The effectiveness of using LEGO® robotics kits as cognitive and social rehabilitative toys

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Abstract: The present article offers a theoretical contribution to the understanding of the effectiveness of using robotics as cognitive and social rehabilitative toys. Starting from the theoretical foundations of educational robotics in the framework of constructionism, it provides methodological indications related to game activities with robotics behaviour construction kits, such as LEGO® Ev3. Moreover, it discusses empirical studies that evaluated the effectiveness of the use of robotics behaviour construction kits in the field of intellectual disabilities. Practical implications of the present study might be useful for educators, school psychologists, or rehabilitative therapists in the field of special educational needs.

Keywords: robotics; LEGO®; rehabilitation; cognitive rehabilitation; social rehabilitation; robotics behaviour construction kits; intellectual disability.

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1 Introduction

The play is essential in children's development and contributes towards cognitive, physical, social, and emotional development. In the marketplace of robotics games, there are different types of robotic toys. Some of them refer to pre-assembled robots, as, for instance, *Dush*. It comes ready to play right out of the game box, responds to the user's voice, and rolls around the living room. It can follow a racetrack, dance, light up, make noises, joust, or play all kinds of other games. As well, *Cozmo* is a robot with a personality that recognises faces, names, and personalities, cheering kids up when they are down and distracting them when they are bored. Other kinds of robotics toys regard the so-called robotics behaviour construction kits, as *LEGO® Ev3* or *mBot* robot. These robotics kits allow users firstly to assemble the robot body, and then to program its actions into the environment. The gaming experience with pre-assembled robots consists only in interacting with pre-programmed artefacts and customising users' preferences. Whereas, the gaming experience with robotics behaviour construction kits involves the user in the creation and subsequent management of the actions that the robot carries out into the physical environment. Besides, the robotics behaviour construction kits trigger users in a continuous process of construction, deconstruction, and reconstruction as well as programming, de-programming, and reprogramming of the actions of the robot. Thus, the robot becomes a real 'object-to-think-with' (Harel and Papert, 1991), which promotes, exercises and, therefore, strengthens the development of a continuous process of cognition (Papert and Mindstorms, 1980).

Scholars explored the potentialities of using robotics behaviour construction kits under the light of educational robotics (Leroux, 1999; Miglino et al., 1999). Educational robotics is an interdisciplinary area of study in the framework of entertainment technologies that involve cognitive psychology, computer science, and education so far. It regards not only the educational outcomes of robotics but also includes a method aiming at optimising the development of cognitive and social skills of people playing with robots.

In this article, we discuss the possibility of applying robotics behaviour construction kits as rehabilitation tools for the improvement of cognitive and social skills of people with different age and educational grade. To this aim, first, we report the theoretical foundations of educational robotics in the framework of constructionism (Papert and Mindstorms, 1980). Second, we provide methodological indications related to game activities with robots. Finally, we discuss empirical studies that evaluated the effectiveness of the use of robotics behaviour construction kits in the field of special educational needs.

2 The theoretical foundation of the robotics behaviour construction kits

Seymour Papert, a South African mathematician, might be considered the genius brain behind the development of the first product line of robotics behaviour construction kits, named LEGO® Mindstorm Robotic Invention System (Resnick, 1993). Having moved to Massachusetts Institute of Technologies (MIT) in Boston after working with Piaget in the 1960s, he had founded the constructionism, a new epistemological model of cognition (Papert and Mindstorms, 1980; Piaget and Inhelder, 1966; Papert, 1993). Papert observed the typical playful activities of some African children such as, for example, to build houses in scale or artefacts in cane. Then, the author based constructionism on the idea that the development of the human mind relies on the process of building concrete materials, called 'objects-to-think-with' that users can show, discuss, examine and admire. Interacting with computers or other robotics instruments, users enhance creativity or innovation, and concretise their computational thinking (Papert, 1991). This idea was quite similar to the well-known principle of knowledge as an action (Piaget and Inhelder, 1966). Piaget stated that individual interacts with concrete objects, and the cognition is the output of this active process of knowledge construction (Piaget, 1937). However, there are some differences between the two theoretical approaches to cognition. Piaget emphasised the formal logical thought that undocks from the concrete objects, as the most advanced expression of cognitive development (Piaget, 1937). *Vice versa*, Papert (Papert and Mindstorms, 1980; Papert, 1991) proposed a kind of reassessment of the real thought, by assigning a new value to the physical dimension and the tangible products of human intelligence. In this sense, robotics behaviour construction kits are real scaffolding that supports the processes of knowledge acquisition. Moreover, they contribute to stimulating, at an individual level, the zone of proximal development of each child (Vygotskij, 1934).

2.1 The robotics behaviour construction kits

In this article, we focus on LEGO® robotics behaviour construction kits. Specifically, they are in the marketplace with the name of *LEGO® Ev3* and provide users with traditional and computational bricks useful for assembling interactive robots. The user is free to choose the shape of the robot, i.e., its morphological structure – and use the same LEGO® bricks to build small vehicle shaped robot, animaloid or humanoid robots. Thus, the robotics behaviour construction kits are toys subject to inspection, because the users could enter both into the mechanisms of construction and in those of behaviour modification of the toy itself (Ackermann et al., 2002). The game with the robotic kits consists, in fact, in the initial construction of a robot whose morphology is usually characterised by a central body and peripheral effectors or actuators. An onboard mini-computer represents the central body that is both the main physical chassis of the robot and its brain. The body/brain is the input and output system processing of the robot's behavioural repertory. It is a programmable LEGO® brick, interlocking with holes and buttons that allow the user to connect to it other pieces. It has an internal microprocessor and a useful memory to store the firmware or operating system of the processor, which enables the robot to operate independently from the computer. The users also assemble to the central body other computational bricks such as motors, light, touch, infrared or colour sensors. Sensors give the robot the possibility to perform specific actions into the real environment (e.g., moving in a dimly lit ambient; avoiding environmental obstacles; following a line). Once the user builds the robot, he/she switches to schedule its behaviours using a software programming application on a computer. Like in a puzzle, the user creates the program making chains of various types of programming blocks, or commands, such as go, next, back, right, left, stop engines, zig zag, dance, and shake. When the user completes the programming phase, he/she downloads the coding algorithm on the robot and verifies its performance in the real surroundings. The robot acts autonomously into the environment, without any cable or another link to the computer. Thus, the game experience offers users a continuous process of construction, programming, and verification of the behavioural repertoires that the robot performs in the real environment. In this way, the playful activities with LEGO® kits create a project-designed gaming environment (Martin, 1992, 1994; Resnick, 1996). Besides, the robot embodies the users' computational thinking – see the concept of embodied cognition (Clark, 2001) – and allows them to adjust it through the continuous feedback received by the autonomous robot (Papert and Mindstorms, 1980; Papert, 1993). In this sense, the robotics behaviour construction kits represent not only a new playful technological toy but also the origin of a real epistemological revolution. They indeed allow the transition from the theoretical approach based on constructivism (Piaget,

1937) to that based on constructionism (Papert and Mindstorms, 1980; Papert, 1993). Robotics behaviour construction kits have a real consistency and, at the same time, provide valuable support to the development of a game based on problem-solving. They also enhance all the cognitive and social abilities of players.

3 Playing with the robotics behaviour construction kits

The game experience with the robotics behaviour construction kits is a hands-on activity that appeals to both the constructionism and experiential learning (Kolb, 1984; Kolb and Kolb, 2001). Playing individually or in a group, users live in a gaming situation that they control. Players wholly manage the entire design and subsequent testing of the game strategies for adapting the robot's action into the environment. The game offers multiple approaches to solve the problem of creating a well-structured and efficient robot so that the task stimulates the creativity of gamer. Everyone could express at the best their cognitive styles or learning strategies. Prior work provided empirical evidence that playing with robotics behaviour construction kits has a high educational value, especially in the areas of science, technology, mathematics, and engineering (STEM). Scholars introduced these kinds of game activities into schools, performing a comprehensive series of edutainment laboratories (i.e., educational plus entertainment laboratories) with students of different age and educational grade. Results have shown the effectiveness of playing with robots for the acquisition of technical or scientific high-level concepts (Martin, 1992, 1994), and abstract or formal rules that govern the scientific and technological disciplines (Krumholtz, 1997; Järvinen, 1998). Other studies evidenced that robotics behaviour construction kits allow children to increase planning and forecasting abilities (Wang et al., 2001), logical reasoning skills (Caci et al., 2002, 2004), perceptual discrimination ability, or visuospatial skills (Caci, 2004; Caci et al., 2013), working memory (Caci et al., 2014) and also metacognition (La Paglia et al., 2010).

Specifically, Caci et al. (2004) involved a group of students attending a middle school in a 12-sessions LEGO® robotics laboratory and showed that scores at measures of reasoning skills positively related with the ability of programming a small LEGO® robot shaped like a vehicle ($r = .608$ $p < .05$). Authors assigned participants with the robotic task of building/programming a LEGO® robot able to carry out, as quickly as possible, a journey inside a rectangular arena, avoiding an obstacle placed at the centre of the trajectory. To evaluate the participants' performance at the robotic task, researchers divided preliminary the whole robotic action in four programming sequences needed for solving the task. Then they assigned scores of 0 = no programming sequence, 1 = incorrect programming sequence, and 2 points = correct programming sequence, respectively. Results of this study demonstrated that reasoning skills are cognitive precursors of the ability of programming a LEGO® robot. Students anticipate and plan the robot's actions to adapt its behaviour to the environment. For instance, they program a suitable algorithm for allowing the robot to avoid environmental obstacles and modify its trajectory. As well, they use their reasoning strategies for defining the robots' sensory-motor actions suitable to the task conditions (Caci et al., 2004). Successively, Caci et al. (2013) found similar results in a group of middle school students. Authors involved students in an eight four-hour sessions robotic laboratory aimed at building/programming first a LEGO® robot. In this case, participants need to solve a more creative robotic task. They had first to define a fictional scenario for robot behaviour. Then, they need to build the robot's arena using pasteboard, colours, and modelling paste. Finally, they could program the algorithms for adapting the robot to the created environment. In a second step of the robotics laboratory, participants also had to recreate the LEGO® scenario using the *Kodu Lab* virtual game by Microsoft. Results showed that participants' scores at reasoning skills ($r = .72$; $p < .01$) and speed of visual processing targets ($r = .45$; $p < .05$) strongly related with the acquisition of LEGO® programming skills. In line with studies mentioned above, La Paglia et al. (2010) provided preliminary results about the association between LEGO® robotics activities and metacognition skills in a group of children attending a primary school. Authors, preliminary, defined four LEGO® robotics tasks with increasing difficult level measured on the number of LEGO® bricks and LEGO® building and programming sequences needed for solving each of them. For instance, the task 'built the single bumper' required 32 LEGO® bricks and eight assembling sequences. As well, the task 'Program the motors and the single bumper' required five commands to create the programming algorithm. Finally, the authors measured the metacognitive skills of participants (e.g., self-corrections) with observational grids.

Other studies showed that LEGO® robots are effective for the improvement of cognitive skills. For instance, Wang et al. (2001) involved a group of children, aged between 5–6 years, in a pre-post design based on programming sessions with pre-assembled LEGO® robots. During the pretesting, they required children to familiarise with LEGO® programming sessions and to anticipate the robot's action into the environment. During the training session, authors assigned children with six programming tasks with an increasing difficulty level. At post-testing, authors proposed the pretesting programming sessions and measured the increment in the children ability to anticipate the actions of the robots. Results confirmed that children improved high-order cognitive skills such as planning and prediction abilities. Chioccarello et al. (2002) confirmed such results also in an Italian group of 5–6 years aged children. However, they involved children in creating robotics micro-worlds with the assistance of experimenters. For instance, they built LEGO® robots moving toward sound sources, robotics trees, or robotics birds interacting reciprocally. Authors reported that children made a high frequency of 'if…then' prediction statements during the robotics activities, and also followed their cognitive styles. Some children mentally anticipated the actions of the robot and applied systematic and logical planning strategies. Others made hypotheses on robots' actions and tested them empirically into the environment, so applying test-retests heuristics. Recent empirical evidence shows that playful activities with LEGO® robots are also useful tools for the improvement of visual-spatial working memory (Caci et al., 2013).

Furthermore, playful activities with LEGO® robotics kits are valid for the increasing of social skills of people engaged in the game. Players collaborate, share ideas and solutions, and acquire strategies for solving conflict or disagreement (Barfurth, 1995). As well, they improve cooperation and collaboration (Denis and Hubert, 2001). For instance, Barfurth (1995), analysed the collaborative strategies of fourth and fifth-grade children (8–9 years) analysing video transcripts during the activities of construction and programming of small autonomous LEGO® robots. Results showed the emergence of moments of disagreement within the couples, especially during the choice of the robots' behaviours. However, the children were able to overcome the situations of disagreement by activating multiple cognitive actions centred on the discussion/modification of the different proposed solutions. To solve the disagreement, the students tried to keep the topic of discussion, created new themes, added new aspects to the topic of initial discussion, tried to integrate their point of view with that of others, or change their position and request clarifications. In the same perspective, Denis and Hubert (2001) highlighted the crucial role of the division of construction and programming tasks between the students. Some children took care of building the LEGO® robot, while others planned it. According to the authors, robotics activities create a learning context that favours the autonomy of children, who focus their interactions on the task, use the materials offered by the kit at will, act strategic behaviours for collaboration within the group. Furthermore, they offer companions feedback on the success achieved and give them explanations about the chosen strategies. These encouraging results have subsequently prompted researchers to verify the effectiveness of playing activities with robots in the field of special needs education.

4 The use of robotics behaviour construction kits as rehabilitation tools

Krumholtz (1997) was the first who described the benefits of using playing activities with robots for children with intellectual disabilities. Children with intellectual disabilities might have trouble playing because of their intellectual limitations and cognitive disabilities. They have reduced the ability to retain attention and might not understand the meaning of the proposed play, and the meaning of the language used to play. Hence, the author focused on the possibility to customise the playing activity with robots and provided empirical evidence that people with intellectual disabilities can follow their ways of thinking, so giving free rein to their creativity. Other studies have shown that the interaction with robots that express an intentional behaviour (e.g., robots that move in a track and sweep away some bricks scattered in it) fosters proactive and finalised attitudes in children with intellectual disabilities (D'Ambrosio et al., 2003). Likewise, Caci and D'Amico (2005) demonstrated that playing with robotics kits allows students with intellectual disabilities to increase both academic achievements in all linguistic, mathematical-scientific and technical subject area and also promotes the enhancement of perceived self-efficacy, autonomy, and metacognitive control. Recently, D'Amico and Guastella (2019) developed a treatment protocol called RE4BES, which is a collection of guidelines for realising robotics personalised activities for children with special needs. Results reinforce the idea that RE4BES protocol can be considered a valuable and innovative tool for the cognitive treatment of children and adolescents with different individual needs. Authors proved the effectiveness of the RE4BES protocol for the empowerment both of cognitive skills (i.e., verbal short-term, working memory) and engagement in the activities. As well, the RE4BES protocol is useful for the reduction of inattentive or hyperactive behaviours.

5 Conclusions

The present article evidenced that the interaction with robotics behaviour construction kits such as *LEGO® Ev3* brings back the importance of concreteness in gaming. Unlike traditional construction games or the immaterial and disembodied artificial agents of video games, the physical robotics constituents represent a real technological scaffolding, by which players increase their cognitive and social skills in a playful game environment. Thinking about the robot materialises the process of thinking with the robot to adapt its sensory-motor action to the game conditions. Otherwise, the player might assume the robots' point of view, and elaborate a sort of 'theory of the mind' for the robot. Thus, the playful interactions with the robots offer subjects the opportunity to experiment with their construction of knowledge. The active process, both of creation and discovery in problem-solving, are embodied into the robotics game (Harel and Papert, 1991). Playing with robotics kits, individuals acquire complex and abstract concepts since robots favour a continuous exchange between concrete and abstract thinking, respectively. The active experimentation of building a set of wheels useful for the robot movements offers the individual a concrete way of thinking about the general laws that governs the functioning of levers and gears (Papert, 1993). Similarly, the real activity of joining, adjusting, or re-adjusting the LEGO® bricks during the construction of the robot's body is linked with the logical process related to the programming of the robots' mind. Players establish conditional relations between events (if…then rules), make decisions and solve the problem, and this, in turn, enhances the development of their cognitive or social skills (Caci et al., 2013). Furthermore, the final verification of the proposed solutions in the real environment offers players immediate feedback, so helping them to develop also metacognitive skills. Players benefit from the participation in the hands-on robotics activities, and this lets us glimpse the possibility of using these advanced technological tools also in the context of cognitive and social rehabilitation. Playing with robots allow controlled and straightforward, but peculiarly incorporated (or embodied) interactions between the player and the robotics toy that include physical contact and concrete manipulation. By placing itself at an intermediate level in a continuum from the interaction with software rehabilitative tools to real interaction with human therapists, the game activity with robots offer a bit more real interaction than those with software displayed on a computer screen, but a little less real than the interaction with another human being. Therefore, playing with robots fill the gap between the exclusive use of software systems or traditional techniques for rehabilitation. As well, playing with robots allows a dynamic subject-robot interaction. The computer program does not control robots, but they occur in the *hic et nunc* of the real environment. Thus, playing with robotics kits might be considered a valid therapeutic aid (Fong et al., 2003).

In sum, the present article foreshadows repercussions for the application of robotics toys not only for the short-term strengthening of specific abilities but also in long-term rehabilitation projects. We, therefore, believe that robotics toys represent a frontier rehabilitative tool both for educators, school psychologists, or rehabilitative therapists in the field of special educational needs.

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