experience, the rules started out as one condition-action pair. With decomposing intervention, the children were able to verbalize more advanced rule structures, commonly between 1/2 rule and 1-1/2 rule more than which they can provide on their own. Eventually, most children reached a complexity level in their descriptions close to the actual complexity of each task.

Table 2: level of complexity in describing a robot's behavior in different tasks

tasks	**1/2 rule**		**Complete rule**		**2 independent rules**		**2 interrelated rules**	
	initial	interv.	initial	interv.	initial	interv.	initial	interv.
S1	1/2	1	1	1	1/2	2	-	1 1/2
S2	-	1/2	-	1/2	-	1 1/2	-	2
S3	1/2	1/2	1/2	1	1	1 1/2	1	2
S4	1/2	1/2	-	1	-	1	-	2
S5	-	1	-	1	-	2	-	1/2

Figure 3 shows the level of complexity of the different tasks, the average initial level of complexity of children's descriptions, and the average maximal level of complexity in their descriptions following adult's decomposing intervention. Two observations are of interest in these results. First, when supported in decomposing the observed functioning of the robot the children were able to generate descriptions of its control rules that were fairly close to its actual complexity in all tasks. Second, the area between the initial and maximal level of complexity of the children's descriptions can be seen as their zone of proximal development, in Vigotsky's terms. The most difficult task for the children was the one involving two interrelated rules. The children were not able to generate initial reasonable explanations capturing the whole configuration of interactions among all conditions and actions. Their strategy for this task was, with supportive decomposing intervention, to "conquer" each cell (a condition-action pair) of the complex construct until completing the whole set of rules.

Figure 3: level of complexity of the task and the children's initial and maximal descriptions of it



Constructs used in the explanations

With decomposing intervention, all children were able to describe the robot's behavior using technological rules (Table 3). The use of script-like descriptions is transient. It is exhibited during the decomposition of the actions of confusing robot behavior in the initial stages of a new task. When a child cannot construct a suitable rule, she may focus for a while only on the robot's actions, following them from moment to moment (episode-type). The conditions are first ignored, to be incorporated later on. The recurrent use of script-like descriptions of the robot's behavior develops with practice and gradually leads to the more general, time independent and abstract rule-like descriptions. It becomes a strategy of choice in analyzing the robot's behaviors. The identification and coding of the actual input/output components of the robot's functioning, results in the formulation of technological rules.

Table 3: type of construct used in describing a robot's behavior in different tasks

tasks	1/2 rule		Complete rule		2 independent rules		2 interrelated rules	
	initial	interv.	initial	interv.	initial	interv.	initial	interv.
S1	t	t	t	t	p	t	e	t
S2	-	t	s	t	s	t	s	t
S3	t	t	c	t	t	t	p	t
S4	c	t	s	t	s	t	s	t
S5	-	t	s	t	-	t	s	t

t= technological rule / p= psychological rule / s= script / c= condition only / e= episode

Role of intervention

As mentioned in the method section, two kinds of interventions were used by the interviewers. The first aimed to encourage the child to expand her initial explanations, and add as many details as she was able to generate about the robot's functioning. The second aimed to induce the decomposition of the situation or problem being analyzed and explained. It is evident from all previously presented results that adult's decomposing intervention supported analytical and reflective processes leading towards descriptions characterized by: (a) a higher level of complexity; (b) the inclusion of more abstract, time-independent, and rule-like constructs; and (c) a technological perspective of the robot's behavior.

CONLUSIONS

This study examined young children's rule-thinking as regards to the functioning of a robot in tasks of increasing level of complexity. Previous work examined children's perception of artifacts (e.g., Matan & Carey, 2001), and the rules by which their functioning can be explained (e.g., Siegler, 1986). In our study children are asked to describe and explain the functioning of technological systems behaving in time and space, while adapting and responding to changing features in the environment. From our findings several conclusions can be drawn:

- Young children are able to generate fairly complex explanations of the adaptive artifacts. The complexity, or the number of rules the children can combine into a compound behavior on their own, is limited to one rule at a time (2 conditions, 2 actions). However, with an adult's support in decomposing these behaviors they can go beyond that limit.

- Psychological (behavioral) explanations always preceded technological explanations. However, the shift was rapidly made by the children. Their entry point to the analysis of the artifacts functioning was always the observable behavior, described in terms of human behavior (including volition and affective attitudes). But as the tasks evolved, the descriptions moved from focusing on simple behaviors (one condition-action pair) to the consideration of a compound of a number of behaviors (functional chunks), as well as of relevant contextual information. With experience in programming the robotics environment, more advanced and complex technological descriptions became frequent.
- The combination of the concrete features of the robotics environment set as a playground for inquiry, and appropriate adult intervention, supports young children's handling of complex concepts related to the systems' functioning. One example is the concept of "emergent behavior": in the second session, the robot is 'guarding an island'. The island is a white sheet of paper, which is placed upon a dark rug. The robot has a light sensor facing downwards. On the paper, the robot goes forward and on the rug, it turns. The combination of the robot structure, its program and the surrounding environment produce a border-following behavior. "Follow the border" is not explicitly defined as a rule for the robot, but is the observable result of the interaction between the two basic rules operating in response to environmental features. All children generated appropriate descriptions of the particular rules, explanations about the resulting (emergent) behavior, and further replication of the idea in a rule-construction task for a different environment (section of the study not reported here). It seems that the realm of working technological devices allows bridging of the concrete and the abstract offering young children "concrete-abstractions" to think with.

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