10th International Conference of the Immersive Learning Research Network
Selected Academic papers for the iLRN Proceedings

DOI: https://doi.org/10.56198/U6C0WYZ8W

Work-in-Progress—Improving Computational Thinking for Learners with Autism in the Virtual World: A Longitudinal Study

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Abstract. Improving computational thinking (CT) skills for learners with Autism Spectrum Disorder (ASD) can positively affect their ability to solve problems, their independence, and success in life. This work-in-progress study sought to examine the effectiveness of virtual world (VW)-based, learning-by-design activities on CT learning for learners with ASD. Two adolescents participated in CT learning sessions over a period of 10 to 15 months. Data were collected from video recordings, recording transcripts, computer logs, and code files. Employing a mixed-methods research design, the quantitative components used a single-case experimental design to gauge the effectiveness of the proposed intervention. A qualitative thematic analysis was then performed to understand learners' interaction with, and experience in the learning activities. Preliminary findings suggested that the VW-based CT learning module can enhance autistic learners' CT skills.

Keywords: Computational Thinking, Learners with Autism Spectrum Disorder, Virtual World.

1 Introduction

According to a recent report, 1 in 36 individuals in the United States, rising from 1 in 45 two years ago, have diagnoses of Autism Spectrum Disorder (ASD) at 8 years [1]. Individuals with ASD are characterized by persistent deficits in social interaction and communication, executive functioning, and demonstrate a pattern of restricted interests and repetitive behaviors [2]. They struggle to interact with others reciprocally, interpret or respond appropriately to various social cues, and effectively solve academic and everyday problems [2]. These difficulties, if unattended, can lead to unemployment, comorbid mental health issues, and a diminished quality of life [3,4]. As such, it is important to provide meaningful and accessible learning opportunities to cultivate critical life skills for individuals with ASD, which help increase their independence and autonomy in their academic, social, and everyday lives.

As one of the 21st-century skills, computational thinking (CT) refers to the attitude and skill set for algorithmic problem solving by employing computer science-related concepts [5]. It has been proposed that individuals with ASD are able to generatively engage in CT learning activities and can benefit from learning CT skills [6, 7], such as improving academic performance and problem-solving skills [8]. Improving their problem solving skills is critical since their ability to solve all types of problems in their natural environment can affect their functioning, independence, and future success [9]. Moreover, CT learning activities, mostly problem-based and collaborative in nature [10], involve learners with ASD in active collaboration with peers or instructors in a socially constructed learning environment. A recent scoping review focusing on CT, social-emotional skills and learners with special needs, including those with ASD, found that over half of the reviewed studies (n=12) reported that CT learning activities can positively impact their social-emotional skills [11].

Despite the prospects of learning CT, questions remain as to how CT activities can be designed to facilitate learning and cater to the unique needs of learners with ASD. Therefore, this study proposes improving CT for learners with ASD in a virtual world (VW)-based environment where they engage in learning by design activities. Specifically, this study addresses two research questions:

1) Can learning-by-design activities in the VW positively impact CT learning for learners with ASD?
2) How did the learners with ASD experience learning-by-design activities in the VW?

1.1 CT Learning and Learners with ASD

There has been limited research that has explored the inclusion of learners with ASD in CT education. Munoz et al. [12] studied adolescents with autism who had no prior programming experience in a digital game programming workshop. They reported that the workshop helped to promote CT skills and the skill development was sustainable. Similar results were reported by Elshahawy and their colleagues [8], who claimed that serious game and block-based programming environments facilitated CT learning and academic achievement for learners with ASD. The findings are preliminary but promising because acquired CT skills are generalizable to different contexts [14], holding the potential to expand their academic trajectories and improve their autonomy in life. Efforts have also been made to explore the instructional strategies that facilitate CT learning for learners with ASD. It was found that this group of learners benefit from explicit instruction, collaboration opportunities, immediate feedback, scaffolded project planning, and model-lead-test instruction [13, 14]. Of great importance is the provision of individualized support to learners with ASD when they struggle with the tasks or get frustrated [13, 14].

Moreover, social skill gains have been shown to be a salient benefit of CT learning. It was found that CT learning offered increased opportunities for social interaction and cooperation, where learners on this spectrum discuss potential solutions with peers or instructors, request and provide help, and explain their problem-solving processes through verbal/nonverbal communication or artifact design [8, 11, 14]. These interaction and collaboration practices can lead to improved social reciprocity and communication skills [11, 12].

1.2 Learning by Design for Learners with ASD

The theory of constructionism [15] argues that learning is an active process where learners actively construct knowledge through experience. This approach to learning, particularly in the realm of CT, engages learners in creative problem-solving and contextual reasoning through the design and creation of artifacts [15, 16]. Learning by design, grounded in constructionism, immerses learners in authentic and experiential learning in that learners assume control as independent designers, pursuing both intellectual and social goals [17]. Learners design complex and interactive artifacts, such as simulations and interactive games, as a way of learning a particular subject or skill set. Compared to other forms of learning, learning by design motivates and engages learners as the tasks are personally relevant, intellectually challenging, and designed for the use of others [17, 18].

1.3 VW-based Learning for Learners with ASD

VWs have been actively employed for skill development for learners with ASD [19, 20]. Unique affordances of a VW-based learning environment include 1) a safe and unthreatening space where learners with ASD practice target skills without embarrassment or consequences; 2) the simulation of authentic learning tasks as well as a high level of customization to meet different needs; 3) repeated practice of target skills; and 4) an immersive environment that increases the engagement and attention of children with ASD [21, 22]. However, despite the promises of VW-based learning environment, prior research focuses predominantly on developing social skills in the VWs [20], the design and implementation of VW-based CT learning activities for learners with ASD remain largely unexplored.

2 Method

This study employed a mixed-methods approach with an explanatory sequential design [23]. For the quantitative component, we adopted a single-case experimental design, an experimental design that aims to examine the effectiveness of an intervention with a small number of participants [24]. We then employed a qualitative case study [25] to gain deeper insights into the experiences of learners with ASD in exploring CT learning activities in the VW.

2.1 Participants

Participants of the current study were recruited online through autism parent groups on social media. Two adolescents (two boys, 19 and 16 years old) voluntarily participated in the study. They had self-reported and documented (with Gilliam Autism Rating Scale, GARS-3) diagnosis of autism, could speak, read, and write, and received grade-level academic instruction. They reported prior 3D gameplay experiences but no programming experience. Both participants' and guardians' consent were obtained.

2.2 VW-based Learning Activities

The CT learning module was designed and developed in *OpenSimulator*, an open-source multiuser VW. The featured assessment and learning task of the module was to design a human-like non-player character (NPC) that can act as a dialogic agent in a simulated scenario (e.g., acting as a restaurant server). Several environments were built in the VW, where the participants took a tour and decided where they wanted their NPCs to spawn. The design activity was open-ended, and the complexity of the design was determined through discussion between the facilitator and participants based on their interests and the feasibility of the proposed NPC [26].

The module is a creative design and block coding task which have shown promising results in improving CT skills for learners with ASD [14, 27]. It mainly comprises four sub-tasks: a) NPC appearance design, in which participants designed and customized the appearance of the NPCs to match their occupations and scenarios; b) pseudo-coding by which learners described NPC's behavior and conversation; c) 3D flow diagrams design, in which participants designed the behavioral and conversational logic using 3D flow diagrams (e.g., a flow diagram of a proximity alert would indicate what NPCs say or do if anyone in the VW activates the alert); and d) block programming, where participants used 3D blocks to do basic block programming (see Fig.1). Combining programming and non-programming activities, the iterative processes of problem-solving in each task affords ample opportunities to elicit evidence for the targeted CT skills (see section 2.3).

The module revolved around open-ended design inquiries in which facilitators could monitor the session closely and provide learner-adaptive, question prompts [28]. Multiple communication channels were enabled in the VW. Participants can choose between voice and text chats to communicate with the facilitator. They can also create 3D objects or use animations to express their thoughts.

Fig. 1. VW-based CT module.

2.3 Data Collection and Analysis

Participants logged in to their virtual avatars in the *OpenSimulator* to join the virtual session with two trained human facilitators. Two participants engaged in the 1-hour design sessions weekly over 10 to 15 months. During the preliminary baseline sessions, the participants familiarized themselves with the VW without engaging in coding or simulation designing activities. During the intervention, the participants designed and coded the NPC. The study ended with a 2-week closing baseline of summarizing the module. Data were collected from video recordings of the sessions, session transcripts, computer logs, and code files.

Single-subject research design. A-B-A was used to examine the effect of VW-based learning activities on the acquisition of CT skills for children with autism. The study consisted of a two-week baseline, a 19- to 29-week intervention, then a two-week baseline. For the current study, we focused on two main CT skills: algorithmic thinking and collaboration. Informed by previous definitions of CT [29, 30], we developed a coding framework of CT with annotated examples from the participants (see Table 1). Aligning with constructionist learning, learning by design values learning as a process rather than an end product [17]. We did not use *proficiency* but *process* as an indicator of CT learning as learning can take place through active involvement. The observed CT behaviors in each category were aggregated by session. Tau-U, a nonparametric effect size metric, was computed for effect size [31].

Qualitative analysis. To gain insights into how learners with ASD experience the learning by design activities in the VW, a qualitative thematic analysis was also performed [32]. The thematic analysis was conducted to provide a contextualized depiction of learners' engagement in and interaction with the activities. Open, axial, and selective coding were performed to derive salient themes.

2.4 The Role of Human Facilitators

Two human facilitators attended the learning sessions with participants. The lead facilitator Mr. Smith (pseudonym) is an expert in computer science with extensive experience working with learners with ASD in design-based projects. Mr. Smith was the instructor who mainly worked with participants and provided guidance to participants' design work. Another facilitator, Mr. Johnson (pseudonym), is an expert in learning science, who facilitated the session when needed and observed learners' experiences. Facilitators guided learners through open-ended design problems, and explicit instruction was employed sparingly when learners struggled with the task.

Table 1. Target CT skills and examples.

CT Skills	Sub-skills	Annotated Examples
Algorithmic thinking	Conceptualizing & creating a system of actionable elements	Facilitator: "*What will happen if our response is "yes"? He checks something right?*" Participant: "*Yes. In this case, he will be checking what the variables are. In this case, I am trying to do this one (*standing on one branch of the 3D flowchart). And this would be: interacted for how many times they said yes. First one being interacted.*"
	Positioning key elements into a solvable pattern	Participant: "*I was gonna say that we should probably take this block at the bottom away, of this one (*pointing to a block)." Facilitator: "You want me to delete it?*" Participant: "*Not yet, in case this is wrong. And put this one under it, like, take up the blue block, put all of the others under. Think that's gonna work, but I am not sure.*"
Collaboration	Interacting with others to achieve a common goal	Facilitator: "*And the last one is a scenario you get to decide by yourself, but it has to incorporate that element of having NPCs that try to act as a real human being roleplay.*" Participant: "*My original idea, when you first discussed this with me, was maybe a hotel with a like a couple people and he like the judge could role play as like someone going through checking all the rooms trying to find the NPC.*"
	Valuing peers as contributors to group work	Participant: "(Proposing an idea) *What do you think?*" Facilitator: "*I think the drink one would be an interesting challenge.*" Participant: "*Alright, let's do that then.*"

3 Preliminary Results

At the current stage of the study, preliminary results included the annotated algorithmic thinking for both learners (see Fig. 2 and 3). The plotted graphs display the number of algorithmic thinking behaviors that were coded during baselines and intervention. The total number of observed algorithmic thinking for two participants was 213 (participant 1) and 182 (participant 2). A considerable increase in algorithmic thinking behaviors during intervention was observed. The results indicated that the learning design in the VW-based learning module facilitated the practice and acquisition of target skills, which include an open-ended design inquiry, coding activities with increasing difficulty, real-time learner-adaptive support, and engaging and immersive learning environment.

4 Conclusions and Implications

In conclusion, this study aimed to improve autistic learners' CT skills, i.e., algorithmic thinking and collaboration skills by engaging them in VW-based, learning by design activities. Preliminary results showed that the participants improved their algorithmic thinking skills through iterative design problem solving and 3D artifact creation.

This study was among the first to explore the use of VW-based learning-by-design activities to support CT learning for learners with ASD. The results of the current study will provide insights into the design and implementation of VW-supported learning activities that support researchers, educators, and practitioners in crafting learning experiences that enhance CT learning, and cater to the unique needs of this group of learners.

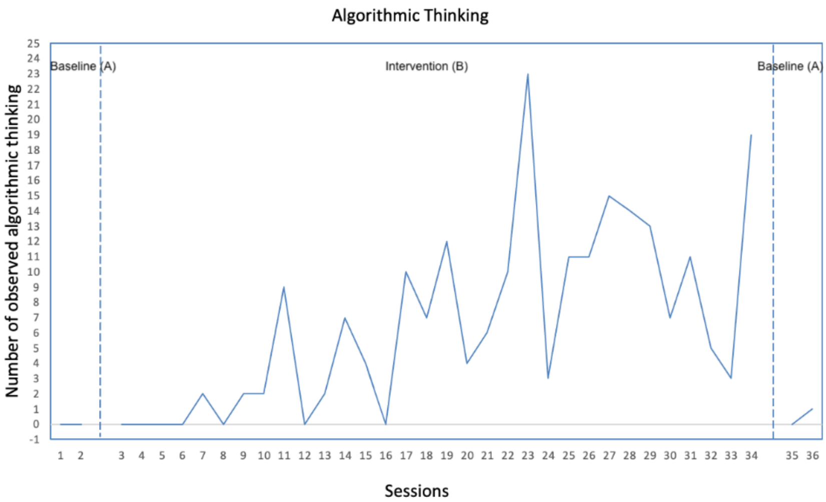

Fig. 2. Evidenced algorithmic thinking for Participant 1.

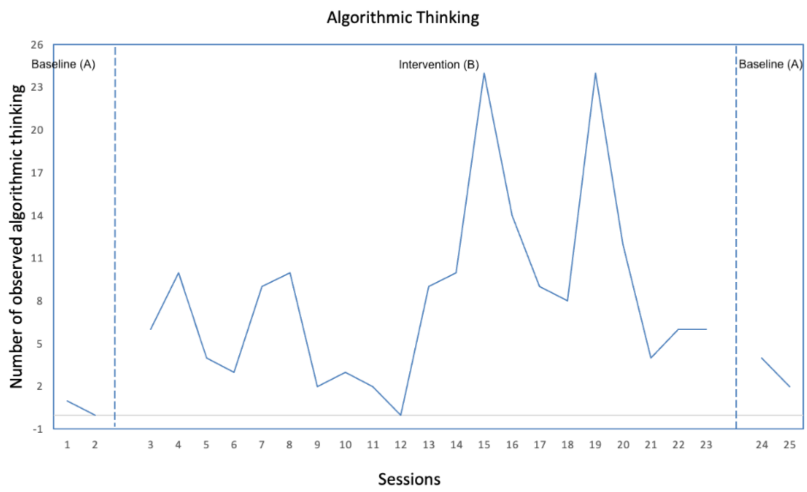

Fig. 3. Evidenced algorithmic thinking for Participant 2.

Acknowledgements

This work is supported by National Science Foundation grant 1837917.

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