Examining Virtual Reality Based Learning Design for Children with Autism via Seasonal Index Analysis

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Abstract: This mixed-method study aims to examine the design features and effectiveness of virtual reality (VR) based, social skill learning tasks that aim to promote the social competencies development of children with high-functioning autism. These tasks support both steered and creative role-playing, collaborative design, and virtual gameplay among the target children. Nine 10-14-year-old children with high functioning autism participated in the study over 16-31 intervention sessions. A time-series, seasonal index analysis was conducted with participants' longitudinal social interaction performance during and across various VR learning tasks. The study findings indicated that the design features of the simulated scenarios and learning tasks in the VR-based learning environment mediated the intervention effects on different social interaction performance.

Introduction

Prevalence rates suggest that 1 in 68 American children are diagnosed with autism. Those diagnosed with high-functioning autism (HFA), in particular, may be the fastest growing segment (Rao, Beidel, & Murray, 2008). Children with HFA lack critical social skills such as initiating and maintaining social interactions, sharing affective experience or understanding the perspectives of others, cooperation and negotiation (Macintosh & Dissanayake, 2006).

Virtual reality (VR) has emerged as a promising platform for social skills learning. Via a 3D simulation of real-world experiences, VR based learning enables the practice of social interaction skills in a non-threatening sandbox setting before testing them out in the real world (Schmidt & Schmidt, 2008). Supporting multisensory interactions for multiple users across a distance is another promising feature of VR based environments because the learning can be extended to multiple settings. Yet prior reviews of the educational applications of VR suggested that its affordance for learning still needs to be studied together with other mediating factors, such as instructional strategies and learner characteristics (Mikropoulos & Natsis, 2011).

This mixed-method, multi-case study aims to examine the salient features of VR based learning tasks that contribute to the social competencies development of children with high-functioning autism. Specifically, the research question to be addresses is: *What VR-based learning tasks and scenarios would reinforce social interaction performance of children with high-functioning autism*?

Literature review

Theory of executive dysfunction and weak central coherence in autism

An important theoretical account of autism is executive dysfunction (Denckla, 1996). Executive functioning (EF) is defined as the ability to initiate and maintain a set of problem-solving behaviors for attainment of a future goal, such as planning, intentionality (e.g., ability to create and maintain goal-directed behaviors), cognitive flexibility (e.g., shifting attention between stimuli/response sets), and inhibition (of irrelevant responses or impulse) (Ozonoff, Pennington, & Rogers, 1991). Adopting this theoretical perspective, a core intervention design and research hypothesis in this study is that designing and arranging environmental stimuli and problem-based learning tasks that purposefully motivate, scaffold, and instill the practice of executive functioning should promote the social competencies development of learners with autism.

Naturalistic interventions for children with autism

Although there are some common diagnostic features, there is still great heterogeneity associated with autism. Hence it is critical yet challenging to design an intervention that will be effective and versatile for diverse learners with autism because their specific needs will vary. Recent reviews of social skill interventions with individuals with autism proposed a reduction of direct intervention for *naturalistic* intervention, and the transferring of control for prompting social interactions from teacher verbal antecedents to self-monitoring or naturally occurring stimuli (e.g., Rao et al., 2008). A naturalistic intervention is usually conducted in loosely controlled contexts and incorporates the target child's preferences into the social skills training.

In spite of their promise, naturalistic and adaptive interventions for children with high-functioning autism are still understudied but worthy candidates for further development and testing (Rao et al., 2008). A recent review on the interventions of social skills learning (Authors, 2017) reported that prior research typically lacks a purposeful investigation of instructional procedures and learning activities in the intervention, and it is difficult to determine circumstances in which the intervention is impactful, or to extract findings that may contribute to the design heuristics and theoretical insights that will guide future intervention development.

Virtual reality for naturalistic social skills training

Research also showed that children with autism tend to enjoy computerized intervention programs and have made significant learning gains using various technology-integrated training packages, such as cartoons, video modeling, computer-assisted instruction, and computer games (Beaumont & Sofronoff, 2008). In comparison with other computerized programs, virtual reality supports high-fidelity role-playing to facilitate the transfer of skills between taught and real contexts, and provides a multi-user, open-ended design space for real time collaboration. VR has intrinsic appeal as an instructional tool for children with autism who are typically visual learners (Mitchell et al., 2007). Yet empirical research examining the design and instructional characteristics of a VR-based social skill training program is still limited. Previous VR-based social skill interventions were typically multimedia direct instruction or highlighting a single social scenario (Laffey, Stichter, & Schmidt, 2010; Mitchell et al., 2007). Extending prior research, we investigated the design and affordance of a variety of VR-based social problem-solving scenarios and tasks, including agent-facilitated and peer-enacted role-playing, collaborative artifact design, and virtual gaming, in motivating and enhancing the social interaction performance by children with autism.

Methods

VR based social skill learning environment

Using OpenSimulator, we constructed a 3D virtual world that simulated the residential community, a virtual school, amusement parks, and various resorts. This virtual world supports social role-playing, collaborative design quests, and virtual gaming. Non-player characters were developed as interactive pedagogical agents that provided structured prompts based on the triggering events. Two virtual facilitators, incarnated into a variety of social characters via a voice-morphing software, provided adaptive scaffolding. The prompts and scaffolds focused on activating and guiding learners' involvement in executive functioning during the aforementioned learning tasks. The intervention program was aimed to promote the performance of responding, initiating social interactions, interpersonal negotiation, cognitive flexibility (e.g., switching between solutions, multiple tasks, or perspectives), and positive self-identity manifestation.

Participants and procedure

A mixed-method multi-case study was conducted to examine the potential association between the virtual scenario and learning task design features and learners' social interaction performance. Nine 10-14-year-old children who had a formal medical or educational diagnosis of high functioning autism, including one girl and eight boys, participated in the VR-based learning program at home. Each child went through the program over 16-31 intervention sessions (.75 to 1 hour per session), based on each child's progress and availability.

Participants' social interaction performance was measured at 3-5 baseline sessions. When all baseline data are stable by level, trend, and variability, the VR-based social skill intervention was introduced to child 1. The other participants remained in the baseline condition. When the measures of child 1 gained stability over consecutive sessions during the intervention, child 2 began the intervention while other children continued in the baseline condition. This process repeated for each child until the last one. The sequence of participation was random and the frequency of participation was customized based on each participant's progress and schedule.

Data collection and analysis

Behavioral data was collected from the participants via screen recording and onsite observation of their participation actions and reactions. We then conducted behavioral analysis with the recorded social interaction performance (215 .75-1hr sessions), using time sampling (per 30 seconds) as the primary unit of coding. The coding focused on the manifestation and frequency of positive and negative enactments of the targeted social competencies. The coding followed a structured protocol proving the operational definition and examples of each performance measure, and was supported by an observational data gathering application that enables real-time collection and coding of data obtained from infield and video-based observational processes. Three trained coders independently coded a randomly-selected 20% of the recordings. The interrater reliability was .86. After

more formal discussion and reaching 100% agreement on the frequency and occurrence contexts for every core performance measure and their exemplified events, two trained coders then coded the remained recordings.

Based on the social interaction behavioral coding results, we then calculated the average frequency of successful enactments of each targeted social interaction competency (i.e., average counts of successful enactments of each competency in a selected 3-min interval) in each baseline and intervention session. The type of learning task and simulated social problem scenario (setting) of each intervention session were also coded. To better examine participants' longitudinal social interaction performance during the progression of learning tasks and scenarios, we adopted the *time series analysis* approach (Jebb, Tay, Wang, & Huang, 2015) to integrate temporal dynamics in salient pattern detection. We calculated a *seasonal index* using the following formula for each participant with each VR-based social learning task and setting in order to examine the association between the type of VR-based learning tasks/scenarios and a participant's social interaction performance.

$$\text{S-index} = \frac{\textit{The average frequency of each social skill enactment within each setting (or activity)}}{\textit{The average frequency of each social skill across all settings (or activities)}}$$

If a simulated social scenario (setting) or a learning task's S-index is higher than 1, this specific setting or task has a privileged intervention effect in comparison with others, whereas a smaller-than-1 S-index represents an underprivileged intervention effect. We also conducted a visual analysis of time series cross-participant graphs (i.e., graphing the data collected and visually inspecting the differences among simulated scenarios and tasks within and across participants) to further examine whether there is a functional relation between the scenario and learning task design features and the outcome variables.

Results

Table 1 provided a summary of average seasonal indices of VR-based learning tasks. Across participants, the activity of virtual world exploration reinforces responding and interaction initiation more than higher-order social skills of negotiation, positive self-identity expression, and cognitive flexibility. Among virtual gaming tasks, the chess game showed a differing intervention effect from virtual sports games on the performance of three higher-order social skills. In the social games that learners voluntarily initiated (e.g., racing game and scavenge hunting), the intervention effect was balanced for various social skills. VR-based digital story telling had two forms – creative storytelling using fantasy-themed 3D visuals versus social storytelling based on emulated historical characters. The former fostered self-identity while the latter better facilitated negotiation. Role-play tasks, whether agent-facilitated or peer-enacted, reinforced social interaction performance consistently. The task of acting as a waiter in a virtual amusement-park fish/chip shop, in particular, promoted the performance of initiation as well as higher-order social skills. In comparison with creative building, client-solicited artifact building had an underprivileged intervention effect on self-identity expression.

Table 1: S-indices of intervention effects of VR-based learning tasks

Activity	Responding	Initiation	Negotiation	Self-Identity	Cognitive Flexibility
Exploration	1.37	0.92	0.47	0.69	0.75
Math Game	1.05	0.94	1.00	1.16	1.09
Chess Game	0.96	0.93	1.69	0.30	2.12
Sports Games	1.04	0.70	0.24	1.06	0.67
Racing Game	1.19	1.21	1.47	1.02	0.49
Scavenge Hunting	0.99	1.13	1.09	0.83	0.98
Creative storytelling	1.18	0.91	0.73	1.97	0.90
Social storytelling	1.08	1.10	3.39	0.97	1.19
Dietitian Roleplay	1.15	0.87	0.90	0.88	1.15
Librarian Interview	1.12	1.07	1.07	0.96	0.99
Park Worker Roleplay	0.97	1.02	0.93	1.15	1.08
Waiter Roleplay	1.32	1.64	0.98	1.00	1.04
Client-solicited Building	0.97	1.02	1.07	0.67	1.06
Creative Building	1.23	0.97	0.98	1.03	0.98

Table 2 summarized the average S-indices of simulated social scenarios/settings in the virtual world. In general, the scenarios where the participants got to roam the virtual land and approach objects freely (e.g., the sandbox, village, amusement park, a Lego kingdom, and an underwater resort) were underprivileged in fostering the performance of negotiation or cognitive flexibility. In comparison, in a scenario where participants' agency was lessened (e.g., school nurses office), the performance of negotiation and cognitive flexibility improved whereas that of initiation and self-identity expression decreased.

Table 2: S-indices of intervention effects of VR-based social scenarios/settings

Scenario/Setting	Responding	Initiation	Negotiation	Self-identity	Cognitive Flexibility
Sandbox (Open World)	1.14	0.81	0.81	0.69	0.73
School Classroom	0.97	0.91	0.89	0.79	0.83
School Cafeteria	0.95	0.83	0.90	0.85	0.77
School Nurses Office	0.94	0.47	1.33	0.60	1.24
Village	1.28	0.93	0.40	0.86	0.54
Amusement Park	1.04	0.92	0.34	1.04	0.75
Fish & Chip Store	1.54	1.65	1.05	0.81	1.08
Lego Kingdom	1.07	0.81	0.58	1.05	0.84
Western Town Resort	0.96	1.04	1.10	0.84	1.24
Underwater Resort	0.87	0.94	0.62	0.83	0.84
Snow Resort	1.01	1.01	1.14	1.42	1.05

The finding on the differential effects of the VR-based learning tasks and social scenarios on each social competency suggested that participants with different social learning needs would benefit from them differently. This implication was validated by the visual analysis of time series cross-participant graphs.

Conclusion and implications

The current study findings indicated that the designers of VR-based learning should dynamically adapt the design and presentation of VR-based learning tasks and simulation scenarios based on the targeted competencies and the in-situ reactions of learners. The study findings will enrich the research of inclusive and adaptive e-learning by illustrating the design of naturalistic, design- and play-mediated social skills training. The project will also offer theoretical and empirical guidance for the future design of a computer-assisted, versatile, and immersive learning experience for learners with special needs.

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