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Supporting Youth With Autism Learning Social Competence: A Comparison of Game- and Nongame-Based Activities in 3D Virtual World

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Abstract

This study explored youth with Autism Spectrum Disorder (ASD) learning social competence in the context of innovative 3D virtual learning environment and the effects of gaming as a central element of the learning experience. The empirical study retrospectively compared the social interactions of 11 adolescents with ASD in game-and nongame-based 3D collaborative learning activities in the same social competence training curriculum. We employed a learning analytics approach - association rule mining to uncover the associative rules of verbal social interaction and nonverbal social interaction contributors from the large dataset of the coded social behaviors. By comparing the rules across the game and nongame activities, we found a significant difference in youth with ASD's social performance. The results of the group comparison study indicated that the co-occurrence of verbal and nonverbal behaviors is much stronger in the game-based learning activities. The game activities also yielded more diverse social interaction behavior patterns. On the other hand, in the nongame activities, students' social interaction behavior patterns are much more limited. Furthermore, the impact of game design principles on learning is then discussed in this paper.

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Introduction

Immersive simulation such as in 3D virtual environments is increasingly being viewed as an enabling technology that transcends traditional educational boundaries and allows individuals to acquire the competencies needed for educational settings (Gallup et al., 2017). Collaborative learning in 3D virtual world has shown significant growth in supporting groups of learners in the complex and highly interactive simulations (Barab et al., 2005; Dalgarno & Lee, 2010; Ketelhut, 2007). New studies are showing that utilizing 3D virtual world can be a platform to support individuals with Autism Spectrum Disorder (ASD) and social skill development (Ke & Im, 2013; Parsons et al., 2005; Stichter et al., 2013). Adolescents with high functioning autism are known to "have a desire to be social but do not yet have the knowledge or skills to successfully perform interactions in a complex and social environment" (DuCharme & Gullotta, 2003). Unspoken social "rules" vary within different environments, situations, and cultures, making it increasingly difficult for a person with high functioning autism (HFA) to understand and adapt to situational social norms (Myles et al., 2001). Deficits in social competence can have severe and long-lasting consequences if left untreated (Stichter et al., 2013). 3D virtual worlds offer many affordances for students who need support and social interaction as part of their learning process. 3D virtual environment can be easily manipulated in ways that the real world cannot. Social rules and constructs can be conveyed through experience. In addition, the privacy of the computer-generated online environment provides a safe and non-threatening context for practicing and acquiring new and difficult skills (Gantman, 2012; Standen & Brown, 2006). 3D virtual worlds hold great promise for learning needs that require both cognitive and behavioral practice such as social competence. Therefore, it is important to design social interventions or learning programs based on 3D virtual worlds to help children and adolescents with HFA improve their social and communicative competence of performing initiation, response, negotiation, and collaboration with peers. There is considerable evidence that students with autistic spectrum conditions can learn targeted social skills in 3D virtual learning environment (Y. Cheng & Ye, 2010; Stichter et al., 2013). Research on youth with ASD learning in 3D virtual worlds has documented the successful use of 3D multi-user learning environments to support generalizations of social appropriateness in social settings (Parsons & Mitchell, 2002; Rutten et al., 2003; Sarah Parsons et al., 2005), emotion recognition through avatar representations (Fabri

& Moore, 2005), and behaviors that facilitate social acceptance such as eye contact and attending (Y. Cheng & Ye, 2010).

In addition, researchers argue that 3D virtual learning of social competence for youth with autism can be further enhanced by leveraging principles from the field of "game design/gamification" in educational research (Abirached et al., 2012; Sailer et al., 2017; Whyte et al., 2015). For over a decade, educators have been considering ways of leveraging serious games in the 3D virtual world to support learning for typical learners in various subject areas. The purpose of game design in the 3D virtual learning environments are knowledge and skills acquisition and these are expected to lead to psychosocial satisfaction and effective learning outcomes (Sailer et al., 2017). Benefits of incorporating serious games in 3D virtual learning is that learners are more motivated and engaged (Barab et al., 2005), and individuals gain positive perspectives toward the team cohesiveness, trust, and collaboration (Bozanta et al., 2016). In addition, the learning that takes place during game play has strong potential to generalizes to improvements in real life outcomes (Abirached et al., 2012; Grossard et al., 2017).

Employing game design in 3D virtual worlds to support social skills development for youth with ASD has also shown initial findings of promoting psychosocial performance and fostering reciprocal and collaborative social behavior (Wang et al., 2018; Grossard et al., 2017; Ke & Moon, 2018; Silva et al., 2017). However, more examination of the design and development approaches for serious game/gamification in 3D virtual world is needed, which in turn may generate important implications for how interventions can be improved for individuals with autism (Whyte et al., 2015). Specifically, comparing the effectiveness of game-based 3D virtual learning with non-game pedagogical approaches that more typically used in classrooms yields contradictory results (Hess & Gunter, 2013; Sadler et al., 2015). Hess and Gunter reported students in 3D video game-based learning performed significantly better than nongame in an online American history course. On the other hand, Sadler et al. conducted quasi-experimentally designed study compared learning outcomes of high school biology between two curricular approaches: around a computer-based game, and the other built around a narrative case. However, the researchers found that students in both groups showed similar learning outcome results. In our study, we are interested in comparing the social competence learning of 3D game-based activities and 3D activities that mirror pedagogical approaches that more typically used in classrooms. Key questions are: Will student perform differently in the game play vs non-game play? What type of social behaviors can be impacted by game vs non-game activities for youth with autism? There is few research that connected 3D game design elements and game-experience constructing mechanics with specific social performance outcome for youth with ASD.

So, while it appears that game-based 3D collaborative virtual environments have the capacity of supporting youth with ASD learning social competence, many questions remain unanswered, such as how games can be used in 3D virtual world, how games may interact with various content domains, and how much learning takes place in games relative to other approaches in 3D virtual learning. This study addressed some of the unanswered issues regarding the use of games in 3D virtual learning of social competence for youth with autism. The goal of our paper is to explore how immersive game design, in comparison to non-game instructional design, affect the social performance of youth with ASD when they are using avatars in a social competence intervention curriculum in a 3D collaborative virtual world.

Define Game-Based Learning in 3D Virtual World

Over the past few years, there has been extensive discussion about the use of games in education and the "gamification" of education (Kapp, 2012). Some researchers may regard learning via 3D virtual learning environment as game-based learning in a broad sense (Berns et al., 2013; Warburton, 2009). However, we believe that there is a significant distinction between the general nongame 3D virtual learning activities and the narrative embedded, exploratory-oriented game activities in a virtual world. The former refers to learning activities that implement typical pedagogical approaches, for example like in a virtual classroom or lecture hall, where learners use avatars to listen to the lecture or complete certain tasks collaboratively (Andreas et al., 2010; Warburton, 2009). When compared to typical 2D web-based instruction these 3D activities are more interactive and students experience a sense of "being there" in the 3D virtual world, which promotes social interactions that are essential in collaborative learning (Pellas, 2014) (see Figure 1). As Dickey [65, p. 122] suggested, there is "compelling evidence of the potential that graphically rich three-dimensional settings provide for constructivist learning activities" (Dickey, 2005). However, these collaborative learning activities are far from immersive gaming activities. Designing game-based learning in 3D virtual worlds requires more than just using avatars and virtual scenes and objects. Salen et al., (2004, Chap. 7) define a game as "a system in which players engage in an artificial conflict, defined by rules, that result in a quantifiable outcome." Games prescribe a conflict or contest that players negotiate through decision-making and actions. As players make progress toward the resolution of the conflict or contest, they earn points or other quantifiable markers denoting success (or failure) (Sadler et al., 2015). 3D virtual worlds give designers great flexibility to design engaging games, which include meaningful story lines, complex virtual scenes, convincing virtual objects and various tools that could not otherwise be made possible in real life.

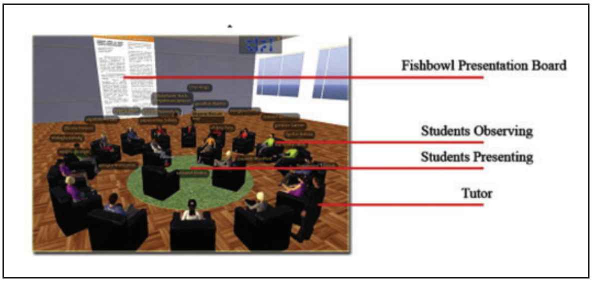

Figure 1. An Example Nongame Classroom-Settings Design in 3D Virtual Collaborative Learning Environment (Andreas et al., 2010).

Game-based learning activities in 3D virtual worlds focus on the integration of educational objectives with specific evidence-based game mechanics known to support learning. These games are designed with the purpose of knowledge and skills acquisition. For example, River City, a game which enables middle school students to assist the mayor of River City as they travel back in time to 1878 and help her figure out why the residents of the town have fallen ill. Students work in teams of three and visit River City to help a town struggling with infectious disease. Playing River City has been shown to help students learn about the science of disease transmission (Nelson & Erlandson, 2008). Hamari et al. (2016) studied students engagement while playing games in learning physics and engineering, and reported that engagement has a clear positive effect on learning through empirical research. Granic et al. (2014) stated that virtual games may foster real-world psychosocial benefits. Considering the immersive social contexts that include social and pro-social activities as part of the gaming experience, gamers rapidly learn social skills through the act of solving complex problems with a team in ways that generalize to social relationships outside of the gaming environment (Bozanta et al., 2016).

According the Ke (2016) and Lameras et al. (2017), purposeful game-based learning in a 3D virtual world should contain the following mechanics: a learning space that is situated in the immersive storylines/narrative, goals directed toward targeted skills, scaffold to support learning within the game, and supports for learning through game actions.

Game-Based Learning in 3D Collaborative Virtual World for Youth With ASD

Recently, researchers have started to implement game designs in 3D virtual worlds for promoting social skills learning for youth with ASD. Given observed improvements in communication skills and socialization that have occurred through the use of virtual social interactions, especially in the context of an avatar mediated, scenario/role based, collaborative gameplay enriched learning experience in 3D learning environments, there is great potential for taking advantage of the technological features of the 3D virtual world and incorporate game design (Gallup et al., 2017; Grossard et al., 2017; Silva et al., 2017).

Given the ubiquitous nature of 3D virtual environments and the collaboration, communication, and socialization that occur during the gameplay, it is possible that individuals with HFA are already engaging in these social realms and utilizing soft-skills (Gallup et al., 2017). Parsons (2015) designed a user-centered collaborative virtual reality game for high functioning youth (10–13 years) with ASD. The researcher reported that youth with ASD were supported to be reciprocal and collaborative in their responses. Chen et al. (2016) used an augmented reality-based video modeling storybook to strengthen and attract the attention of adolescents (11-13 years) with ASD to nonverbal social cues because they have difficulty adjusting and switching their attentional focus (C.-H. Chen et al., 2016). Ke and Moon (2018) found that virtual reality-based gameplay promoted the social interaction performance of HFA (high functioning autism) adolescents (10-14 years). The study findings also suggested that gameplay should be adapted based on the competencies and in situ reactions of learners (Ke & Moon, 2018). Abirached et al. analyzed user needs for a serious game for teaching children and adolescents with ASD emotions and suggested customizable, adaptive and contextualized principles for future serious game design (Abirached et al., 2012). These pioneering studies have reported preliminary results of youth with ASD benefiting from serious game design-based 3D virtual immersive learning.

However, Grossard (2017) reviewed literature on 31 serious games that are being used to teach social interactions to individuals with ASD. What they have discovered is that the game design is not usually described; and in many cases, the clinical validation and playability/game design are not compatible. To design games that best support the acquisition of social skills for youth with ASD research is needed to articulate the relationship between game design approaches and student/player outcomes.

Whyte et al. (2015) in a review of literature discovered that interventions showing the greatest evidence of generalized learning included the greatest number of serious game elements. The researchers suggest that future research using computer-based interventions in autism should focus on three key elements of serious game design: (1) use of storyline and goal-directed behaviors, (2) use of cooperative multi-player games that build upon the efficacy of interpersonal interactions in previous virtual reality interventions, and (3) increased use of gaming elements that facilitate the transfer of knowledge and skills from the intervention to more ecologically valid in-person social situations.

As the reviewed literature pointed out, adopting game design in a 3D virtual world for youth with ASD has great potential, however, there is a lack of research on how game design of the curricular tasks influence students' collaborative learning of social skills, or at very least, how game design could influence students' social performance in the environment in comparison to a nongame approach.

Avatar-Mediated Reciprocal Social Interaction Framework

Social performance in a 3D virtual world is most often represented by through the actions of the avatar representing the player. Avatars are embodiments of the learners and are used to interact with the virtual objects and space as well as other avatars in the 3D immersive environment. Understanding avatar mediated social interactions of students with ASD is essential for researchers and teaching professionals, because understanding how students socially interact in the 3D virtual world is needed for choosing instructional designs that best support the desired social competence.

In a 3D virtual learning world, there are substantial challenges to fostering social interaction among the students with ASD. Some of the key characteristics of youth with ASD that must be overcome are a lack of understanding of the basic rules of social engagement and an inability to identify and act on non-verbal social cues (Wang et al., 2017). Non-verbal communication constitutes an essential aspect of social cognition. Indeed, non-verbal cues are known to influence person perception and construal processes early during social encounters (Willis & Todorov, 2006), and a large proportion of social meaning is substantially informed by non-verbal cues (Argyle, 1990; Burgoon, 1994). One of the areas where individuals with HFA find particular difficulties is the understanding of non-verbal communication cues. Thus, investigating the underlying psychological processes and neural mechanisms of non-verbal communication in HFA allows a better understanding of this disorder, and potentially enables the development of more efficient forms of psychotherapy and trainings. (Georgescu et al., 2014)

We intend to describe adolescents with ASD's verbal and nonverbal social behaviors/performance in the 3D collaborative virtual world using a verbal and nonverbal reciprocal social interaction framework as in Figure 2 (Wang et al., 2017). The verbal social interaction includes initiation and response, and nonverbal contributors include avatar proximity, avatar orientation/facing, avatar gesture, and avatar joint attention.

Using the reciprocal social interaction framework to represent youth with ASD social performance in a serious game embedded 3D virtual world enables exploration of how the game design impacts the social behaviors of the students. Previous studies, while only focusing on neuro-typical learners, have provided a research approach. Sailer et al. (2017) investigated the impact of game design on learners' social and psychological needs in an online simulation environment. The researchers argued that the collaborative learning activities in the 3D virtual world should not be assumed to be effective, instead, the serious game design elements should be further examined for in what ways they affect learners' social

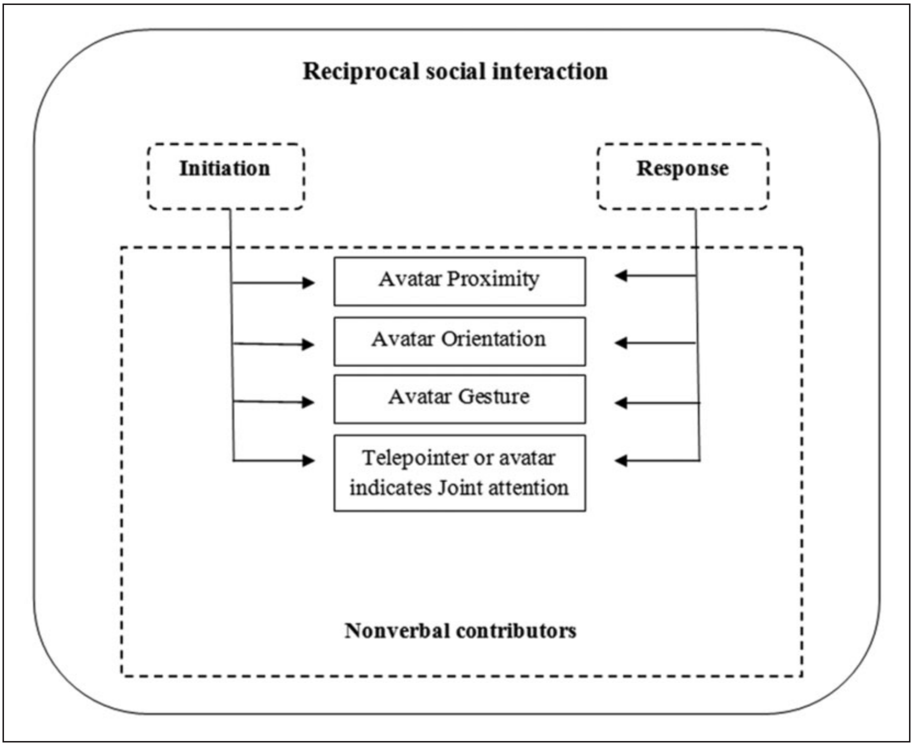

Figure 2. Reciprocal Social Interaction Framework (Wang et al., 2017).

learning experience. Hopson (2001) argued that behavior analysis offers a linguistic framework for understanding how the contingencies arranged in games affect players' behaviors. Hopson also claimed that having an improved understanding of basic principles of player's social behavior and adopting a more conceptually systematic framework might allow for more effective identification of successful game design strategies. (Grossard et al., 2017; Morford et al., 2014).

Purpose of Study

Based on reviewing previous studies, we identified a key research gap as exploring how game design could impact the social behaviors of adolescents with ASD in learning social competence in 3D virtual worlds. By comparing 3D immersive learning activities that adopted game design and the activities that did not have game design mechanics, we are interested in exploring the differences of youth with ASD's social behavior patterns in these two conditions, especially in comparing what social behavior patterns (verbal and nonverbal) are more likely to co-occur in the game vs. nongame learning activities. By doing so, we believe that we could better support youth with ASD's social skills development in 3D serious game-based collaborative virtual learning environment. Furthermore, we could gain insights of in what ways game design could promote (or hinder) youth with ASD learning social competence in the 3D virtual world.

Study Context

iSocial

iSocial is a 3D CVLE that supports youth with Autism Spectrum Disorder to learn social competence from physically distributed locations (Laffey et al., 2009, 2014; Stichter et al., 2013). To be more specific, iSocial is a translation into a 3D CVLE for delivery over the Internet from a face to face, clinic based curriculum-Social Competence Intervention-Adolescents (SCI-A), which targets deficits of youth with High Functioning Autism/Asperger Syndrome (HFA/AS) in three social cognition processes: theory of mind, emotion recognition and executive functioning (Stichter et al., 2010). iSocial seeks to translate and implement in a 3DCVLE the SCI-A curriculum (Laffey et al., 2009). The 10-week curriculum, SCI-A is based on a framework of Cognitive Behavioral Intervention (SCI-CBI). Results from face to face implementations of SCI-CBI indicate promising trends for growth (across pre- and post-intervention assessments) among youth with ASD (Stichter et al., 2010). SCI-A aims to remediate core deficits in social competence for youth with ASD through five curricular units: understanding facial expressions, sharing ideas, turn taking in conversation, recognizing feelings and emotions of self and others, and problem solving. Each unit contained 5–7 lessons. In each unit, the lesson plan follows a consistent structure of learning and rehearsing skills culminating in a Naturalistic Practice activity where the students put their new competencies into practice in a challenging activity meant to engage them with their peers in a fairly open-ended task. Naturalistic Practice sections in the iSocial curriculum offer the greatest opportunity for students to interact and problem solve with peers, and where there is the least amount of scaffolding and direct instruction from the online guide (teacher).

In iSocial lessons, each user is represented by one's own avatar. Students can interact with peers and the Online Guide (OG) using both verbal and nonverbal communications via avatars. Learning activities in iSocial provide opportunities for students to manipulate objects and select options in the 3D space. Goal-oriented learning tasks stimulate discussions and negotiations among students. Figure 3 shows snapshots of students participating in lessons in iSocial.

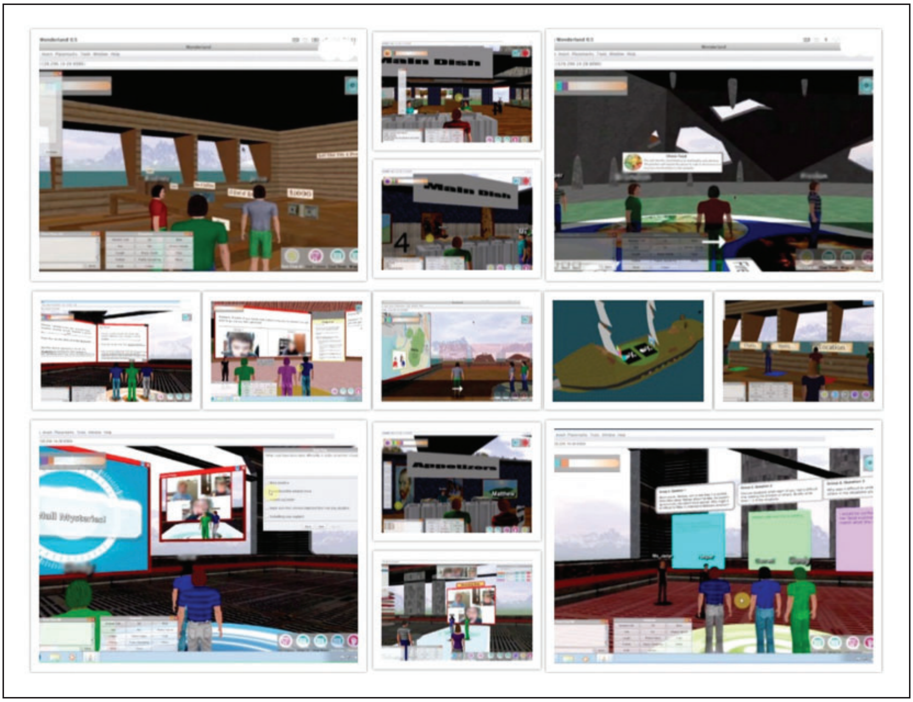

Figure 3. Screenshots of iSocial Curriculum.

Game VS. Non-Game Learning Activities

As mentioned above, Naturalistic Practice (NP) activities in iSocial is a curricular component of the later lessons in a unit in which students are encouraged to speak freely and discuss with the group about the challenging activity they are being asked to undertake in iSocial. The NP activities were chosen as the data source for this study because they are the stage in the curriculum when students have the greatest opportunities to interact with their peers in natural ways for accomplishing authentic social tasks. iSocial represents about 22-24 hours of online curriculum divided over five units, and there are 30-62 total minutes of NP activities in each unit. NP activities last from 10 to 33 minutes. There are 13 NP activities in the iSocial curriculum.

Based on game design criteria from Sailers et al. and Whyte et al.'s serious game design elements, we have divided the NP activities into two groups: Game activities and non-game activities. The categorization was based upon whether the NP implemented the following four game design elements: (1) Immersive storyline. Narratives or stories that are embedded in the virtual environment, e.g. in lost at sea game activities, students were on a virtual ship cabin, with ocean view outside the window. (2) Multiplayer or teammate roles. The roles not only match the storyline for the game play but also fit with the individualized targeted social skills training. (3) Visual representation of achievements. Badges, scores, or virtual objects as the reward or feedback, e.g. in the restaurant buffet, when the team chose an option of the main dish, the visual dish appears on the buffet table. (4) Clear goal of the task. The goal of the collaborative task has to be made clear at the beginning, e.g. in the King's quest activity, the goal is to retrieve all the lost items based on following all the clues, then the team can see the king himself and get knighted. As a result, we identified NP 3, 4, 6, 7, 10, 13 as game activities and NP 1, 2, 5, 8, 9, 11, 12 as non-game activities. See Table 1 for the detail description of the game and non-game activities.

Method

Participants

This study took place as an iSocial field test. Participants are eleven youth aged from 11 to 14 who were diagnosed with Asperger's syndrome by Autism Diagnostic Interview Revised (ADI-R) (Rutter et al., 2003) and/or the Autism Diagnostic Observation Schedule (ADOS) (Risi et al., 2006). Additionally, an IQ of 75 or above and capable of speech are required for participation. These 11 participants are all male. Participants were from three different junior high or middle schools in the mid-west area of the United States. As part of the development process for iSocial, participants in the same school district were formed into a cohort and took the course together via internet connections. Cohort 1 has 3 students and Cohorts 2 and 3 have 4 students. These 3 cohorts were taught by the same teacher, an online guide (OG) in the 3D CVLE, who is highly trained in teaching social competencies for youth with ASD. The three cohorts went through the same entire iSocial curriculum. The iSocial field test lasted for 4 months. Each cohort had approximately 2 lessons per week, with 45 min per lesson.

Data Collection and Annotations

The screens of every student and the online guide were recorded for the entire set of lessons using a video recording software- ScreenFlow. Then the videos of the students and OG in the same cohort and the same lesson were synced and merged into an all-view video using ScreenFlow. Each all-view video allows the researchers to see every participant's view and the OG's view simultaneously during the lesson (see Figure 4).

Frequencies of each code for all 11 students were captured by coders using a software tool—ELAN, an open source software for the complex annotations on video and audio resources.

Table 1. Game and Non-Game Learning Activities Description.

	Description
Game activity	
#3 Lost at sea: take items	Students were on a sinking ship at sea, they need to discuss as a group to select 8 out of 20 items to help them survive.
#4 Lost at sea: go to island	Students were on the deserted island, they need to decide as a group on who is taking what chore.
#6 Restaurant buffet I	Students were in a restaurant, they needed to decide the buffet items (e.g., main dish while playing their roles as a group.
#7 Restaurant buffet II	Students were in a restaurant, they needed to decide the buffet items (e.g., dessert and beverages) while playing their roles.
#10 Role-play planning and taping	Students acted out the scenario they had written together in front of a camera inside a virtual studio.
#13 King's quest	Students were on a scavenger hunt of the King's lost items in a castle. They need to discuss using the clues to retrieve all of the items as a group.
Non-game activity	
#1 Facial expression scenarios	Students discuss how to make facial expressions matching various emotion scenarios.
#2 Facial expression share out	Students discuss and share opinions about students-made facial expressions.
#5 Sell it!	Students have discussion about sales pitches by sharing/responding to ideas in a group by using the "speaker"/ "listener" roles.
#8 Identify emotions	Students reflect on times when they had difficulty reading the emotional status of others.
#9 Emotion status discussion	Students demonstrate a range of emotions and recognize the emotions of others by planning and performing a role play.
#11 Watch and rate role play	Students discuss and rate the role plays as a group.
#12 Plan Quest activity	Students use the skills learned throughout the entire curriculum to accomplish planning the quest game as a group.

Reciprocal social interaction includes verbal reciprocal social interaction and non-verbal contributors (Wang et al., 2017). Verbal reciprocal social interaction behavior was represented with four annotations: appropriate initiation (AI), inappropriate initiation (II), appropriate response (AR), inappropriate response (IR). Nonverbal reciprocal social interaction contributors include "avatar

Figure 4. An All-View Video Screenshot.

Orientation (O)", "point or move to show joint attention (J)", "use of gesture (G)", "avatar body proximity (P)". Operational definitions of the codes are in Appendix A. Youth with ASD usually used a combination of verbal and non-verbal reciprocal interactions. For example: Tommy appropriately asked Jerry a question, and Tommy's avatar was facing Jason, and kept a good avatar proximity. The code combination for Tommy's behavior can be represented as AI, O, P.

The three cohorts of youth with ASD's social interaction behaviors in the 13 NP activities were coded. Because of attendance and technical problems, we eliminated 5 lessons from the data set, which leave us 34 NP video datasets. The overall agreement for verbal reciprocal social interaction coding is a Cohen's Kappa of .86. For nonverbal reciprocal social interaction contributors, the overall Cohen's Kappa is .92.

Data Preparation

After the video data had been processed and coded, as described in the previous section: data collection and coding, there were 34 files, each file for a learning activity of a cohort. The game condition group has 15 data files, 302 minutes in total, and the nongame condition group has 19 data files, 223 minutes in total. We processed each file into 30 second thin-sliced segments and counted each segment as a transaction. We used 30 seconds as the cut-off time constraints because it was suggested as an appropriate length for behavior analysis studies (Ambady & Rosenthal, 2004).

We performed association rule mining on both the game condition group and the non-game condition group. Although the total length of activities in game condition group is longer than non-game group, due to the nature of the curriculum, and variety of content it needs to deliver. This study is interested in examining social interaction patterns that uncovered by association rule mining.

Association Rule Mining

This work focuses on data-driven discovery of the co-occurring and contingent behavioral patterns of students learning in the game and non-game activities in iSocial 3D collaborative virtual world. The current study employed association rule mining to investigate how adolescents with ASD perform both verbally and nonverbally in the different game vs nongame learning modes where they are in 3D virtual embodied states and interacting in the virtual world.

Association rule mining is a classic algorithm in an exploratory mining approach to uncover the co-occurrence of important social behavioral characteristics and patterns (Hipp et al., 2000). Specifically, associated rule mining is employed to "extract interesting correlations, frequent patterns, associations, or causal structures among sets of items in large datasets" (p. 2). Association rule mining has been widely used in e-learning. For instance, it has been used to find associations between different learning activities so that it can be embedded in recommender agents to suggest learning activities and courses (Tan & Wu, 2018; Zaiane, 2002). Association rule mining was also applied to discover interest relationships from students' usage information in order to provide feedback to the course author (Romero et al., 2004). Others also relied on association rule mining to identify students' mistakes that often occur together to inform instructors' decision-making process (Merceron & Yacef, 2004; Oladipupo & Oyelade, 2010); and discover features to characterize students' performance disparity between various groups of students (Minaei-Bidgoli et al., 2004). Researchers also have been adopted association rule mining to discover behavior patterns in social interactions (Raihan et al., 2020; Tew et al., 2014). Similar to the previous application, this current study will also use the association rule mining to discover the verbal and non-verbal social interaction co-occurance pattern across game and non-game activities in 3D virtual world.

Most common approaches to association discovery are based on the Apriori algorithm. This algorithm discovers groups of features (verbal behaviors and nonverbal behaviors) appearing frequently together in more transactions (i.e., a set period of time).

Let $\mathrm{I} = \{i_1, i_2, \ldots, i_n\}$ be a set of literals call items, in our case, $\mathrm{I} = \{AR, AI, II, IR, O, P, J, G\}$. Let D be a set of all transactions where each transaction T is a set of items such that $\mathrm{T} \subseteq \mathrm{I}$. Let X and Y be a set of items such that $\mathrm{X}, \mathrm{Y} \subseteq \mathrm{I}$ (Agrawal et al., 1993). The resulting format of association rule mining is a set of rules expressed as

$$\mathrm{X} => \mathrm{Y}, \text{ where } \mathrm{X} \subset \mathrm{I}, \mathrm{Y} \subset \mathrm{I}, \mathrm{X} \cap \mathrm{Y} = \varnothing$$

while X and Y represent the two sets of items, such a rule indicates that social behaviors on the X are likely to co-occur with the social behaviors in the Y. This automatic discovery of co-occurrence of behavior patterns is the fundamental mechanism of association rule mining.

Support, Confidence and Lift Calculation. Association rule mining is usually applied in large-scale data settings. As a result, we could compare the number of rules discovered and the rule quality difference using the confidence metric between the game and non-game conditions. This also generated a more robust, valid, and reliable set of rules for our analysis.

Support is an indication of how frequently the itemset appears in the dataset.

$$support(X) = \frac{|\{t \in T;\ \ X \subseteq t\}}{T}$$

The strength and quality of a rule is measured by a statistic measurement called confidence. Confidence is a common quality measure used in association rule mining to indicate how certain the rule is found to be true (Agrawal et al., 1993).

$$Confidence(X \Rightarrow Y) = \frac{support(X \cup Y)}{support(X)}.$$

The lift of a rule is defined as:

$$Lift(X \Rightarrow Y) = \frac{support(X \cap Y)}{support(X) \times support(Y)}$$

If the rule had a lift of 1, it would imply that the probability of occurrence of the antecedent and that of the consequent are independent of each other. When two events are independent of each other, no rule can be drawn involving those two events. If the lift is >1, that lets us know the degree to which those two occurrences are dependent on one another, and makes those rules potentially useful for predicting the consequent in future data sets. If the lift is <1, that lets us know the items are substitute to each other. This means that presence of one item has negative effect on presence of other items and vice versa. The value of lift is that it considers both the confidence of the rule and the overall data set (Hornik et al., 2005).

Analysis of the data in the first stage provides a set of frequent itemsets. The second step is to construct the association rules from the itemsets. It is agreed that computational complexity of the problem lies within finding the frequent itemsets (Agrawal et al., 1993). The generation of association rules from this set of frequent itemsets is linear and therefore has little impact on overall performance (Denwattana et al., 2001).

Results

Descriptions of Rules in Nongame and Game-Based Activities

Through association rule mining, the non-game group generated 51 rules in total, the game group generated 135 rules. The game group has much larger number of rules than non-game group. We list some example rules in the game group in a descending order by their support and matched them with the same items in the non-game group (see Table 2).

Although the three cohorts have used avatar gesture (coded as G), avatar joint attention movement (Coded as J) during the 13 NP activities, these nonverbal social behaviors were rare, and did not come up in any rule in the non-game group. In the game group, there were only two rules {AR, J} => {AI, P} (support value 0.05) and {AR, J} => {AR, P} (support value 0.07) that included joint attention (J) and those rules had low support values. Similarly to the nongame group the game group did not include any rules that included gesture (G).

Nongame and game groups share some of the rules. We report the support values of these shared rules in Table 1. The most supported rule is appropriate ***response*** with avatar ***orientation*** and avatar ***proximity*** in both game and non-game groups. The support value for this rule is 0.64 (non-game) and 0.62

Table 2. Comparing Rules Between the Non-Game and Game-Based Learning Activities.

	Support value	
Example rules	Non-game	Game
{AR}=>{O, P}	0.64	0.62
{AI, AR}=>{P}	0.44	0.66
{AI}=>{O, P}	0.29	0.42
{AI, P}=>{AR, O, P}	0.31	0.46
{AI, O, P}=>{AR, P}	0.25	0.38
{AI, O, P}=>{AR, O, P}	0.21	0.32
{AI, O, P}=>{AR, O}	0.21	0.33
{AI, O}=>{AR, O}	0.21	0.33
{IR, P}=>{AR, P}	0.10	0.20
Total number of rules	51	135

AR stands for Appropriate Response, AI stands for Appropriate Initiation, IR stands for Inappropriate Response, II stands for Inappropriate Initiation. O stands for avatar Orient(facing), P stands for Proximity.

(game). This finding indicates that, the adolescents with ASD were almost equally likely to respond to others verbally while using avatar facing and keeping good avatar proximity in both game and nongame activities.

Appropriate ***initiations*** were co-occurring with avatar ***orientation*** and ***proximity*** as well, only this rule is less supported compared to the rule of appropriate ***response*** with avatar orientation and proximity ($0.29<0.64$ in nongame activities, and $0.42<0.62$ in game activities). This indicates that in the game as well as the nongame activities, adolescents with ASD were more likely to use the nonverbal conventions of standing close and facing the other speaker when responding to others than initiating to others. Furthermore, in the game-based activities, adolescents with ASD were more likely to verbally initiate a conversation with avatar facing the other and keeping a good proximity than in the nongame learning activities. This indicates that in the game-based activities, the youth with ASD initiate the conversation using nonverbal social cues to accent the social interactions.

Appropriate ***initiation*** and ***response*** were strongly associated with avatar ***proximity*** in both groups, especially in the game group. Surprisingly, considering that in the game-based activities, students needed to navigate their avatars around with the group to different locations of the virtual environment much more frequently than in the nongame activities, this rule is still more supported in game activities group. This indicates that students in the game-based activities were able to better maintain the social interactions with nonverbal conventions of standing close to having a conversation.

Rules such as {AI, P}=>{AR, O, P}, {AI, O, P}=>{AR, P}, {AI, O, P}=> {AR, O, P} and {AI, O, P}=>{AR, O, P}, {AI, O, P}=>{AR, O} are all more supported in the game activities. This means that in the game activities, appropriate initiation with nonverbal cues such as avatar orientation and proximity were more likely to get a response with these nonverbal behaviors.

The mean support value of the game group is higher than the non-game group. Consistently, the mean lift value of the game group is also higher than the non-game group (see Table 3). MANOVA analysis demonstrates that there is a significant difference for rule support and rule confidence between these two groups ($p < 0.01$). The effect size reflected as partial η^2 is 0.175. According to Miles and Shevlin (2001), it is considered as large effect size since the η^2 is larger than 0.14. Follow up ANOVA analysis of the two groups has a support F value of 7.1366 ($p < 0.001$) and partial η^2 is 0.106, and lift F value of 3.8723 ($p < 0.05$) and partial η^2 is 0.061. Both of them have medium to large effect sizes. The ANOVA results further demonstrate a statistically significant interaction between the effects of game/nongame-based activities on the social behaviors rules quality.

Table 3. Support Mean Value and Lift Mean Value and MANOVA Results for Game and Non-Game.

	Game	Non game
Support mean	0.23	0.12
Lift mean	1.30	0.99
p		0.003**

$^{**}p < .01$

Game-Based Activities Generated More Interaction Behavioral Rules

The Game group has a substantially larger number of rules than the non-game group (Table 1, Figure 5). This means that the game group demonstrated more diverse behavior patterns. In the game, students may have appropriate initiation or response and co-occur with a combination of avatar facing, good proximity, avatar gesture and joint attention. On the other hand, in the nongame, students' social interactions are more limited.

Game-Based Activities Demonstrated Stronger Associations of Verbal and Nonverbal Interactions

Although appropriate response (AR) has a strong association with nonverbal behaviors: orientation and proximity in both game (rule support value 0.62) and non-game activities (rule support value 0.64), other rules indicated that the co-occurrence of verbal and nonverbal behaviors is much stronger in the game-based learning activities (see Table 1). Figure 5B shows a balanced and well-connected network of rules for the game group, while Figure 5A shows a less and weaker connected network for the nongame group.

Discussion

Youth with Autism Spectrum Disorders (ASD) find it difficult to engage in reciprocal, shared behaviors and technology could be particularly helpful in supporting adolescent's motivations and skills in this area (Sarah Parsons, 2015; Stichter et al., 2013). Designing social intervention for children with ASD in 3D virtual worlds requires the integration of a complex range of factors and theories (Grossard et al., 2017; Ke & Im, 2013). Serious games have the potential of motivating and engaging learners and promoting social interactions and collaborations and eventually effective learning (Bozanta et al., 2016; Dickey, 2005; Hamari et al., 2016). Adopting serious game design approaches for implementing a social intervention curriculum in a 3D virtual environment has been gaining popularity (Abirached et al., 2012; Silva et al., 2017), however,

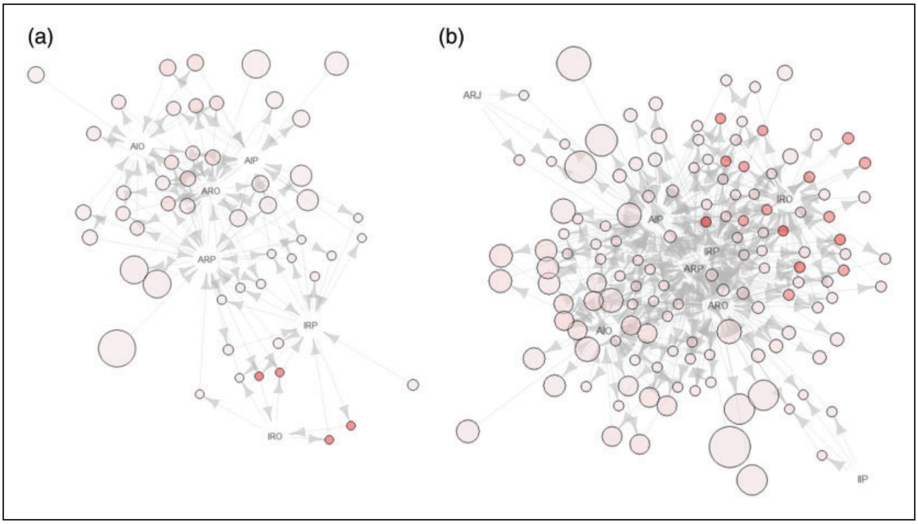

Figure 5. Rules Visualizations of Nongame and Game Groups. (A) Non-game activities rules. (B) Game activities rules.

there is only a limited amount of research on how choices in serious game design affect social interactions in 3D collaborative learning, especially for learners with ASD, in what ways the serious game design influence their social performance/behaviors in the 3D virtual world.

The current study used data mining techniques-association rule mining to examine the verbal and nonverbal social behaviors of adolescents with ASD in serious game activities and non-game learning activities in the iSocial naturalistic practice activities. The results showed rules that have stronger or weaker association for a certain instructional design.

Game Design Shapes Social Behaviors

This study responds to the call for research by Morford et al. (2014) "Specific elements of games should be investigated regarding their effects on behavior". In both the game and non-game conditions, students completed the collaborative task. However, in the game-based activities, the verbal social interaction behaviors of the adolescents with ASD have a stronger association with positive nonverbal social cues such as avatar orientation and proximity. Furthermore, the social interactions in the game activities have more diverse combinations of verbal social interaction such as appropriate/inappropriate initiation or response and nonverbal social interaction contributors such as orientation, proximity gesture and point or movement to indicate joint attention. The results also indicated that in the game activities, the students' avatar were facing the speaker more than the non-game activities. These findings demonstrate that game design facilitates attributes associated with better quality of verbal and nonverbal social interactions in the 3D virtual environment.

Serious games have proven to motivate and engage learners in learning (Berns et al., 2013; M.-T. Cheng et al., 2015). Having adolescents with ASD in a 3D virtual reality environment, where they have real-time avatars-mediated virtual interactions may be a strong simulated social interactions, but still be far from a game experience, as they lack important game-like elements (Whyte et al., 2015). However, with serious game design in a 3D virtual world, the students are offered the opportunities to explore the embedded narrative that are integrated with the target learning objectives, work with peers to have authentic social interactions and practice social skills, as well as getting instant feedback and reward from the environment.

Serious game design elements such as immersive storyline and collaborative role playing engages adolescents with ASD to be present in the virtual social interactions, and achieve the goal of improving social competence, hence having a strong chance for producing transferable real-life like verbal social interactions with nonverbal social cues.

The findings of game design facilitating desirable social behaviors of adolescents with ASD learning in the 3D virtual world echo Parsons (2015)'s finding that multi-user virtual reality games for children with autism supported being reciprocal and collaborative in their responses. This study also shows similar results as Ke and Moon (2018) that virtual reality-based gameplay promoted the social interaction performance of HFA adolescents. Moreover, this study described the association rules of adolescents with ASD's verbal and nonverbal behaviors. From a granular perspective, the research revealed the effect of game activities, in comparison to the non-game activities, on the avatar-mediated social interaction being more in conformance with real-life like social interactions. This shows the potential of transfer of social skills from the real-world to the virtual world, and from the virtual world to the real-world.

Serious Game Design in 3D Virtual World

Empirical analysis of social interactions in the virtual world might be the key to assist serious game designers in sorting out conceptual and practical frameworks to improve game design for adolescents with ASD (Hullett et al., 2012). In our study, we identified 4 essential serious game design elements for 3D collaborative learning of social competence: immersive story, collaborative role-play, visual representation of achievement and clear game goal.

A narrative storyline that elucidates the motivations of why characters in the game might be angry (and what behaviors should follow correctly identifying the emotion) is essential for linking knowledge of an emotional expression to actionable social and communicative behavior (Whyte et al., 2015). The storyline also dominates the virtual space where the team collaboration and social interactions took place. It helps the game designer decide what virtual scenario, objects, and interactive tools to put in the space. It also helps set the team in a situation where the target social interactions are transferable to the real world. For example, NP#3, where the players are in a sinking ship, the team needs to quickly decide what items to take to the island. This immersive storyline simulates a real-world negotiation that has a time constraint and pressure to make good decisions.

Collaborative game-based learning allows the learners to achieve goals with peers in the narrative-led gameplay. Bozanta et al. (2016) reported that multiplayer serious games promote team cohesiveness, which motivates learners/players to perform better in the virtual environment. For youth with ASD, the collaborative role-play particularly generated more opportunities for practicing social interactions and further achieving the goal collaboratively. Through team game play, there is enhanced communication, interaction and rapport between the youth and other team members (Goh et al., 2008).

Visual representation of achievement/reward is a gamification design element that specifically fits with the technology affordances of the 3D virtual environment (Sailer et al., 2017). The visual feedback of an achievement is instant and highly individualized. For example, when students were in the castle looking for items belong to the king. Students could see the retrieved item in the inventory panel of the gaming interface. Students could also see the number of one's own tokens on screen. Having clear goal in the game helps students stays on track with the task. Some researchers pointed out that the game settings that encourage exploration could distract learners from the social interactions of practicing the social skills that they have learned. With the specification of goal to "win" the game, students are motivated and engaged in the task at hand. For example, although there were many virtual restaurant objects around, students know they need to play their role and collaboratively build all the menu items for their restaurant.

As Goh et al. (2008) concluded, successful 3D virtual game design ensures high level of engagement. By reinforcing desired social behaviors through game play, youth with ASD learn social skills via the embodiment of human-like avatars. Not only does collaborative game promote motivation and self-efficacy, communication, interaction and rapport are enhanced, leading to better social performance outcome. Our findings show that having or not having these game design approaches leads to a significant difference in youth with ASD's social behaviors.

Implications

The implications of our research are three-fold: first, the findings of the study described adolescents with ASD social behavior patterns in the serious game versus nongame-based learning activities. The verbal and nonverbal social interactions framework is used to explain the characteristics of the avatar mediated social interactions. The results showed a significant difference in association rules of verbal and nonverbal social behaviors between the game and non-game activities, which demonstrated that game design affected how adolescents with ASD interacted in the 3D virtual environment. Social intervention curriculum that was built upon the affordance of the 3D virtual environment, with game elements embedded, can enable adolescents with ASD an enhanced level of social presence, That, in turn, provides a unique opportunity to develop high quality of social interactions that include both verbal initiations/responses and non-verbal cues. The findings are in accordance with other studies (Dasgupta et al., 2018; Ke & Moon, 2018; Lan et al., 2018).

Second, the study used data mining methods to discover patterns from a large data set of human coded social behavior as a new approach in the technology assisted learning and human computer interaction research field. Although there have been previously reports using statistical analysis of the data (Grossard et al., 2017; Hess & Gunter, 2013; Lameras et al., 2017) the prior approaches were not able to make the associations and provide confidence assessments of the associations as has been done with data mining techniques for this report. Data mining methods like association rule mining provide new methods to help researchers understand complex behavior patterns from multiple perspectives. Compared with the popular application of association rule mining in traditional e-learning contexts (Romero et al., 2004, Tan & Wu, 2018), this study extends this methodology to 3D virtual world and generate empirical evidence on its usage.

Third, the findings of the study can inform the design of serious games in 3D virtual learning environments. The understanding of how social behaviors are associated with game design elements can help guide future design of serious games in 3D virtual worlds, especially for individuals with autism. For example, narrative could be used and 3D virtual scenes that built around the narrative can support an embedded presence for learners (Whyte et al., 2015). Individuals with autism could benefit from the authenticity of the environment for practicing on-topic social interactions. The role playing during collaborative task with each role tag on the avatar could help individuals with autism take the perspective and interact with others while "wear someone else's shoe" (M.-T. Cheng et al., 2015; Sarah Parsons, 2015). The immediate feedback from virtual world, e.g., select an item and the item appears in the world, or choose a plan and the map shows up for the team, could make the learners motivated to collaborate and extend the conversation and interactions (Ke & Moon, 2018). The goal oriented game design could facilitate acquire skills of compromising and reaching to consensus among individuals with autism (Hamari et al., 2016). The link between serious game activities and higher quality of social interaction performance that this study uncovered should encourage more explorations of game theory in 3D virtual learning environment for individuals with autism.

Conclusion

In this study, we analyzed video data of iSocial-a 3D social intervention curriculum for adolescents with ASD based on the verbal and nonverbal reciprocal social interaction framework. We investigated the extent to which the affordance of serious game-based collaborative virtual learning activities have a significant influence on learners' social interactions. When compared with non-game-based learning activities, game play shaped the avatar-mediated interactions to be more realistic and conform to face-to-face interaction conventions.

Appendix

Table A1. Verbal Reciprocal Social Interaction Coding Definitions and Examples.

Codes	Definition	Examples
Appropriate Initiation (AI)	A vocal behavior clearly directed to a peer/online guide that attempts to occasion a response, including greeting, asking and answering questions, commenting, sharing materials, helping behavior, saying someone's name	One student said, "Hi Joe." Or When students were talking about restaurant choices, one student said, "how about we make a vote?"
Inappropriate Initiation (II)	A vocal behavior directed to a peer/online guide that does not meet the definition of an appropriate initiation (for reasons such as: topic being contextually irrelevant, perseverative, socially inappropriate, or an inappropriate interruption).	When the group was talking about choosing roles on a deserted island, one student said, "hey, do you guys want to hear what I did last weekend?"
Appropriate Response (AR)	A vocal behavior that acknowledges an initiation within 3second (e.g. answering when name was called, responding to a comment, answering a question)	A student said, "yes" when online guide asked him if that's his final answer.
Inappropriate Response (IR)	A vocal behavior that inappropriately acknowledges an	A student was responding to another student's question to

(continued)

Table A1. Continued.

Codes	Definition	Examples
	initiation within 3 seconds (e.g. providing a response that is off topic, using inappropriate tone of voice or voice volume) The initiation can be either verbal, gestural, or stimulus prompt (e.g. task)	online guide "come on, what a stupid question!"

Table A2. Nonverbal Reciprocal Social Interaction Contributors Coding Definitions and Examples.

	Codes	Definitions	Examples
Nonverbal contributors	Orient	"1" Orient his/her avatar to face the person/group when he/she makes an initiation or response	• Josh said to Jim, "hi Jim, what do you think about the decision" meanwhile Josh's avatar was facing Jim's avatar.
		"0" avatar was not facing the person/group when the student makes an initiation or response	• When Joe heard Matt was saying " hey Joe, how's your weekend", Joe's avatar was facing the wall and said "pretty good".
	Joint	"1" Indicating joint attention to a certain object by moving toward/near the object or pointing the object using tele-pointer while make an initiation or response	• Matt said to Joe, "hey, do you see the wall decoration, it's over here right behind you" while Matt moving his avatar to stand by the wall.
		"0" there is no nonverbal means to indicate joint attention while make an initiation or response	• Stephen was responding to Joe "yes, I see that" with his avatar standing still in the learning area.
	Proximity	"1" Maintain appropriate body proximity during initiation or response	• Joe's avatar was standing not too near or too far (an avatar arm length) from Matt when Joe initiated a greeting.
		"0" student did not have an appropriate avatar body proximity during initiation or response	• Ron's avatar was standing across the room when he initiate to the group "Do you all agree with me?"

(continued)

Table A2. Continued.

Codes	Definitions	Examples
Gesture	"1" Use appropriate gesture to accent the initiation or response	• Jim said, "Hi Jaclyn" while use the "wave" gesture. • Matt used "shaking hand" while responding to Joe: "Nice to meet you too"
	"0" the student did not use gesture to accent the initiation or response	• Terry initiated to Bob "I think we should choose option NO. 1 because. . ." with no avatar gesture

Ethical Approval

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed Consent

Informed consent was obtained from all individual participants included in the study.

Declaration of Conflicting Interests

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