5-7 Year Old Children's Conceptions of Behaving Artifacts and the Influence of Constructing Their Behavior on the Development of Theory of Mind (ToM) and Theory of Artificial Mind (ToAM)

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Abstract

The study examined a new theoretical scheme named ToAM (Theory of Artificial Mind) by means of qualitative and quantitative methodology among twenty four 5-7 year old children from central Israel. It also examined the effects of interacting with behaving artifacts (constructing versus observing the robot's behavior) using the "RoboGan" interface on children's development of ToAM and ToM and looked for conceptions that evolve among children while interacting with behaving artifacts which are indicative of the acquisition of ToAM. In the quantitative analysis it was found that the interaction with behaving artifacts, whether as observers or constructors and for both age groups brought into awareness children's ToM as well as influenced their ability to understand that robots can behave independently and based on external and environmental conditions. In the qualitative analysis it was found that participating in the intervention influenced the children's ToAM for both constructors and for the younger observer. Engaging in building the robot's behavior influenced the children's ability to explain several of the robots' behaviors, their understanding of the robot's script-based behavior and rule-based behavior and the children's metacognitive development. The theoretical and practical importance of the study is discussed.

Keywords: Theory of Mind (ToM), Theory of Artificial Mind (ToAM), Cognitive Development, Behaving artifacts, Robots.

Introduction

In recent decades a new breed of artifacts is increasingly populating our artificial world: We are surrounded by a large number of artifacts that are capable of decision-making and adaptive behavior (e.g., electric pots, boiler timers, automatic doors and robots). Consequently, the traditional and intuitive distinction between the alive and not-alive, animate and inanimate, human-operated and autonomous has become blurred. Since these artifacts are provided with an "artificial mind," it is of interest to assess whether and how children develop a Theory of Artificial Mind (ToAM) potentially distinct from their Theory of Mind (ToM). This study examined the influence of constructing artificial minds of behaving artifacts on children's ToM and ToAM.

Three main questions were addressed:

(1) Is ToAM a theoretical construct distinct from ToM?
(2) What are the effects of interacting with behaving artifacts (explaining or constructing artifacts' behaviors) on children's development of ToAM and ToM?
(3) Which conceptions developed by 5- and 7-year-old children while interacting with behaving artifacts are indicative of the development of ToAM?

Background

The literature concerning human beings' conceptions of "traditional" artifacts is vast, however, little is known about children's conceptions of behaving artifacts, or the influence of the interaction with such artifacts on cognitive development.

Since these artifacts are provided with an artificial "mind," it is interesting to assess whether and how children develop a Theory of Artificial Mind (ToAM) which is distinct from their Theory of Mind (ToM), which refers to the ability to conceive mental states, knowing that other people know, want, feel or believe things (Premack & Woodruff, 1978). The majority of the studies that focused on the pre-school child examined ToM by means of first-order (such as the False belief task, Wimmer & Perner, 1983) and second-order tasks (i.e. understanding what another person thinks a third person knows - the "ice-cream" story, i.e., Perner & Wimmer, 1985).

Our review of previous studies indicated that knowledge is constructed throughout interaction with robots that serve as "objects to think with" (Papert, 1980) as well as that interacting with technological devices including robots, has an influence on children's cognitive development (i.e., Resnick, 1998). Although much research has been conducted regarding children's conceptions of natural kinds and human made artifacts (e.g., Bloom, 1996; Matan & Carey, 2001), research on children's conceptions of behaving artifacts and artificial mind is sparse.

Studies by the group of Mioduser and his colleagues examined various aspects of children's conceptions of behaving artifacts, e.g., frameworks used by 5- to 6-year-old children when reasoning about a robot; young children's ability to construct and explain adaptive behaviors of a robot; the development of non-anthropomorphic explanations of adaptive behavior as a function of the involvement in constructing robots' behaviors (Levy & Mioduser, 2008; Mioduser & Kuperman, 2012).

To the best of our knowledge, no studies have examined children's ToAM, or its development as a consequence of the construction of the robots' behaviors.

Methodology

Research Design

A mixed method methodology (Burke Johnson & Onwuegbuzie, 2004) combined with a microgenetic approach (Siegler & Chen, 1998) was used in the current study.

Research Population

Twelve 5-year-old and twelve 7-year-old children from central Israel participated in the study. All children were recruited to the pilot study using a convenience sampling method. All children were administered the battery of tasks.

Research Instruments

Two main research instruments were used: (1) A robotic learning environment which was developed for young children, the "RoboGan" (Mioduser, Levi, & Talis, 2009) was used in the study. This environment includes a computer interface, a physical robot (made with the LEGO® system) and modifiable "landscapes" for the robot's navigation. The environment is an iconic interface for defining the control rules in a simple and intuitive fashion (Mioduser et al., 2009; Talis et al., 1998) and (2) Data collection tools: intelligence (IQ), pre- and post- and process tasks.

Intelligence (IQ) task. The Hebrew version (Peyser, Shimborsky, Wolf, & Hazany, 1996) of the Kaufman Assessment Battery for Children (K-ABC) (Kaufman & Kaufman, 1983) in order to characterize the research population as homogeneous in relation to intelligence.

Pre- and post-tests:

Assessment of the development of ToM. Two sets of tasks were administered to assess ToM: Tasks assessing classic aspects of ToM (first and second order beliefs tasks), and newly developed tasks assessing aspects related to behavior control and adaptivity (not used in previous ToM studies).

Assessment of the development of ToAM: In correspondence, two sets of tasks were developed to assess ToAM, by adapting the classic and new ToM tasks to processes involving artifacts' behavior control and adaptivity.

Process tasks. Nine tasks in 4 complexity levels were developed. For example, in the low complexity task (using scripts) the robot is placed in a neighborhood with one school, a play-ground and a basketball yard; children had to program the robot to go to the basketball yard. In a complex task (using rules) children had to program the robot to move freely on a white surface while being "polite" – avoiding black areas.

Design and Procedure

Children were selected and divided randomly into one of two groups: *observation* or construction of the robot's behavior. Children were administered the data collection tools, and the data was collected in nine to ten 20-minute sessions. All sessions were recorded and videotaped and analyzed using both quantitative and qualitative procedures.

Data Analysis

Three types of analysis were conducted: (1) analysis of the raw data of the ToM and ToAM pre- and post- tests, (2) analysis of the mean of the correct responses and of the frequency of children's explanations in all tasks and (3) qualitative analysis of the entire intervention for four children.

Results and Discussion

In order to answer the first research questions *Is ToAM a theoretical construct distinct from ToM?* We will first present the main results of questions 2 and 3.

Research question 2: *What are the effects of interacting with behaving artifacts on children's development of ToM and ToAM?*

In relation to ToM, we found that in general, the interaction with behaving artifacts, whether as observers or constructors and for both 5- and 7-year-old children brought into awareness children's ability to understand that other people hold different beliefs and desires than their own, the human mind's ability to make decisions based on beliefs and desires which are dependent on environmental conditions, as well as second-order understanding (understanding what another person thinks a third person knows).

In relation to ToAM, we found that in general, the interaction with behaving artifacts, whether as observers or constructors and for both 5- and 7-year-old children influenced the children's ability to understand that robots can behave independently and based on external and environmental conditions. In addition, they were able to understand the relationship between the behaviors of two robots (ToAM). These findings are in line with previous findings that indicated the construction of knowledge via interaction with robots that serve as "objects to think with" (e.g. Caci, D'amico, & Chizzese, 2012; Granott, 1991, 1993, 2002; Papert, 1980).

We found that even though ToM and ToAM share several characteristics (both include first-order and second-order understanding, rule-based understanding and decision making and adaptive behavior understanding) most of their characteristics differ: in their essence, in the content of first- and second-order understanding and in children's ability to grasp various of the construct's concepts. For example, we found that hypothetical decision making in robots (i.e., "can the robot help finding a dog?") is harder for children to grasp in contrast with concrete behavior of a robot (i.e., "which balls/balloons will the robot pull?") and with decision making in humans that is based on beliefs (i.e., "Where would Ronen look for the dog?"). These findings supports the dichotomy between abstract-concrete concepts (e.g. Altarriba, Bauer, & Benvenuto, 1999; Paivio, Yuille, & Madigan, 1968). Thus, it might be that ToM and ToAM are two separable constructs that develop independently.

Research question 3: *Which conceptions that evolve among 5- and 7-year-old children while interacting with behaving artifacts are indicative of the acquisition of ToAM*?

We found conceptions that evolve among 5- and 7-year-old children while interacting with behaving artifacts which are indicative of the acquisition of ToAM. For example, we found that the engagement in building the robot's behavior in both 5-year-old and 7-year-old constructors enhanced a full technological model of the mind (i.e., "*"The tower is connected to the computer. The computer passes it [the information] to the robot")* and metacognitive abilities already at age 5 (i.e., *"In the second level every time I pressed on a row the robot moved. In the third level it didn't move. It was more difficult for me to do* [the third level] *because I didn't know what to do. I showed you what I planned to do and it helped me because I already knew what to do.. Eventually I succeeded because I thought")*. This supports Papert's (1980) ideas that metacognitive skills are constructed by children through active building of their own intellect.

We also found that engaging in building the robot's behavior influenced the children's ability to explain several of the robot's behaviors, their understanding of script-based and rule-based behavior (i.e., *"The robot will behave the same.. because it received an input from the tower.. what I told it.. to go backwards in strong light")*. These findings too, support Papert's constructionism theory (1980).

We found evidence of a correlation between the level of difficulty of a task and the language used by the children: as the task became harder, the language became a "bridging" one, combining both technological and psychological concepts. Observers tended to use such combining language more than constructors. These findings support previous findings (Levy & Mioduser's, 2008; Mioduser & Kuperman, 2012; Mioduser & Levy, 2010).

Among the constructors, both 5- and 7- year-old children evidenced immunity to functional fixedness, (which refers to a situation when subjects are hindered in reaching a solution to a problem by their knowledge of an object's conventional function, Duncker, 1945) in relation to their conceptions of the artificial mind. Among the observers - only the younger observer showed such immunity. It might be that older children who were found to be less flexible in their thinking and learning compared to younger children in previous studies (i.e., German & Defeyter, 2000) flexible in their thinking, similar to the younger children, when engaged in an activity that involves programming.

Research question 1: *Is ToAM a theoretical construct distinct from ToM?*

Results of both qualitative and qualitative analyses indicated the existence of a theoretical scheme –ToAM- in 5- and 7-year-old children, which comprises:

(1) First- and second order understanding (in artifacts)
(2) A model of the artificial mind - within a continuum ranging from: (a) ToM-like model - completely based on children's model of the human mind; (b) ToM-based ToAM - technological model referring to the artificial mind but using elements borrowed from their model of the human mind; (c) Partial ToAM model – technological model aware of the artificial mind but not of its content or processes; (d) fully technological ToAM model.
(3) ToAM models (b to d) of either of two types: (1) "obeying" model referring to a mind that obeys to external and pre-determined programs; (2) "adaptive" model referring to a mind that makes decisions based on environmental conditions.

Theoretically, the study supplies important insights on the identification of intriguing aspects of children's thinking about behaving and adaptive artifacts, the nature of suitable tools, tasks and "objects to think with" allowing children to enact, construct and reflect on their understandings of the world of behaving artifacts and the language used while interacting with behaving artifacts.

Practically, the theoretical knowledge found in the study has clear implications for education, supporting the development of learning environments in the area of intelligent machines and control already in preschool. These environments should enable young children to enact and construct artificial behavior by themselves which will enable them to reflect on their understanding of the world of behaving artifacts and the artificial mind and as a consequence on the world of the human mind.

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