Programming a Robot or an Avatar

A Study on Learning Outcomes, Motivation, and Cooperation

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ABSTRACT

Robots have been found to be effective tools for programming instruction, although it is not yet clear why students learn more using robots as compared to receiving 'traditional' programming instruction. In this study, 121 nine- to twelve-year-old children received a programming training in pairs, in one of two conditions: using either a robot or a virtual avatar. The training was videotaped to study differences in children's cooperation. Furthermore, children's learning outcomes and motivation were assessed through questionnaires. Children were found to learn more from programming the robot than the avatar, although no differences in their cooperation during the training or self-reported motivation were found between the two conditions. Thus, future research is required to further understand how exactly robots lead to higher learning outcomes than 'traditional' tools.

KEYWORDS

Robot; Avatar; Children; Programming training; Learning outcomes; Motivation; Cooperation

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1 Robot vs. Avatar

Robots are a popular tool in STEM education and have been found to be effective tools in teaching programming skills[1]–[4]. Children learn from programming with robots and often enjoy the learning process. However, the use of robots for programming instruction has rarely been compared to other tools, such as computer programs with avatars. It is not yet clear whether robots are more effective tools to teach programming skills than more 'traditional' tools. Advantages of robots over other tools should be clear to implement robots in curricula in schools[5]. In this paper, we aimed to find out whether robots led to different learning outcomes and learning motivation than avatars, with a specific focus on differences in children's cooperation while learning.

The main reason that robots could be more effective tools than screen-based technology is that they allow for physical interactions [6], [7], and thus, to multimodal learning. Robots and virtual avatars differ in their perceptions and affordances (i.e., action possibilities [8]). In contrast to virtual avatars in computer programs, robots allow children to physically hold and manipulate them, and to see the results of their codes in real-life rather than on a screen. Being physically involved has been found to benefit learning across many domains[9]–[11]. We suspected that a robot's embodiment may help children learn programming skills in more than one way. First, results of one's codes are visually clear (e.g., a robot may run a shorter or longer distance depending on the code). Children may perceive more, act more, and, in general, use more senses and motor systems, which may have a positive effect on retention. Furthermore, a physically present robot may also stimulate children to cooperate differently when engaging in a programming training together. Robots may, more than virtual avatars, invite children to wonder about the mechanisms within the robot, engage in conversations about the robot, and explore the robot's possibilities. Such experiential learning stimulates conceptual development [12], for example how robots transfer sensory input to actions [13].

Thus, in this study, we not only investigated whether children's learning outcomes and motivation differed between learning with a robot or an avatar, but we also explored whether children cooperated differently when using a robot or an avatar. Our hypothesis was that children learn more, have higher motivation, and, crucially, cooperate more actively when being taught programming skills through using a robot than an avatar.

2 Method

The participants were 121 children (*M*age = 11.26 years, *SD* = 0.86 years, range 9.40-12.84 years, 55 females) from six different primary schools in the Netherlands. Children were grouped into pairs, such that age and gender were taken into account to ensure a roughly similar distribution of children over the two conditions. Sixty-two children participated in the robot condition (*M*age = 11.21 years, *SD* = 0.88 years, range 9.42-12.47 years, 28 females) and 59 in the avatar condition (*M*age = 11.31 years, *SD* = 0.85 years, range 9.40-12.84 years, 27 females). Parents signed an informed-

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consent form prior to the study. The data from three additional children was collected in the avatar condition but discarded due to issues with the consent forms.

Each pair of children participated in a programming training in one of two conditions: with a non-humanoid robot (an Ozobot) or an avatar in a computer program (Giga in Scratch). A non-humanoid robot was used instead of a humanoid one, because children may expect humanoid robots to assume a social role rather than that of a programmable object like the avatar used in this study. The training was highly similar in the two conditions. Children were given several programming tasks to execute, such as making the robot or avatar move forward. They were taught forward motion, loops, and if-then statements. They used a Microsoft Surface tablet to program the Ozobot in Ozoblockly and the avatar in Scratch. The major difference between the two conditions was that the robot ran over a paper maze in the robot condition, and the avatar ran through a virtual maze in the avatar condition. The training lasted a maximum of 20 minutes.

In each training session, cooperation between students was measured by videotaping these sessions and coding them afterwards, using a coding scheme consisting of 18 behaviors (eleven verbal and seven non-verbal behaviors). The scheme was created beforehand based on a pilot study. Examples of verbal behaviors were children asking each other questions or discussing the tasks, and examples of non-verbal behaviors are pointing at something or executing a task. The occurrences of these behaviors during the programming training were tallied and total scores were calculated for verbal and non-verbal behaviors separately. Video data from four children was missing due to technical issues.

In addition to the video data, data on children's programming knowledge and motivation was gathered through questionnaires. Learning outcomes were measured through a questionnaire consisting of five questions (both open-ended and multiple-choice), resulting in a maximum score of five. Motivation was measured through the Dutch translation of the Intrinsic Motivation Inventory, which was adapted to our specific context [14]. The IMI consists of 22 statements which have to be rated on a scale of one to seven. Children's IMI score was calculated as the average over the 22 statements, resulting in a maximum score of seven. A pretest was administered but not reported in this paper due to space limitations.

3 Results

Table 1 lists the average scores on the questionnaires and the coding scheme, separated for each condition. A series of independent-samples t-tests shows that children obtained higher scores on the learning-outcomes questionnaire in the robot condition than the avatar condition, $t(105.5=33)=4.23$, $p<.001$. No differences in motivation scores were found between the two conditions, $t(119)=1.51$, $p=.135$. Moreover, no differences were found between the two conditions in both verbal, $t(115)=-.66$, $p=.508$, and non-verbal behaviors, $t(115)=-.31$, $p=.760$.

TABLE I

MEAN OUTCOMES (SD) OF THE QUESTIONNAIRES AND CODING SCHEME, SEPARATED BY CONDITION.

Test	Robot	Avatar
Learning outcomes	3.73 (0.96)	2.83 (1.33)
Motivation	5.65 (0.68)	5.48 (0.73)
Verbal behaviors	54.60 (36.46)	59.65 (45.46)
Non-verbal behaviors	57.45 (28.02)	58.98 (25.98)

4 Discussion

This study compared children receiving a programming training with a non-humanoid robot or an avatar. Children's learning outcomes and motivation were measured after the training, and their cooperation during the training were coded. Based on differences in their affordances [8], the robot was expected to lead to higher learning outcomes, higher motivation, and more cooperation than the avatar in the computer program. Children were found to have higher learning outcomes in the robot condition than in the avatar condition, as expected. However, self-reported motivation and cooperation were not found to differ between the two conditions.

The finding that children learn more using a robot than an avatar is in line with earlier research on the effectiveness of robots for programming instruction [1]–[4]. Our expectation was that these higher learning outcomes would result from a difference in the affordances of the robot and the avatar and the subsequent cooperation of children. The robot was expected to lead to more cooperation between children, such as discussing the tasks, executing the tasks, and exploring the properties of the robot. However, this was not the case, as no differences in verbal and non-verbal behaviors were found between the two conditions. Thus, it is not yet clear why learning outcomes are higher in the robot condition than in the avatar condition.

As in many studies on educational robots, the difference in learning outcomes could result from a novelty effect of the robot. We asked children prior to the training whether they had already programmed before and were familiar with the robot or the avatar's computer program. More children had experience with Scratch (n=15) than with the Ozobot (n=2). Most children (n=74), however, did not have any programming experience at all. Crucially, self-reported learning motivation did not differ between the two conditions. If the novelty of the robot had played a role, self-reported motivation would likely have been higher in the robot condition than the avatar condition. Thus, future research is required to study how exactly robots lead to higher learning outcomes than 'traditional' tools. Future studies could further investigate the potential benefits of robots for programming instruction by varying the degree to which learners are physically involved, or by studying which types of learning benefit most from physical interactions. Moreover, coding schemes could include variables such as turn-taking behavior and reciprocity, to study not only how much cooperative behaviors children initiate when using robots, but also how they respond to each other.

The current study compared learning to program a robot or an avatar. Although no differences in self-reported motivation or cooperation during the training were found, children showed higher learning outcomes when learning to program a robot rather than an avatar. This finding supports the use of robots in STEM education, although further evidence on the effectiveness of different types of robots as a mediating factor in learning is required to implement robots in education.

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