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DEVELOPMENT ARTICLE

Fostering verbal and non-verbal social interactions in a 3D collaborative virtual learning environment: a case study of youth with Autism Spectrum Disorders learning social competence in iSocial

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Abstract This case study describes the verbal and nonverbal social interaction of 11 youth with Autism Spectrum Disorders in a 3D Collaborative Virtual Learning Environment—iSocial. The youth were developing social competence through participation in a social competence intervention curriculum implemented online so as to provide access to high quality instruction for youth in small and rural communities. The data show the ability and variability of verbal and nonverbal reciprocal social interactions while online. In addition, the results of this case study revealed associations between pedagogical design features of the iSocial 3D CVLE, such as, goal-oriented, narrative embedded, game/role play enriched and peer-supported 3D CVLE activity design and higher frequencies and better quality of reciprocal social interaction. Therefore, these findings have potential to inform future design of 3D social learning spaces.

Keywords Social interaction · Autisum · 3D collaborative virtual environment · Verbal and nonverbal interaction · Learning environment design

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Introduction

3D collaborative virtual learning environments (3D CVLEs) have the potential to engage learners in a local context or from around the globe. 3D CVLEs simulate real world environments with objects, landscapes and people and allow users to interact, communicate and collaborate via avatars. The power of utilizing collaborative virtual learning rather than simply implementing single-user 3D environments is to address learning needs that require social interaction to build competencies and to use the benefits of social learning to motivate and enrich learning. Researchers have begun to explore, with some promising results, the ability of youth with Autism Spectrum Disorders (ASD) to learn social skills via 3D CVLE (Cheng and Ye 2010; Mitchell et al. 2007; Parsons et al. 2005; Schmidt et al. 2012). The potential benefits of learning in 3D CVLE for youth with ASD are that they will be able to learn social competence in a simulated and controlled environment by engaging in authentic practice and role-playing without suffering real-world consequences and in some formats without trying the patience of their peers or teachers (Standen and Brown 2006).

The Social Competence Intervention-Adolescents (SCI-A) is a 10-week face-to-face, small-group, expert facilitator-led curriculum with demonstrated impact for improving social competence. SCI-A has been implemented as a technological translation in iSocial 3D CVLE in order to support more youth with ASD who live in geographically distributed areas in the state (Laffey et al. 2014; Laffey et al. 2009; Stichter et al. 2014). After the translation, the iSocial curriculum and iSocial environment provide the combined benefits of the effectiveness of SCI-A curriculum and the advantages of 3D CVLE (Schmidt et al. 2011; Schmidt et al. 2012; Stichter et al. 2010). The iSocial curriculum is designed to improve the social skills of youth with ASD through fostering authentic reciprocal social interaction during lessons. The curricular approach to teaching and learning depends on social interaction and conversation among students and with the online guide (expert facilitator). One of the teaching objectives of iSocial curriculum is to foster substantial and appropriate student initiations and responses during lessons.

Schmidt et al. (2012) developed methods to identify and code reciprocal social interactions in 3D CVLEs such as iSocial. In addition, behavioral attributes such as verbal, movement, action, gesture, text and other are also coded for the purpose of a richer description of social interaction in 3D CVLE. The work of Schmidt and colleagues contributes to our understanding of social interactions of youth with ASD in 3D CVLE. The current study followed Schmidt and colleagues' methods and extended them by including key nonverbal behaviors that serve to accent and regulate initiations and responses.

This research was designed as a case study, due to the need for rich description of emergent behavior of the verbal and non-verbal social interaction of youth with ASD in the complex context of the iSocial CVLE (Yin 2014). The purpose of this exploratory case study is to describe youth with ASD's verbal and nonverbal reciprocal social interactions in iSocial 3D CVLE. Furthermore, findings of the characteristics of verbal and nonverbal reciprocal social interactions allow the authors to draw implications to inform design and development of 3D CVLEs and learning activities within 3D CVLEs to foster desired social interactions among learners.

iSocial

As mentioned previously, iSocial is a 3D-CVLE-based intervention for social and behavioral outcomes for youth with ASD. iSocial seeks to translate and implement in a 3D-CVLE 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). Initial 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 challenges thinking patterns and includes the following key components: theory of mind, emotion recognition and executive functioning. 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. 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. Therefore, because this part of the curriculum offered the greatest freedom for student independent action (not specifically directed by the online guide or scaffolding) we chose to focus on analyzing data from the Naturalistic Practice activities of the curriculum.

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 1 shows snapshots of students participating in lessons in iSocial.

Literature review

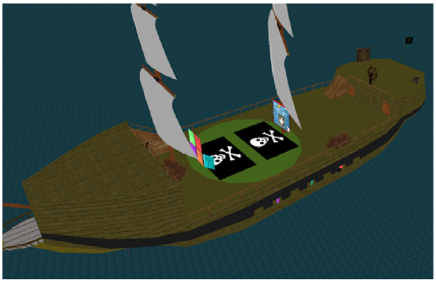
Characterizing social interactions in 3D collaborative virtual learning

Social interactions of learners in 3D CVLE hold the key for successful collaborative virtual learning (Monahan et al. 2008; Montoya et al. 2011; Vrellis et al. 2012). However, in order to promote social interactions in 3D CVLE we first need to understand social interactions. Some researchers claim that interactions in 3D CVLE have great likeness to real life social norms (Bailenson et al. 2006; Yee et al. 2007). It is becoming apparent that just as in real-life interaction, there is not one specific characteristic of social interactions in 3D CVLE that is determinative of high or low quality interaction and presence. Researchers have started to explore methods to understand and describe the complex social behaviors of learners during their social interactions in 3D CVLE.

Schroeder et al. (2006) investigated the usability of 3D CVE designs. The researchers summarized two studies that developed methods for analyzing interactions in collaborative virtual environments: one is quantitative analysis of sequences; another is analysis of interaction transcripts. For the first method, the researchers coded all observable/identifiable single acts or behaviors in the learners' interaction into eight basic categories: communicate (C), external (E; i.e., person relates to an event in the world outside the VE), gesture (G), manipulate (M), navigate (N), position (P), scan (S), and verify (V). Then the frequency and sequence of these codes were analyzed using statistical methods (Tromp et al. 2003). For the second method, the researchers analyzed the content of learners' verbal communication when collaborating in the virtual environment. The interaction

(a) Students were learning "emotion ranges". They were in the main learning area with peers and the Online Guide.

(b) Students were discussing which option for their restaurant's main dish. The dishes can appear and disappear from the environment interactively.



(c) The ship environment from a chase camera view. Learning activities took place on the deck and the cabin of the ship.

(d) Students were discussing their roles for the "lost at sea" activity inside a virtual ship. They then go through a portal to a virtual island.

Fig. 1 Example screenshots of students participating in the lessons in iSocial

fragments show a number of important differences between types of tasks and the experience of collaboration. For example, participants sometimes respected social conventions, as when they faced each other, and sometimes did not, as when running through each other. How the avatar was treated depended not only on the circumstances or the task, but also on when the interaction between avatars took place: at the beginning of the session, participants commented on each other's appearance, wanted to know about their own appearance, and made jokes about this. During the collaboration, and when the focus was on objects, people did not comment or care about each other's avatars except as points of reference in relation to the task. This method of analysis was identified as advantageous as it provides great details about the interaction, making sense of the whole scene and the dynamic within it (Steed et al. 2003). In Schroeder et al.'s study the first method revealed that both verbal and non-verbal behaviors were playing crucial roles in collaborative activities. Non-verbal behaviors, such as, navigate, position (proximity), gesture, and manipulate were often used by learners during collaboration. The second method that focuses on the content of the verbal/text social communication yielded results that inform the researchers about how the students were performing the learning task and collaborating with others in the virtual community.

Other researchers also discovered interesting findings of the characteristics of non-verbal social interactions in 3D CVLE. Friedman et al. (2007), Guye-Vuillème et al. (1999) and Bailenson et al. (2003) investigated interpersonal space or avatar proximity during social interactions in a 3D multi-user virtual environments and immersive virtual environments. Freidman and colleagues developed software bots that inhabit the popular 3D online social environment Second Life. The bot can wander around, collect data, engage in simple interactions, and carry out simple automated experiments. In their study, bots collected data from 20 different locations in Second Life. From the data collected by the bots the researchers identified 49 pairs of avatars interacting. An analysis of the avatar distances revealed that the distances between two interacting avatars were varied but within a reasonable range (3–10 virtual feet). In addition, in an automated experiment carried out by the bots, the researchers found that users, when their avatars were approached by a bot, tended to respond by moving their avatar away from the bot, further indicating the significance of proximity in avatar mediated interactions. In Guye-Vuillème's study, when observing the interaction of participants in an 3D CVLE, the researchers described, "The avatars of J (male) and L (female) collided with each other. They naturally apologized and then laughed off the experience" (Guye-Vuillème et al. 1999). Bailenson et al. (2003) also had similar results from experiments in an immersive virtual environment that confirm the important role of interpersonal space in social interactions in 3D virtual environment.

Talamo and Ligorio (2001) investigated the construction of identities in a 3D CVE using ethnographic and conversational methodology to analyze the verbal social interactions. The task of the multicultural participant group (N = 48) was to build a community in Euroland, a 3D collaborative virtual environment in 8 months. The researchers applied conversational analysis methods to analyze interactions of the "Eurolanders" by coding the recorded chat. It was found that identity construction was heavily context dependent and identities were not static but negotiated in interactions. Many strategies for playing with different identities and making them distinct were observed-most commonly that of trying different avatars.

Schroeder et al. (2006) suggested that methods that analyze frequency of the discrete behaviors and methods and that analyze the interaction transcripts for learning contexts can be combined. In other words, both the verbal and non-verbal communication during collaborative learning activities in 3D VLE should be captured. From the studies reviewed, we learned that in 3D collaborative virtual learning, gesture, body posture, avatar proximity, and movements are most often identified as non-verbal communication means that indicate additional information, emotions, level of social presence and quality of social interaction of the users (Bailenson et al. 2003; Guye-Vuillème et al. 1999; Lim et al. 2006).

Reciprocal social interaction of youth with ASD

Social interaction is defined as a reciprocal process in which people effectively initiate and respond to social stimuli presented by others (Merrell and Gimpel 1998; Shores 1987). The reciprocal social interaction model (Patterson 1970) is widely used in interpreting and representing interaction of youth with ASD (Barry et al. 2003; Bauminger 2002; Brewton et al. 2012; Freedman and Silverman 2008). Similar to a two way street, initiation and response are two components of social interaction. In order to start an interaction, youth with ASD must initiate to a peer, also they must respond to the social behavior of a peer to sustain the interaction (Hauck and Fein 1995; Strain et al. 1977).

It is well documented that the social participation of youth with ASD in peer interaction is typically low in frequency and poor in quality (Bauminger 2002; Mundy et al. 1986). Generally speaking, high-functioning youth with ASD are more likely to initiate and respond compared with low-functioning youth with ASD. However, the quality and frequency of such social behavior is still different between high functioning children with autism and typically developing children (Lord et al. 1994). Youth with ASD lack the ability to identify and act on nonverbal social cues and social prompts which tends to result in displays of socially unacceptable behavior (Barry et al. 2003; Shores 1987).

Bauminger (2002) evaluated the effectiveness of a face-to-face 7-month cognitive behavioral intervention for the facilitation of the social-emotional understanding and social interaction of 15 high-functioning youth (8–17 years old) with autism. Observations of social interaction were used to assess changes in the child's actual social behavior. The observed social behaviors include social initiation, social response, positive/negative/low-level social interactions. The responses were defined as both verbal and nonverbal (gesture, body movement, and eye contact). The results showed that children with high functioning autism were more likely to initiate positive social interaction with peers after treatment; in particular, they improved eye contact and their ability to share experiences with peers and to show interest in peers.

Both verbal and nonverbal aspects of reciprocal social interaction are equally important (Knapp and Hall 2009; Mundy et al. 1986). In 3D CVLE, the opportunities for a more real-life like interactions for youth with ASD call for researchers to develop methods to understand social interactions in this new contexts and to use that understanding to inform the design of 3D virtual learning activities.

Understanding reciprocal social interaction of youth with ASD in 3D CVLE

For a 3D CVLE like iSocial, there are substantial challenges to fostering social interaction among the youth and between the youth and the online teacher. Understanding reciprocal social interactions of youth with ASD in 3D CVLE leads to insights for how to improve 3D collaborative learning activities to better support the unique characteristics of youth with ASD and foster verbal and nonverbal social interaction. 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. There is little previous research to guide design decisions. Research on exploring social interactions of youth with ASD in a 3D CVLE is rare. Cheng and Ye (2010) and prior work on iSocial such as Schmidt et al. (2012) are the most prominent studies to shed light on the design of the environment and activities to foster social interaction in this context.

Cheng and Ye (2010) explored social competence of three students with ASD in a 3D CVLE. The CVLE-social interaction system used in the study involves a 3D expressive avatar, an animated social situation, and verbal as well as text-communication. The researchers measured the understanding and use of an emotional avatar by the participants in the 3D virtual environment. The researchers also used Social Situation Pictures(SSP) as the material for the participants to demonstrate reciprocal social interactions with the researchers in the real world after the intervention. SSP (Howlin et al. 1999) provide social scenes which depict emotions, social behaviors and interactions so as to act as a stimulus for the students to recognize attributes of interactions. Frequency of the correct answer to SSP, appropriate eye contact, appropriate manner and ability to listen to others were coded by the researchers. The experimental study consisted of 17 days and 40 min for each participant per day. The results showed that using the CVLE-social interaction system had significant positive effects on participants' performance, both within the CVLE social interaction system and in terms of reciprocal social interaction in the real world.

However, in the Cheng and Ye study, the students did not actually interact with peers and have conversations in the 3D CVLE, instead, the students were interacting with the teacher/researcher by typing text and choosing the emotional avatar to match the animated scenarios. Reciprocal social interaction assessment was conducted in the physical world when the participants were interacting with the researchers. Therefore, their study did not investigate the authentic real-life like verbal and non-verbal social interactions of youth with ASD during 3D collaborative virtual learning world (Cheng and Ye 2010).

The iSocial project has developed methods and applied them in order to understand social interaction in the 3D CVLE. For example, Schmidt et al. (2012) developed methods to represent reciprocal social interaction of youth with ASD in iSocial. The researchers developed a two-level coding scheme: (1) “interaction model” that includes verbal initiation, verbal response and verbal continuation and represents them as socially appropriate or inappropriate, (2) “interaction mode” that identifies every behavior of the participants, including: verbal, movement, gesture, action, text. The researchers’ pilot study found that the coding methods represented participant behavior at a very detailed level which helped to explain how well the youth were meeting and progressing on expectations for certain forms of social behavior, as well as to pinpoint the contexts and activities that best promote the types of behavior that the social skills curriculum teaches, both at an individual level and in comparison to one another. For example, the researchers found the dominant mode of interaction was verbalization and the dominant reciprocal social interaction element was response. Their report describes an approach to collecting and representing discrete behaviors of individuals interacting within activity and learning contexts.

Schmidt et al.’s work has been innovative and provides a substantially greater amount of detail about student social behavior than prior research. However, their adaptation of the reciprocal social interaction framework to represent youth with ASD social interactions in 3D CVLE has several limitations. The researchers’ methods did not fully account for the social meaning of nonverbal behaviors in 3D CVLE. They did in fact code non-verbal behaviors like movement, gesture, and action, but most of these codes are not interpreted as a part of the reciprocal social interaction framework. These nonverbal behavior codes are just a way to capture behavioral characteristics in 3D CVLE in a broader sense, but did not count as a meaningful component in the reciprocal social interaction framework. Finding ways to integrate the non-verbal codes into the reciprocal social interaction framework has potential to provide a more comprehensive description of social interaction in 3D CVLE.

As Schroeder et al. (2006) pointed out, in 3D collaborative virtual learning, nonverbal discrete behaviors should be interpreted in the context of the social interactions and activity. The combination of meaning from the verbal communication and the non-verbal communication can give an enriched understanding of reciprocal social interaction in a 3D CVLE (M. Schmidt et al. 2012). From pilot analysis of iSocial data, literature focusing on nonverbal social behaviors in 3D CVLE (Cobb et al. 2002; Parsons et al. 2005; Tromp et al. 2003; Yee et al. 2007) and literature focusing on nonverbal reciprocal social interaction of youth with ASD in face-to-face settings (Barry et al. 2003; Mundy et al. 1986), we created a preliminary set of non-verbal contributors, which are defined in the method section later, to understanding reciprocal social interaction. Avatar Orientation, Avatar Proximity, Avatar Gesture, Avatar Joint Attention, Stay in the Group and Keep a Calm Avatar were identified as the most probable prominent nonverbal contributors to reciprocal social interactions in iSocial 3D CVLE. See Fig. 2 for a schematic of non-verbal contributors to Reciprocal Social Interaction model.

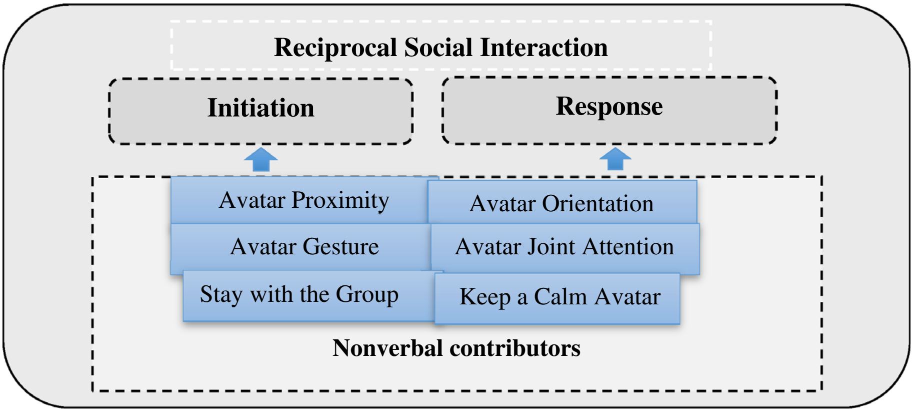


Fig. 2 Reciprocal social interaction model for iSocial 3D CVLE

Research questions

To understand the complex nature of social interactions among youth with ASD in iSocial and to build insight for the design and development of 3D CVLE, the research questions of this case study are:

(1) What are the characteristics of verbal and non-verbal reciprocal social interactions of youth with ASD across the variety of Naturalistic Practice activities in iSocial 3D CVLE?
(2) What are the implications for future design of 3D virtual learning activities so as to foster social interactions of youth with ASD when learning in 3D CVLE?

Methods

Participants

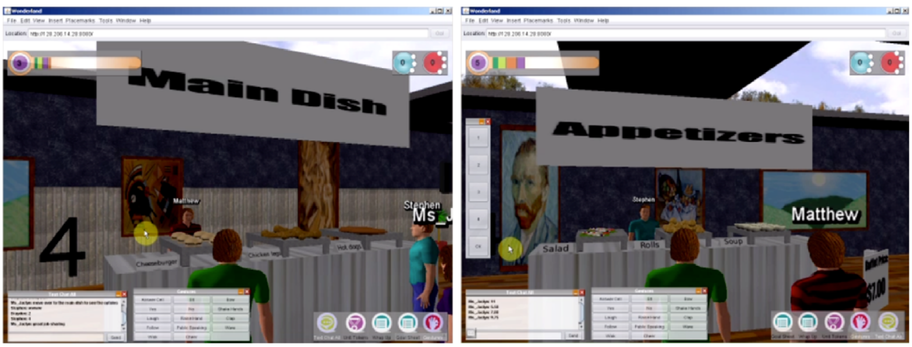
Participants were eleven youth aged from 11 to 14 who were diagnosed with Asperger's syndrome with the Autism Diagnostic Interview Revised (ADI-R) (Rutter et al. 2003) and/or the Autism Diagnostic Observation Schedule (ADOS) (Lord et al. 2002). Additionally, an IQ of 75 or above and capable of speech were required for participation. These 11 participants were all male as are most youth with the ASD diagnosis and were full time middle-school attendees with at least some general population classes. Participants were from three different school districts, including 2 small and rural districts, in the mid-west area of the United States. The districts ranged in size from a school population of approximately 1800 to a population of 4500. The districts ranged between 40 and 70% of students qualifying for free and reduced lunch. The iSocial study received IRB approval and participation was approved by district administrators, principals, teachers, parent and youth. Selection for participation in the study was based on meeting diagnostic criteria for Asperger's syndrome, determination of need for services by administrators and parents and assent by students. All students who were invited to participate did so.

Participants in the same school district were formed into a cohort and took the course together. Cohort 1 has 3 students and Cohorts 2 and 3 have 4 students. A cohort was taught by the same teacher, an online guide (OG) in the 3D CVLE, who was highly trained in teaching social competencies for youth with ASD. The OG interacted with the students in the 3D CVLE and just like a teacher in a small group setting guided the students through the series of activities of each unit. The OG was the instantiation of the expert facilitator of the SCI-A curriculum when implemented for face-to-face instruction. The work of the OG was supported by various online tools such as webcam views of the students, timers, notepads, and scoreboards for giving and representing credits and demerits. The three cohorts went through the same iSocial curriculum.

Naturalistic practice activities

The context for this case study was a field test of the iSocial curriculum in three school districts. While the cohorts of students were all from the same school districts, they were separated and conducted all of the iSocial activity on computers linked by the Internet. The testing was set up to simulate the experience of having youth from various small and rural schools working in a cohort over the Internet. The iSocial curriculum lasted for 4 months. Each cohort had approximately 2 lessons per week, with 45 min per lesson. Students were first trained on how to navigate avatars, interact with objects, use curricular tools, and follow behavior rules in the 3D CVLE during two orientation sessions. Then, they went through 5 units of curriculum: facial expression, sharing ideas, turn taking in conversation, emotions and feelings, and problem solving, with each unit building upon the previous skills. Each unit contained 5–7 lessons.

Naturalistic Practice was a curricular component of the later lessons in a unit in which students were encouraged to speak freely and discuss with the group about the challenging activity they were being asked to undertake in iSocial. The NP activities were chosen as the data source for this case study because they were the stage in the curriculum when students had the greatest opportunities to interact with their peers in natural ways for accomplishing authentic social tasks. In NP activities, students were facilitated by the online guide, to complete certain tasks that require using the social skills learned in the prior units and lessons to collaborate, discuss, evaluate, negotiate and eventually complete a task. Naturalistic Practice activities were primarily student-led activities that required students to work as a group to achieve the activity goal. See Fig. 3 for illustrations of a cohort at work.



(a) Students were discussing option #4 for main dishes.

(b) Students were deciding what appetizers they want for their buffet.

Fig. 3 A student's screen during the buffet naturalistic practice activity

In these five units, there were 30–62 total minutes of NP activities in each unit. NP activities lasted from 10 to 33 min. See Table 6 in Appendix for descriptions of the NP activities in the iSocial curriculum.

Research design

Because we were interested in describing the characteristics of behavior and exploring for emerging patterns of behavior in a complex and extended (multiple occasions) context we adopted a case study design, using NP activities of iSocial curriculum as units of analysis (Yin 2014). The study was descriptive and exploratory in nature, and was conducted in the context of youth with ASD learning social competence in a 3D CVLE-iSocial. The data source for this case study were observations of participants' verbal and non-verbal social interactions in 13 NP activities of iSocial curriculum.

Data collection

The screens of all participants were recorded for the entire set of lessons using the video recording software ScreenFlow. After each field test, the videos of the students and OG in the same cohort and the same lesson were synced and merged into an all-view video for that lesson using ScreenFlow. Each all-view video allows the authors to see every participant's view and the OG's view simultaneously during the lesson. All-view video were then edited to cut off any other part of the lesson that was not NP activity. Due to some technical errors that happened during the NP activities, such as client crash, screen frozen and audio issues that kept a student or students from participating in NP activities, the all-view videos that have two or more students having these severe technical errors were excluded from analysis. Also, during a lesson, if two or more students were absent for that lesson, the all-view video was also excluded. The reason to do so is that each cohort in our study has only three to four students, if two or more students could not participate in the NP activity, then the form of collaboration and social interaction for the NP activity is likely different than the typical form which is the subject of this study. As a result, 5 videos from the total number of 39 videos (13 NP video per cohort) were excluded.

Data analysis

Students' verbal and non-verbal behaviors were coded based on the reciprocal social interaction model, which includes both verbal reciprocal social interaction and nonverbal reciprocal social interaction contributors. Ten-minute segments were used for coding to allow normative comparisons and account for the shortest duration of an NP activity.

Coding verbal reciprocal social interaction

There are five codes for verbal reciprocal social interaction: appropriate initiation (AI), inappropriate initiation (II), appropriate response (AR), inappropriate response (IR), and non-response (NR). See Table 1. 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 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 3 s (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 initiation within 3 s (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)	A student was responding to another student's question to online guide "come on, what a stupid question!"
Non response (NR)	A vocal response is expected but the participant fails to acknowledge the interaction in any way within 3 s	A student was typing on media board and did not respond to his partner's question within 3 s

Coding nonverbal reciprocal social interaction contributors

There are 6 nonverbal reciprocal social interaction contributors: "Avatar Orientation", "Avatar Joint Attention", "Use of Gesture", "Avatar Body Proximity", "Keep a Calm Avatar" and "Stay With the Group". For the first 4 nonverbal reciprocal social interaction contributors: Orient, Joint, gesture, proximity, they were coded as either "1" or "0". A code of "1" means this contributor is present and "0" means this contributor is absent. See Table 2 for coding definitions and examples.

After coding the four nonverbal contributors that correspond to each initiation and response, the authors coded Stay with the Group and Keep a Calm Avatar based on the student's overall performance on these two nonverbal contributors across the whole NP activity. Different from coding Orient, Joint, Gesture and Proximity, the coder watched the whole NP activity video then rated Stay with the Group and Keep a Calm Avatar contributors for each student using a 0–2 scale. Stay with the Group contributor indicates to what extent the student's avatar was staying with the rest of the class during the activity. Keep a Calm Avatar contributor indicates to what extent the student used the gesture and movement of the avatar appropriately."0" was given when contributor was observed rarely, "1" was given when the contributor was observed present moderately and "2" was given when the contributor was observed present throughout the activity. The list of

Table 2 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?"
	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

descriptors that follow it provide a detailed representation of the scales (Table 7 in Appendix).

Inter-rater agreement

According to Kazdin (2011), central to the collection of direct observation data is evaluation of agreement among observers. Inter-rater agreement, an indicator of reliability, refers to the extent to which observers agree in their identification and classification of behavior. In this study, 3 raters were involved in the coding process. The raters were all Ph.D. students hired as assistants on the iSocial project and were trained on the specific coding methodology as well as appropriate IRB considerations. 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.

Results

Verbal reciprocal interaction

The durations for the 13 NP activities ranged from 6 min and 30 s to 30 min and 17 s. To make the reciprocal verbal interaction frequency comparable across NP activities that have different durations, the authors calculated each student's appropriate and inappropriate verbal interaction frequency on a 10-min duration period for each NP. See Figs. 4 and 5.

The two figures showed students had substantially lower inappropriate verbal interactions, compared to appropriate verbal interactions.

Figure 6 shows that NP3, NP10, and NP 13 have the highest levels of verbal frequency (median frequency > 22.5). NP 1, 4, 6, 5, 7, and 12 can be characterized as having medium levels of verbal frequency. And NP 2, 8 and 11 have relatively low levels of verbal frequency (median frequency < 15) (Figs. 7, 8).

Student initiation frequency is lower than response frequency. The 11 students' average appropriate initiation (AI) varies from 3.01 to 8.28 across all NP activity. Eight out of 11 students have average AI frequencies that are less than 5. While students' average appropriate response (AR) frequencies in NP activities varies from 10.47 to 31.24, except for Brandon, who has an average appropriate response frequency of 6.17.

Nonverbal reciprocal social interaction contributors

The findings reveal that students rarely use gesture in most of the NP activities. Only in NP 13 did most students use some gestures during the activity. In NP 1–NP 12, almost none of the students used any gestures during initiation and response.

There were only a few NP activities where students used non-verbal means to indicate joint attention. Findings indicate that students in NP 3, 4, 6, 7, 10 and 13 used nonverbal means to indicate joint attention, while in the rest of the NP activities there were few nonverbal behaviors indicating joint attention.

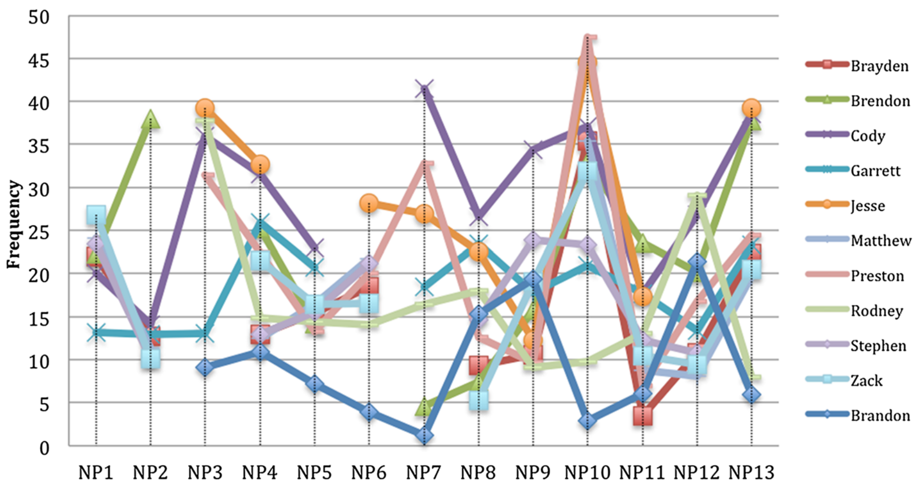


Fig. 4 Students' appropriate verbal interactions frequency across NP activities (Color figure online)

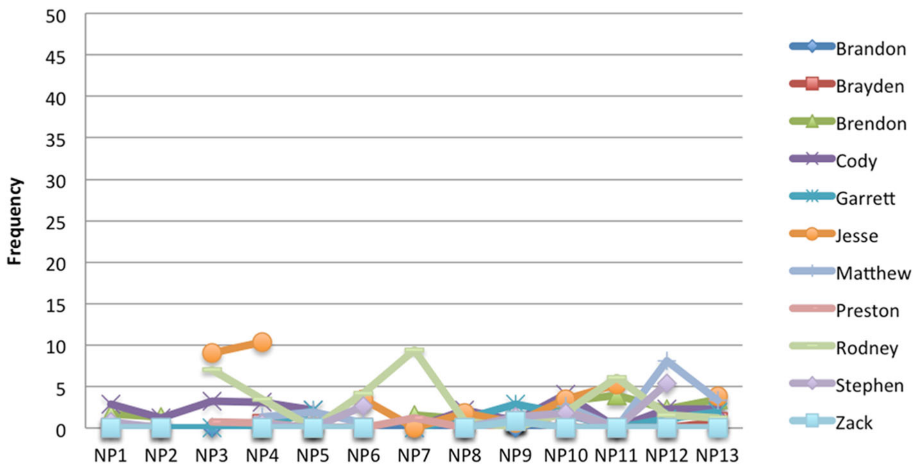
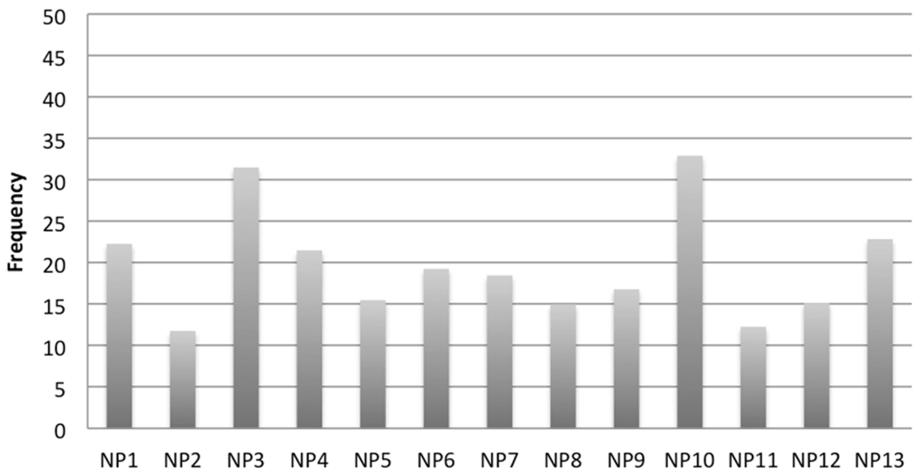


Fig. 5 Students' inappropriate verbal interactions frequency across NP activities (Color figure online)



High verbal interactions	NP3, NP10, NP13
Medium verbal interactions	NP1, NP4, NP6, NP5, NP7, NP12
Low verbal interactions	NP2, NP8, NP11

Fig. 6 Students' median verbal interactions frequency across NP activities

However, all students (n = 11) kept appropriate avatar proximity with peers and the Online Guide most of the time across NP activities. Students also did well on staying with group and keeping a calm avatar.

Avatar orientation results showed variation across NP activities. Figure 9 shows the average percentage of students orienting their avatar to face the avatar that they were initiating with or responding to. The activities in which students had overall high percentages of orienting avatar are NP 2, 11, and 9. And the activities in which students had overall low percentages of avatar orientation are NP 1, 8, 10, 12.

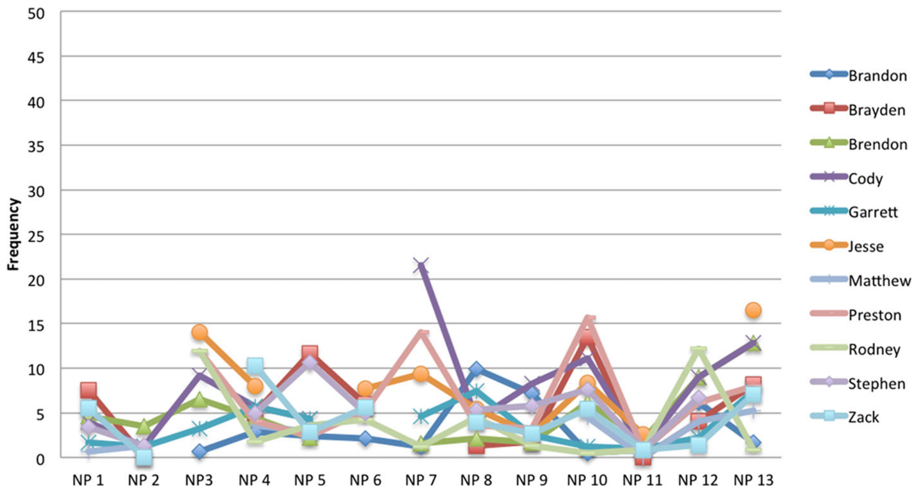


Fig. 7 Students' appropriate initiations across NP activities (Color figure online)

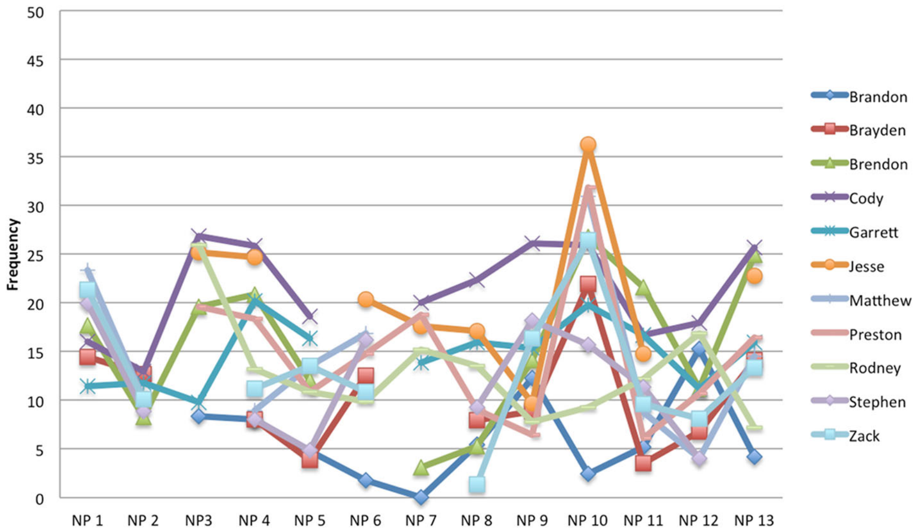


Fig. 8 Students' appropriate response across NP activities (Color figure online)

The NP activities 1, 8, 10 and 12 are activities that require students to have discussions with each other based on the information on a shared board or wall. Actions on the shared board or wall are also required. For example, in NP 1 students need to use the mediaboard to take a picture of themselves. In NP 8, students need to type answers on the sticky note. In NP 10 students need to fill in the role-play questions on the mediaboard. And, in NP 12 students need to move the number sticker to the correct position on the castle map.

In these cases, students needed to orient their avatar to the shared board or wall to get the information for discussion. These shared board and wall activities reduced the number of times that students voluntarily faced each other during interaction. See screenshots for these NP activities in Table 3.

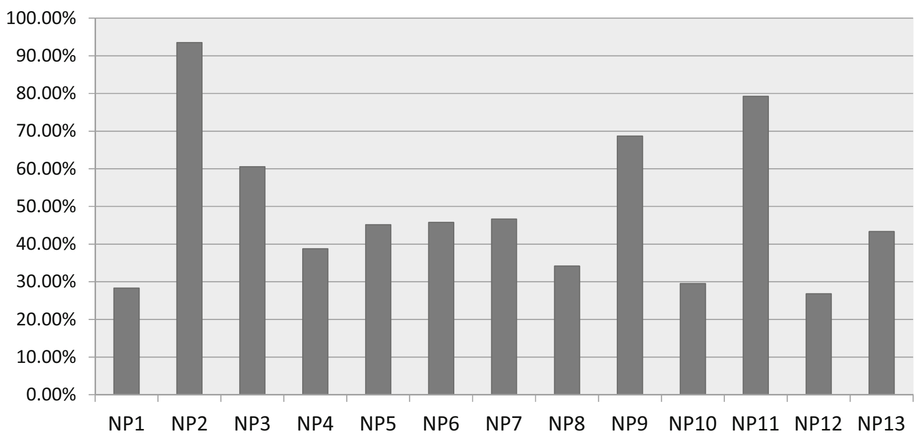


Fig. 9 Orientation percentage per student across NP activities

Emerging pedagogical design features

After comparing appropriate verbal interaction frequencies across NP activities, a few NP activities (NP 3, 10, 13) stand out as having high numbers of reciprocal social interactions among students, while NP activities (NP 2, 8 and 11) have low reciprocal social interaction frequency. See a description of these NP activities in Tables 4 and 5.

Table 3 Screenshots of low percentage avatar orientation activities

Table 4 Descriptions of high RSI frequency NP activities

NP #3	"Lost at sea"—choosing items The students and the Online Guide were on a virtual ship in the sea. The ship is slowly sinking. Fortunately, there is a deserted island nearby. Students need to negotiate together to choose 8 out of 20 items on the ship to take with them to the island before the ship sinks
NP#10	"Role play act-out"—choose emotions and act out in front of camera Students pretend to show emotions of different scenarios and act in front of a camera. They took different roles to act out a play. Different roles have different emotions (happy, sad, scared, etc.)
NP#13	"Quest in King's Castle"—collect cues to retrieve King's lost items Students work together in the quest to find the King in the virtual castle. They need to go to different locations as a group in the castle to collect all the King's missing items based on the clues

Table 5 Descriptions of low RSI frequency NP activities

NP #2	Facial expression—discussing the pictures In a virtual room, students' avatars were standing in front of the Mediaboard and discussing the pictures they took in NP 1 and using TSM (Triangle Scanning Method) to explain how the pictures of themselves show the emotion they want to express
NP#8	Emotion and feelings—discussing the emotions In a virtual room, students' avatars were standing in front of the StickyNote and discussing the emotional status of people described in the given scenarios written on the Sticky Note
NP#11	Rate video recordings—watch role play recording In a virtual room, students' avatar stand in front of a Media player to watch the video recordings of the role play that was recorded in NP 10. Then students fill out and submit the pop up video rating sheet

From the NP activities description, some pedagogical design differences emerge: The higher number of reciprocal social interactions happened in NP activities that adopted a "game-play" design. According to Dickey (2006), "game-play" design employs a variety of strategies that lead to engagement, which may include role playing, narrative arcs, challenges, and interactive choices within the game, as well as interaction with other players. Also, the activities are more open-ended and exploratory for the students. For example, NP 3, 10 and 13 all include elements like narrative/storyline, role play, interactive choices and collaborative team goals. However, in NP 2, 8 and 11, the activities do not have narrative, nor any role-playing design element. Students were to recall and respond to questions.

Discussion

3D collaborative virtual environments provide support for multiple learners in different physical locations to interact and collaborate synchronously (Dalgarno and Lee 2010; Lim et al. 2006). Learners interact through their human-like avatars with avatar representations of other learners within the social context provided by the 3D CVLE (Falloon 2010). 3D collaborative learning is believed to be effective only when the learners engage in social interactions and collaborate with others (Montoya et al. 2011). Recently, 3D CVLEs have been implemented to support leaners in various learning disciplines (Ketelhut 2007; Lim et al. 2006; Vrellis et al. 2012). Youth with ASD learning social skills in 3D CVLEs have also been studied and the use of 3D CVLE has been found to have potentially promising results (Cheng and Ye 2010; Cobb et al. 2002; Schmidt et al. 2012). Using collaborative environments as a vehicle for providing social encounters and social interactions for youth with ASD, albeit in a virtual world, might have “a knock-on effect of promoting improved social skills in the real world” (Mitchell et al. 2007). Indeed, field tests of iSocial showed substantial and significant gains on assessments of social skills in the “real world” (Stichter et al. 2014).

Researchers are starting to recognize that, for both typical learners and learners with ASD, the social dimensions in collaborative learning in a 3D virtual environment are indispensable for effective learning (Aymerich-Franch 2010; Vrellis et al. 2012; Wallace et al. 2010). The social interactions among learners in 3D CVLE are essential for collaborative virtual learning. Researchers are interested in developing methods to understand and describe social behaviors and characteristics of social interaction of learners in 3D CVLE (Burgess et al. 2010; Friedman et al. 2007; Gottschalk 2010). For youth with ASD learning social competence in iSocial, it is even more important for us to understand their communication and collaboration in the 3D CVLE. The reason for that is twofold. First, understanding characteristics of youth with ASD’s social interactions enriches the current body of knowledge on human–computer interaction of users in 3D CVLE. Second, developing new methods, as has been done in this study, to describe youth with ASD’s social behavior in a 3D CVLE builds knowledge for examining social performances of youth with ASD in this novel learning environment. These new methods also help answer the question of how the capability or affordance of iSocial 3D CVLE best supports youth with ASD in order to foster verbal and nonverbal reciprocal social interaction. Furthermore, the work of this study offers insights for directions for future studies that may want to evaluate the effectiveness of 3D CVLE for learning social skills for youth with ASD down the road.

Verbal reciprocal social interactions

Results from this study showed that verbal frequency for the 11 youth using 10-min segments varied greatly across the 13 NP activities. Appropriate interactions were the most frequent interactions. Inappropriate interactions are significantly fewer than appropriate interactions. This indicates that for the most part students were interacting in a socially appropriate way across the NP activities. Response usually was the dominant element in the verbal reciprocal social interaction in iSocial NP activities compared to initiation and non-response. This result is consistent with Schmidt et al. (2012)’s findings that in the 3D virtual collaborative learning activities, youth with ASD tended to have many more responses than initiations.

Nonverbal reciprocal social interaction contributors

Nonverbal reciprocal social interaction contributors examined in this study revealed the patterns and limitations of social interactions within the current iSocial 3D CVLE. Social interactions in 3D CVLE typically mimic body-to-body interactions in real world situations (Dalgarno and Lee 2010). Youth with ASD in iSocial were interacting with others synchronously through a digital body-avatar demonstrating awareness of social norms. For example, maintain good body proximity, stay with the group during activities, keep a calm body and orient to others during social interactions. However, interaction in 3D CVLE has its own uniqueness. Learners’ behaviors in 3D CVLE are also quite different from the real world. For example, students seldom use gesture. Unlike using body gesture in real world, to use gestures in iSocial, one needs to click on a button of pre-defined gesture. This action maybe troublesome to take, especially when students were participating in cognitively demanding and verbally intensive learning activities. Interestingly, in NP 13, students used "raise hand" gestures when they wanted to vote for an option while they were still talking, as they would in real life.

As for avatar orientation, the findings showed that when students' avatars were positioned in front of a shared board with information written on the board, they were less likely to orient their avatar to face each other. However, if they were in an open, less structured area, they were more likely to orient avatars to face each other like they would do in face-to-face interaction.

Implications of emerging pedagogical design features

When learners engaged in goal-oriented, narrative embedded learning tasks within 3D CVLE, it promoted social interactions among them (Barab et al. 2005; Cole and Griffiths 2007; Dickey 2006). De Freitas et al. (2010) pointed out that the design of 3D collaborative learning activities should not mimic more traditional approaches and should emphasize a notion of learning as centered upon experience and exploration. The researchers also suggested that interactions with the environment and social interactions with others should adopt an approach of constructing learning experiences as a process of 'choreography' rather than being based on data recall strategies (De Freitas and Neumann 2009; De Freitas et al. 2010). This approach re-organizes how we produce and develop learning activities, with a greater emphasis upon learner control, greater engagement, learner-generated content and peer-supported communities, which jointly may increase learning gains. Of course, as in iSocial there may be legitimate reasons for choosing less story-line and game-like activities for the student lessons, such as coverage of content within time constraints, but the data from this study show that these choices have trade-offs with the nature of the student social learning experience.

Conclusion

This exploratory study describes a method of collecting and representing discrete behaviors of individuals within NP activity and learning contexts afforded by iSocial. The researcher's key objective for selecting the methods used in this case study was to provide thorough description and representation of verbal and nonverbal reciprocal social interaction behaviors in iSocial. The approach developed for this study identifies initiation, response and non-response as the three categories for verbal behaviors in the 3D CVLE. In addition, nonverbal behaviors were coded and analyzed as they are complementing or accenting the initiations and responses. For example, orienting an avatar to face the speaker, using a gesture while responding to another, indicating joint attention by moving one's avatar to the object, or keeping an avatar's proximity when talking to others were all parts of being social.

Not only does this approach take into account prior methods of coding and analyzing verbal reciprocal interaction in 3D CVLE, it uniquely contributes to the field by accounting for nonverbal reciprocal social interaction contributors which has characteristics and affordances unique to the 3D VLE. This approach could be informative for researching small group interaction in 3D CVLEs that support learners across various disciplines.

Future researchers could benefit from this study especially if they have the opportunity to analyze video recordings of learning activities in 3D CVLEs or if they are interested in interpreting behavior patterns of learners in 3D CVLE by looking at discrete behaviors. However, generalization of these findings should be done with caution as the study looked at a specific implementation of a 3D CVLE, addressed a specific set of learners (youth with ASD), and implemented a curriculum for learning social competencies.

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Compliance with Ethical Standards

Conflict of interest The authors declare that they have no conflict of interest with the publication of this research.

Appendix

See Tables 6 and 7.

Table 6 Naturalistic practice activities descriptions and durations in each unit

Unit #	Name of NP activity	Duration (min)	Activity description
Unit 1 Facial expressions	Facial expression scenarios	20	A student-led group activity to discuss how to make facial expressions matching various emotion scenarios
	Share out	10	A student-led group activity to discuss and share opinions about students-made facial expressions
Unit 2 Sharing ideas	Lost at sea: take items	25	A student-led group activity to have discussions about choosing items by sharing/responding to ideas in a group using the speaker/listener roles
	Lost at sea: go to island	25	A student-led group activity to have collaborative discussions about island locations and choose chores by sharing/responding to ideas in a group by using the speaker/listener roles
	Sell it!	10	A student-led group activity to have discussion about sales pitches by sharing/responding to ideas in a group by using the speaker/listener roles
Unit 3 Turn taking	Restaurant buffet I	33	A student-led group project in which they will provide input and seek the input of others for decision-making about choosing buffet styles, etc
	Restaurant buffet II	10	A student-led group project to provide input and seek input of others for decision-making about choosing main dishes and desserts

Table 6 continued

Unit #	Name of NP activity	Duration (min)	Activity description
Unit 4 Feelings and emotions	Emotion status activity	12	A student-led small group activity to reflect on times when they had difficulty reading the emotional status of others
	Emotional role play	25	A student-led small group activity to demonstrate a range of emotions and recognize the emotions of others by planning and performing a role play
	Role play planning and taping	25	A student-led small group activity to demonstrate a range of emotions and recognize the emotions of others by planning and performing a role play
	Watch and rate role plays	12	A student-led small group activity to discuss and rate the role plays
Unit 5 Problem solving	Plan Quest activity	10	A student-led small group project to use the skills learned throughout the entire curriculum to accomplish planning the quest game
	Quest activity	30	A student-led group project using the skills learned throughout the entire curriculum in the quest activity, finding the quest for the king in the virtual castle

Table 7 Coding sheet for nonverbal contributors Stay with the Group and Keep a Calm Avatar

Lesson# Naturalistic practice	Codes	0 (poor)	1 (fair)	2 (well)
Student-01	Stay with the group	The participant leaves the group (means the participant is not within earshot of the group) two or more times during the NP activity	The participant leaves the group (means the participant is not within earshot of the group) one time during the NP activity	The participant never leaves the group during the NP activity
	Keep a calm avatar	The participant abuses gestures or movement to an extent that his avatar is distracting others (either OG gives him a warning/reminder or other student ask him to stop)	Participant uses gestures or movements more than the reasonable amount but not excessive as a distraction to others	The participant only uses gestures and movements when it can help himself during the interaction in the NP activity
Student-02	Stay with the group	The participant leaves the group (means the participant is not within earshot of the group) two or more times during the NP activity	The participant leaves the group (means the participant is not within earshot of the group) one time during the NP activity	The participant never leaves the group during the NP activity

Table 7 continued

Lesson# Naturalistic practice	Codes	0 (poor)	1 (fair)	2 (well)
	Keep a calm avatar	The participant abuses gestures or movement to an extent that his avatar is distracting others (either OG gives him a warning/ reminder or other student ask him to stop)	Participant uses gestures or movements more than the reasonable amount but not excessive as a distraction to others	The participant only uses gestures and movements when it can help himself during the interaction in the NP activity
Student-03	Stay with the group	The participant leaves the group (means the participant is not within earshot of the group) two or more times during the NP activity	The participant leaves the group (means the participant is not within earshot of the group) one time during the NP activity	The participant never leaves the group during the NP activity
	Keep a calm avatar	The participant abuses gestures or movement to an extent that his avatar is distracting others (either OG gives him a warning/ reminder or other student ask him to stop)	Participant uses gestures or movements more than the reasonable amount but not excessive as a distraction to others	The participant only uses gestures and movements when it can help himself during the interaction in the NP activity

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