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Making Sense by Building Sense – Young Children’s Understanding of the Adaptive Behaviors of Artifacts

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ABSTRACT

In the last decades a new version of artifacts has penetrated our world; artifacts capable of adaptive behavior. Well known among these artifacts are robotic systems and a wide range of controlled devices in various technological areas. But these are also present in our everyday environment, in the form of programmable toys, domestic devices, automatic doors, communication or computational devices. These artifacts are characterized by purposeful functioning capabilities (namely, they 'behave'), autonomous decision-making, programmability and knowledge accumulation capabilities (they 'learn' ?), and adaptive behavior. This new category of artifacts affected the traditional and intuitive distinctions between the alive and not-alive, animate and inanimate, human-operated and autonomous. But how do we – in particular young children- conceive this new category of artifacts? In our studies we explore young children's evolving understanding of controlled artifacts as they program their behaviors using an environment we have designed. We investigate children's understanding through a progression of artificial-behavior construction tasks. We analyze their ***explanatory frameworks*** *for the artifacts' adaptive behavior, the evolving cognitive* ***constructs*** *(e.g., scripts, rules) the children use to represent and plan the artifacts' behaviors, the* ***behavior-construction process****, and the* ***role of constructing*** *on children's' understanding of the nature and functioning of the adaptive devices and of rule-based and adaptive behavior in general.*

KEYWORDS: *Preschool children, Behaving artifacts, Adaptive-behavior construction, Constructionism*

INTRODUCTION

Controlled self-regulated systems pervade our daily environment, embodying central concepts related to systems, adaptation and emergence. Robotic systems, which have been part of educational settings for over two decades, provide opportunities to *interact* with, and *construct* controlled adaptive behaviors (Papert, 1980/1993; Resnick et. al., 1996; Bers and Portsmore, 2005). Our presentation reports on results from a series of studies conducted to explore young children's evolving understanding of a robot's emergent adaptive behaviors, as they learn to program such behaviors with simple rules. We investigated the children's understanding through a sequence of observations and interviews, analyzing: (a) the children's expressed ideas in terms of the **explanatory frameworks** framing their perceptions of the functional and computational aspects of the artifacts; (b) the evolving cognitive **constructs** (e.g., scripts, rules) the children use to represent and plan the artifacts' behaviors; and (c) children's ability to **construct** the robot's adaptive behaviors.

BACKGROUND

Explanatory frameworks

What conceptual perspectives guide children's thinking about behaving robots? The ambiguous status of computational objects among artifacts was demonstrated in a series of developmental studies (van Duuren and Scaife, 1996). Between the ages of five and seven years, children begin forming a differentiated concept of "intelligent artifacts", which can think, decide and act, have a brain, and are a special category of cognitively competent artifacts with robots eliciting earlier understandings of such notions than computers.

Ackermann (1991), in describing children and adults' understanding of complex controlled systems or self-regulating devices, proposes two perspectives: the psychological and the engineering. By the psychological point-of-view, intelligent artifacts are described as living creatures, attributed with intentions, awareness, personalities and volition. The engineering point-of-view is typically used when building and programming the system. No intentions are ascribed to the system; its behavior arises from interactions between its components and those with its surroundings, i.e. how one part of the system may move another part. Thus, Ackermann separates between a physical-causal and a psychological-animate perception of behaving artifacts. Integrating the two kinds of explanations – synthesis of the behavioral and the psychological – are the core of a whole explanation. She claims that the ability to animate or give life to objects is a crucial step toward the construction of cybernetic theories, and not a sign of cognitive immaturity. In animating the object, it is viewed as an "agent", able to change its course of behavior by its own volition. With development, people progressively disentangle purpose and causality.

Behavior-representation constructs

Several knowledge representations can be used to describe a robot's behavior. The least general of these representations is a specific episode, a representation of the flow of events, a one-time occurrence. It is made up of actors, actions and props, organized along a spatial and temporal structure. A script is a generalized, temporally and spatially organized sequence of events about some common routine with a goal. Prior work has shown that young children's representations of events are mainly script-like, and become so after a very small number of repetitions (Flavell et al. 1993). Literature on event knowledge does not refer to rules. However, in the case of robots (and other systems), events can be constructed from rules. Rules, which are independent of the order of events, are the most abstract knowledge representation of the three. They commonly take the form of 'if…

then...' statements, connecting conditions and their related actions.

Young children can *apply* rules to solve problems (Frye et al. 1996). On the other hand, children's *conditional reasoning* is at best, limited. Conditional reasoning is usually associated with the formal operational level of reasoning and develops through adolescence. However, between these two poles lies a middle ground of inferring rules from a flow of events. One can view the task of discovering a robot's rules as generalizing from a set of instances, noticing the co-variation of environmental features with the robot's actions, such as 'on black surfaces the robot flashes its light'.

Different lines of research point to conflicting conclusions regarding young children's ability to form rules from data, and in our case, to form rules regarding the self-organizing behavior of a robot. Research on scientific reasoning suggests that young children will have difficulty forming abstractions and coordinating them with the evidence; developmental studies claim that temporally structured events would be represented as scripts, rather than abstract rules. However, studies on causal inference show that young children can detect patterns in the observed data and use them to predict and plan, as our observations corroborate.

Behavior-construction environments for young children

Technologies focusing on the construction of behaving artifacts were brought into children's learning and playing environments since the early 70's. According to Papert (1980/1993), children become epistemologists when they encounter "objects to think with" – since knowledge is embodied in them, they serve as cognitive artifacts that provide a link between sensory and abstract knowledge. By the Constructionist viewpoint, a robot can be defined as "an object to think with". The "floor turtle" developed by Papert and his colleagues at MIT Media Lab is an example of an "object to think with". When children worked with LEGO/Logo they learned powerful ideas such as control and feedback (Resnick et. al, 1996), principles of engineering, design, artistic expression, programming and scientific inquiry. In the last two decades, a variety of robot construction kits -like the one implemented in our study – have been developed, e.g., Electronic Bricks (Wyeth & Purchase 2000), or ToonTalk™ used in preschool classrooms (Kahn 1996; Morgado, Cruz & Kahn. 2001). While working with these kits, young children face the challenges involved in constructing the actual behaviors of physical devices.

METHOD – BRIEF OVERVIEW

The subjects – preschool children- participated in a sequence braided of two strands of tasks focusing on a robot's adaptive behavior: Description and Construction. The tasks made use of the same robot in a variety of physical landscapes, and were designed as a progression of rule-base configurations. The operational definition of rule-base configuration is the number of condition-action couples (If… Then… couples). For example, one control rule consists of a pair of condition-action couples: [If(true)… Then…; If(false)… Then…]. The tasks progress through a range of increasing difficulty: from half a rule (one condition-action couple), a complete rule, two independent rules and two interrelated rules, which are made up of two pairs of condition-action couples. The progression of tasks is shown in Figure 1.

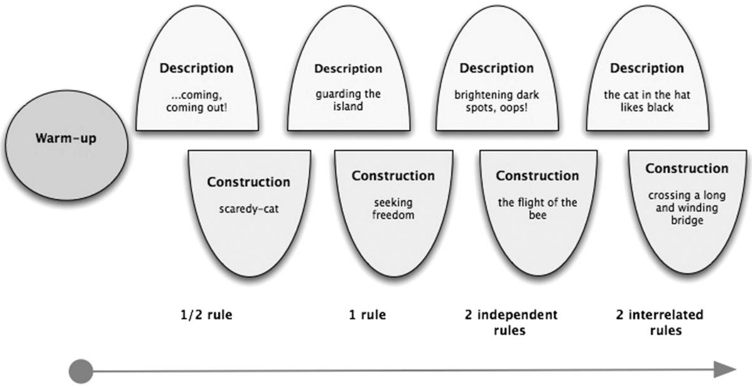
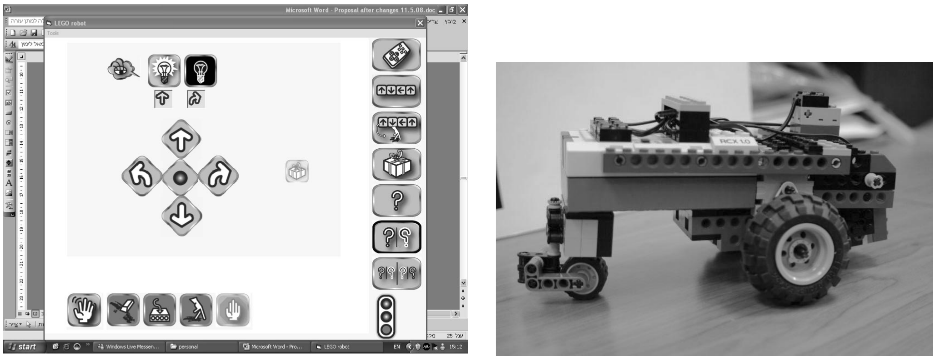


***Figure 1**: Progression of explanation and construction tasks*

A computerized behavior-control environment was designed for the studies. This environment includes a computer interface (Figure 1a), a physical robot (Figure 1b) and modifiable "landscapes" for the robot's navigation. The iconic interface allows defining the control rules in simple and intuitive fashion. The right panel presents the progression of the modes for constructing the robot's behavior, from immediate remote control of the behavior (top, easy task) to constructing two interrelated rules (bottom, advanced task). In the central section children construct the behavior procedures. The learning of the modes' options is accomplished while performing the tasks. For example in Figure 2, the rule requires actions for two input states (light, darkness). Upon constructing the rule, it is downloaded to the robot using the 'download' icon (circled). A Construction task began with explicating the programming interface with respect to the Description task. The child was then presented with a goal, such as "teach the robot to move freely about an obstacles field" and proceeded to program and test this behavior. In this presentation we report on observations from five 30-45 minute sessions, spaced about one week apart. The children worked and were interviewed individually in a small room off the teachers' lounge. All sessions were videotaped.

The interviewers supported the children throughout the sessions in the following ways: introducing the sequence of interfaces and the functionality of their tools and widgets; presenting the task and discussing it with the child until the goal was clarified; following this, support was released – the child is on her own. However, once a hurdle is met and the child does not succeed in overcoming it on her own, "light" support was provided in the following way: to clarify the problem, the child is asked to describe the program and the robot's behavior. When this did not help, "heavy" support was provided in the following way: specific features regarding the



(a) The behavior-construction interface *(b) The Lego-made robot*

Figure 2*: The behavior construction environment*

environment, the robot's actions or the interface, that are relevant to the problem are pointed to, and the child is asked how they impact the robot's behavior. This support targets two goals: increased encoding of the relevant features and decomposing the problem into its components.

MAIN OBSERVATIONS

The main observations of the studies are summarized here as brief focal points following the format and sections of the presentation at the conference. Detailed presentation and discussion of the studies' findings can be found in Levy & Mioduser, 2008; Mioduser, Levy & Talis, 2008; Precel & Mioduser, in press.

Explanation tasks

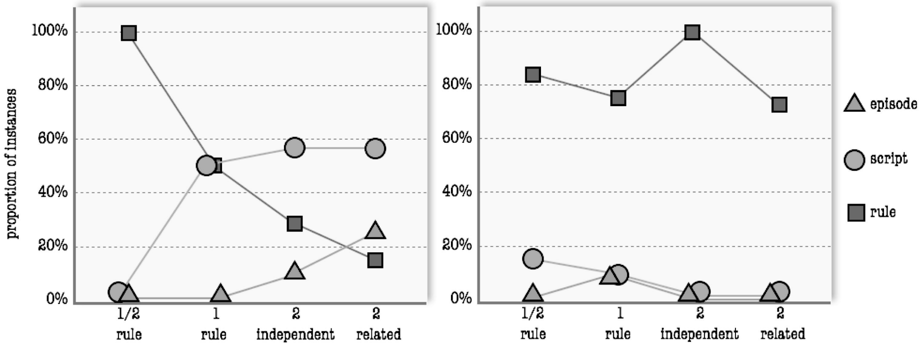
Knowledge level: The young children's knowledge of the structural and functional features of the devices evolved gradually thorough the tasks. This gradual construction of knowledge was observed at to two main levels:

- *device knowledge* – e.g., structural features, sensors, the programming interface.
- *behavior-control knowledge* – e.g., the role of sensors in the device's adaptive behavior, the relation between the representation of the behavior-components in the symbolic interface and the actual behavior of the device.

Explanatory frameworks: Several patterns were observed in which children's explanations reflected either a behavioral (psychological) or technological perspective, or shifts between these in specific conditions. However, the general trend observed evidenced clear transition *from a psychological to a technological* perspective over tasks.

Use of behavior-representation constructs: In our analyses we coded the children's utterances by increasing generality, as episodes, scripts and rules. The children used all three types of constructs, however at different frequencies and according to the demands and difficulties of the different tasks e.g., increasing task difficulty was associated with less general constructs). Overall, with decomposition support, the observed trend indicated transition from temporal and ad-hoc (event), to semi-temporal/cyclical (episode), to a-temporal and general (rule) behavior-representation constructs.

Role of decomposition support: As mentioned above, interventions aimed to support encoding of the relevant features of the tasks and decomposing the problem into its components (not to teach or to lead to the 'correct' answers). Decomposition support has been of clear contribution as agent in children's ZPD. Figure 3 shows children's use of constructs over the tasks with and without support.



(a) spontaneous explanations *(b) supported explanations*

***Figure 3**: use of behavior-representation constructs*

Construction tasks

The following focal points present in brief our main observations of the process in which children actually constructed the robot's adaptive behaviors according to the characteristics of the different tasks. In general, we have observed that children:

- *do **beyond the expected** based on known developmental constraints/assumptions*
- *are able to construct –by constructing- knowledge about:*
  - behavior-generation rudiments and mechanisms
  - input/output relationships – adaptivity procedures
- *are able to **decompose** a problem or a tasks in its main features and construct a solution/program*
- *are able to define behavior in terms of regularities, and represent these by **rules***
- *develop a wide range of **strategies** for coping with construction tasks, such as:*
  - playful investigations
  - planful investigations
  - coordination of perspectives – between the child's and the robot's
  - development of efficient rule-construction processes by which they:
    - *focus on actions*

- *seek for regularities*
- *formulate a-temporal definitions*
- *build rules*
- development of procedures for reducing complexity, e.g., *decomposition; pruning branches.*

An important observation worth to be emphasized is related to the crucial contribution of the behavior-construction processes to the children's understanding, knowledge construction, and concept development. As shown in Figure 4, children's explanations reflected increasing understanding over the tasks (and towards the most demanding tasks) when the were involved in constructing the robot's behavior.

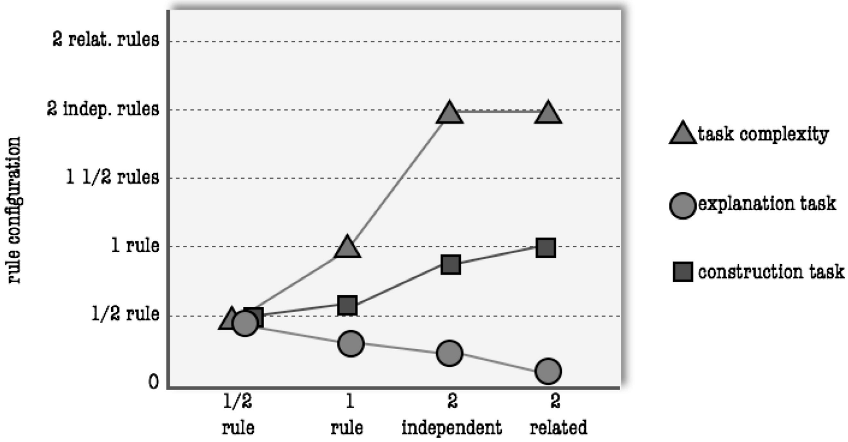


***Figure 4**: Level of performance in explanation vs. construction tasks*

On con-straction (concrete abstraction) performance:

A key characteristic of the studies' settings – and of the working environment we have designed- is that it encourages continuous dialog between the symbolic and the concrete, the abstract representation and the actual device's functioning. Examples of observations related to this continuous and cyclical dialog are:

- *concrete enaction & symbolic enaction*, e.g., the child 'plying the robot' either with the interface components (symbolic) or in the physical environment of the task to be programmed.
- *objectifying thought & abstracting actions*
- *construction-embedded debugging*
- *concrete investigation of abstract concepts/ideas underlying the device's adaptive behavior*

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