Programming Robotic Behavior by High-Functioning Autistic Children

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***Abstract*—This study focused on examining the ability of a high-functioning autistic child to program robotic behavior and to understand how they describe and construct the robot's behavior using iconic programming software. The robotic learning environment was based on iPad, an iconic programming software (KinderBot), and EV3. The results of this study show how the participant succeeded in programming the behavior of an "other" at different programming complexity levels (from simple action to combinations of states of two binary sensors and rule with subroutine). A transformation from procedural to declarative description was also found.**

Keywords—high-functioning autistic children, program, robot

I. Introduction

This study focuses on how high-functioning autistic (HFA) children can design the behavior of others, in this case their ability to program robotic behavior in a robotic setup that includes minor changes.

Autism spectrum disorder (ASD) is a complex developmental disorder that affects behavior, social interaction, communication, and academic skills. Its exact causes are unknown, although it is thought to involve genetic, psychological, neurological, fragile health, and environmental factors. Baird et al. (2006) [1] and Brugha et al. (2011) [2] have described deficits in social communication and interaction across multiple contexts. Children with ASD have repetitive patterns of behavior, interests, and/or activities and can have a wide range of symptoms, skills, and levels of impairment. Some are mildly impaired by their symptoms, while others are severely disabled. The Diagnostic and Statistical Manual of Mental Disorders (DSM-5) [3] defines three severity levels for ASD: Level 1—requiring support; Level 2—requiring substantial support; Level 3—requiring very substantial support. These three levels differ in social communication and restricted, repetitive behaviors. HFA children usually have good communication skills and are inflexible in behavior, causing interference with functions such as accepting change and switching between activities. In this study, focusing on HFA children, we suggest an innovative approach that for the first time enables HFA children to "design" the behavior of smart artefacts by using their sensors to adapt in accordance with the environment. For most HFA children this would be the first opportunity to "design and control the behavior of the other" not the "me", since usually they are the ones who are controlled by another.

In the past 14 years, there has been an increase in research and development of assistive technology for use by ASD children. The technologies enable them to communicate and to learn social and daily life skills. Dautenhahn, Werry, Salter, and Boekhorst (2003) [4] discuss four potential benefits robots could provide as a device in autism therapy: robots allow simplified but embodied interaction, involving touch and physical manipulation; in terms of abstraction, robots are between the software and real world; interaction dynamics; and robots' naturally supporting multimodal interaction, including touch.

The responses to robot or robotlike characteristics in Aurora (Autonomous robotic platform as a remedial tool for children with autism) showed that ASD children preferred robots to passive toys [5], preferred robotlike characteristics over humanlike characteristics in social interactions [6], and responded faster when cued by robotic rather than human movement [7-8]. Tapus et al. (2012) [9] and others [10] have explored the Nao robot. Tapus et al. (2012) [9] imitated gross arm movements of the child in real time. Different behavioral criteria (i.e., eye gaze, gaze shifting, free and prompted initiations of arm movements, and smile/laughter) were analyzed based on the video data of the interaction. The results are mixed and suggest a high variability in reactions to the Nao robot. Standen et al. (2014) [11] investigated the role of a humanoid robot in engaging the attention of young children with autism. Teachers of students with profound and multiple disabilities described actions they wished the robot to make in order to help nominated students achieve learning objectives. They identified a wide array of learning objectives, ranging from an appreciation of cause and effect to improving the pupil's sense of direction. The robot's role could be to reward behavior, provide cues, or provide an active element in learning. Rated engagement was significantly higher with the robot than in the classroom. Bekele, Crittendon, Swanson, Sarkar, and Warren (2014) [12] confirmed the hypotheses that children with ASD would pay more attention to a humanoid

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robot than a human being and that children would be more accurate in working with the robot than with a human. Similarly, in mobile robot research Duquette, Michaud, and Mercier (2007) [13] found that two children paired with a robot mediator demonstrated increased shared attention and imitated more facial expressions compared to the children paired with a human mediator.

Turkle (1984) [14] and Ackermann (1991) [15] researched what conceptual perspectives guided children's thinking about the behavior of robots. Both found two different frameworks: the psychological (such as animate intentions, emotions, personality, and volition), and the physical or technological (such as gears, motors, sensors, and control program). Levy and Mioduser (2008) [16] examined these two conceptual perspectives among kindergarten children. They found two distinct patterns: "engineering" a technological perspective, where the young children were focused on the technical workings and the behavioral building blocks of the robot; and "bridging", which combined two distinct perspectives: psychological and technological. They found a relation between the task's complexity and type of conceptual perspectives. Subsequent research by Mioduser, Levy, and Talis (2009) [17] examined how kindergarten children explain a robot's behavior; they found that kindergartners abstracted rules from observing a robot's behavior, a process marked by increased generalization, a shift from temporal to atemporal constructs, and decentering from the robot to include its environment. Throughout this process, their representations shifted from episodes to scripts to rules, in other words from a procedural to a declarative description.

In this study, the robotic learning environment was based on the iPad and an iconic programming (KinderBot), and EV3, a smart robot that allows the HFA child to design and program its behavior independently. This iconic programming compensates for poor communication, writing, or reading skills and offers ease of use to HFA children without the need to read or write commands in letters. The KinderBot uses rule-based programming, a declarative approach to programming, in addition to the standard procedural approach of script programming. Furthermore, feedback for the programming action is presented immediately by the robot action and not by a therapist.

The main focus of this study is to examine the ability of HFA child to program robotic behavior and to understand how they programing the robot's behavior at different programming complexity levels via KinderBot. At the theoretical level, we expect to contribute to the expansion and consolidation of knowledge about the learning and construction process of behavior of smart artefacts through the observation of iconic programming by HFA children.

II. METHOD

A. Participant

In this case study, we examined A. A. is a Level 1 HFA child of age 10.5; he does not takes medication regularly. A. is integrated in a local public school. A. uses a computer independently. The University Ethics Committee and Ministry of Education Ethics Committee have approved this research.

B. Research Variables

The independent variable included one variable: the complexity of robot programming, which included six levels of complexity from simple action, teach, programming with or without subroutine, half rule, one rule, and two sensors (see Fig. 1).

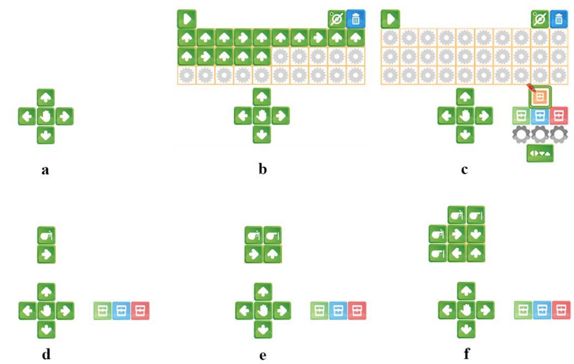

Fig. 1. KinderBot interfaces: (a) simple action; (b) the action with a view of the entire sequence; (c) programming with or without subroutines; (d) half rule with one sensor; (e) one rule with one sensor; and (f) two sensors.

Three groups of dependent variables were defined: programming task, learning task, and coping with common changes task. The participant's programming task included five variables: (a) success, (b) number of debugging loops, (c) detection and repair debugging, (d) support tool, and (e) researcher intervention. The participants's learning tasks included five variables, which were the same as the variables in the programming task. The participant's coping with common changes task included seven variables: the five variables of the programming task listed above and two more, (f) similarities in programs of both tasks, and (g) phrases expressing the identical tasks.

C. Research Instruments

Four research instruments were developed for this study:

- EV3 Robot. The robot was built from Lego Mindstorms EV3 flexible kit (Fig. 2). This kit combines sensors, motors, and an electronic brain. This is the newest way to learn to build and program a robot.

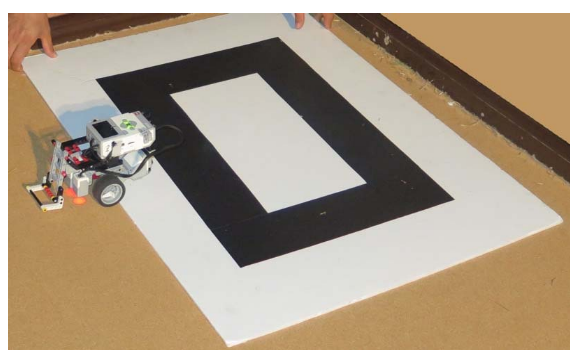

Fig. 2. EV3 robot and the robotic environmental setup.

- KinderBot. This is a visual programming language app, developed especially for young children for research purposes [17; 18-19]. The KinderBot allows the user to program the robot's movements in open and closed loop (with and without sensors). The KinderBot is a visual programming language that provides iconic elements, which can compensate for poor communication, writing, or reading skills, and offers ease of use to HFA children without the need to read or write commands in letters. It is based on a fixed-position key interface through all the levels of complexity. It applies rule-based programming—a declarative approach to programming—in addition to the standard procedural approach of script programming. Furthermore, feedback for the programming action is presented immediately by the robot action and not by the researcher. This application runs on an iPad, divided into six interfaces of varying degrees of complexity, and allows programming of the robot's behavior in a simple and intuitive manner (Fig. 1).

  The KinderBot's seven interfaces are:

  1. Simple action. A click on the appropriate interface button will lead the robot to perform one simple action: a step forward, a step back, a turn right, or a turn left (Fig. 1a).

  2. Teach. Perform the action with a view of an entire sequence. Robot control is as in the first interface, but here the entire step sequence is recorded on the screen and the entire sequence of recorded actions can run in automatic interface (Fig. 1b).

  3 and 4. Programming with or without subroutines. Unlike the second interface, the robot performs the whole sequence of recorded actions in automatic interface at the end of the programming process. In this interface, it is possible to create and use subroutines (Fig. 1c).

  In the following steps, binary sensors (touch, light, etc.) are used to program the robot's behavior.

  5. Half rule with one sensor. By dragging the corresponding icon, the user selects the action that the robot will perform during the transition of a binary sensor in one of the states (Fig. 1d).

  6. One rule with one sensor. The user selects actions for the two states of the binary sensor (Fig. 1e).

  7. Two sensors. User selects actions for all combinations of states of the two binary sensors (Fig. 1f).

- The KinderBot learning curriculum. This curriculum included a set of tasks based on the KinderBot application, which integrated description task, programming task, learning task, and coping with common changes task. These tasks were designed in increasing difficulty according to the configurations of rules required to perform tasks.

- Robotic Environment Setting. This environment includes all the components that are used in the constructed tasks, such as a variety of layouts, obstacles, and robot outfits (Fig. 2).

D. *Data Collection Instruments*

Six data collection tools were developed for this study:

- Background Questionnaire. Participant's parent questionnaire included three parts: personal information (16 questions), open-ended and scale questions about the child's ability to cope with small change based on previous research [20-24] (35 questions), and participant's computer technology knowledge (eight questions).

- Technology Knowledge Questionnaire. A two-part participant questionnaire. The first part had seven open questions about participant's use of information technology devices. The second part included 12 multiple-choice questions on mechanics based on the Bennett Mechanical Comprehension Test [24].

- Programming Tasks. These tasks aimed to teach the participant how to program through the KinderBot application. They were designed in increasing difficulty according to the configurations of rules required to perform tasks.

- Coping with common changes in the robotic environment setup tasks. These tasks aimed to examine the participant's ability to cope with common change, in accordance with the robotic environment setup.

- Observations. Participant's construction and verbal description were video recorded during all sessions.

- Screen Recorder. The user's programming activities using the KinderBot were recorded with a screen recorder app.

E. *Data Analysis*

Data analysis involved qualitative and quantitative analyzes; these data focused on questionnaires, participant's performance, interactions, and learning process.

F. *Procedure*

This research took place at the participant's public school. During the study, A. worked and was observed individually. At the first stage the parents were fully informed of the research framework and signed the consent form, followed by their answering the background questionnaire. At the first meeting the participant received a short verbal explanation about the experimental process. Next, he answered the technology knowledge questionnaire and the pretest on understanding of robotic behavior. Following these stages, he was trained on the Robot EV3's and KinderBot app, learning the seven interfaces from simple action through two sensors. During the training stage in each interface A. was asked to perform programming tasks and at the end of each interface he received common paired tasks that were focused on coping

with changes in the robotic environment setup. A posttest was conducted after the end of the sixth learning interface.
The length of each session was adapted to the participant's needs and spanned from 15 to 30 min (a total of 14 sessions, overall length 04:30 hr).

III. Results

How does A. perform the programming tasks at different programming complexity levels via KinderBot?

As shown in Table I, in most of the programming tasks (P) A. succeeded in programming the robot behavior in accordance with the robotic scenario (95%). He had difficulties in performing programming tasks only once in the programming interface with subroutines (interface 4). The number of debugging loops decreased each time he performed a new programming task in the same interface. A high number of debugging loops were found in two interfaces: programming interface with subroutines (interface 4) and programming tasks that involved two binary sensors (interface 7). In programming tasks that involved robot movement in open loop the participant tended to use hand and eye estimation to estimate distances and movement. The participant did not experience spatial difficulties in determining the robot's orientation in most of the tasks (97%), although in most he was seated in a position different from the robot's.

Interface	Task type	Time duration in seconds	Debugging loops	Detection and repair debugging	Similarities in programming two tasks
Teach	L	76	3	Delete all, delete & add	
	C	60	0		Identical
	L	22	0		
	C	18	0		With small change
Programming with subroutines	L	215	3	Delete all	
	C	151	1	Delete all	Identical
	L	55	0		
	C	98	1	Delete & change few steps	Identical
Half rule with touch sensor	L	52	1		
	C	21	0		Identical
Half rule with light sensor	L	41	2		
	C	13	0		Identical
One rule with touch sensor	L	82	1		
	C	22	0		Identical
One rule with light sensor	L	7	0		
	C	14	0		Identical
Two sensors	L	314	4		
	C	12	0		Identical
	L	104	2		
	C	56	1		Identical

TABLE I. PERFORMANCE OF PROGRAMMING TASKS

How does A. perform while coping with common changes in programming tasks in the robotic environment setup via KinderBot?

A. succeeded in performing all the paired programming tasks. He succeeded in programming the first task – learning task (L) and the second task – chang task (C), which included a common minor change in the robotic environment setup of the first task. In two out of 10 paired tasks the duration of the change tasks were shorter. Most of his second programming tasks (with the small change) included fewer debugging loops (Table II).

A. was able to identify the resemblances of the paired programming tasks. For example, in the first paired task, after receiving the second task (with the small change), he commented, "Hey, but it's the same [pointing at the iPad], it's the same," and didn't change the programming code. In all the other paired tasks in the second task (with the small change) he wrote an identical programming code from scratch; he made a small change (add few steps) in only one task.

During his performance of the coping with common changes programming tasks, A. uttered positive phrases about the tasks more than 15 times. His reactions included, "It's fun…. Great, this robot is awesome." At another point he said, "also here… (writing the programming code) I did it!, Hey I touched it… wow it was hard (a big smile on his face) haha I did it!" During these sessions, the participant laughed a lot and his facial expressions displayed his enjoyment of his interactions with the robot.

TABLE II. PERFORMANCE OF COPING WITH COMMON CHANGES PROGRAMMING TASKS

Interface	Task	Success	Debugging loops
Simple action	P1	Yes	0
Teach	P1	Yes	0
	P2	Yes	3
	P3	Yes	0
Programming without subroutines	P1	Yes	1
Programming with subroutines	P1	Partially	4
	P2	Yes	3
	P3	Yes	0
Half rule with touch sensor	P1	Yes	0
	P2	Yes	1
Half rule with light sensor	P1	Yes	0
	P2	Yes	1
One rule with touch sensor	P1	Yes	0
	P2	Yes	1
One rule with light sensor	P1	Yes	1
	P2	Yes	0
Two sensors	P1	Yes	0
	P2	Yes	4
	P3	Yes	2

IV. Discussion

The study reported here is part of a research effort aimed at understanding if and how HFA children are able to program the behavior of others, in this case examining their ability to program robotic behavior in a robotic setup, especially with a programming task that involves coping with minor common changes in the robotic environment setup. The results of this study helped us to elucidate several issues concerning the contribution to the programming tasks by HFA children.

In “designing” the behavior of “other”, the participant was able to program the behavior of smart artefacts by adapting use of their sensors in accordance with the environment. As in the research by Mioduser et al. (2009), the HFA participant in this study succeeded in programming the robot’s behavior in accordance with the robotic scenario.

Previous research has described difficulties that HFA children experience in coping with change. However, in this study A. was able to identify the similarities between the paired tasks (learn and change tasks), to identify the minor common changes that were added in the robotic environment setup, and to write a program that adjusted the robot’s behavior to minor changes. In these tasks the participant was not stressed or confused, nor did he refuse to perform the task. He actually was very proud of his success in the complex tasks.

V. CONCLUSIONS

These research results have important implications for the continuation of the research and for its implementation. Further studies might focus on programming approaches and skills or knowledge transfer: (a) exploring HFA students’ programming skills using programming software based on a declarative approach (e.g., KinderBot) compared with other programming software based on a procedural approach (e.g., Scratch) and (b) examining the ability of HFA children to transfer knowledge and strategies from the KinderBot scenarios to real-life scenarios.

Implementation of the results of this research regarding the ability of HFA children to program robotic behavior can occur in K–12 education. HFA children are integrated in public schools, and this research demonstrates that they can be integrated with their peers in computer and robotic disciplines. Moreover, they are able to learn about the technology that surrounds them, learning how it works and how to control it. The declarative approach discussed in this study is abstractive, helping participants cope with programming tasks. We can extend this problem-solving method based on the declarative approach to aid HFA children in solving other types of problems.

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