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Learning through VR gaming with virtual pink dolphins for children with ASD

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ABSTRACT
Autism Spectrum Disorder (ASD) is a developmental disorder with different levels of severity. Although the exact causes of ASD is not yet known, nor is there a medical cure for ASD to date, special facilities and schools have been established to help individuals coping better and becoming more independent. With the advancement in Virtual Reality (VR) technology, there has been a greater depth of development of technology-enhanced game-based learning for children with ASD. This paper will describe our effort on virtual pink dolphins to assist children with ASD in their learning, at the same time, to avoid the use of physical pink dolphins which is a species endangered. A study on the use of a low-cost VR enabled pink dolphins game for children with ASD to learn direction following, psychomotor skills and hand-eye coordination will be reported.

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Introduction

Autism spectrum disorders

Characterized by slowness in social skills, as well as constrained or repetitive behavioural patterns and interests, Autism Spectrum Disorders (ASD) is the diagnostic range of developmental disabilities. Typically, these symptoms begin to surface early in the growing stages of a child. The characteristics can be classified in two broad categories: social and communication impairment, and repetitive and stereotyped behaviours. In cases of ASD, social and communication impairment refers to the deficiency in interaction skills. These may include the inability to maintain eye contact or a lack of focus in other parties. Children with ASD do not fully attain the typical milestones of a growing child. For some, language development may be delayed and slow. However, it must be noted that not all children with ASD have speech difficulties; some are even able to speak in perfect sentences. Such children still may not be able to keep an ongoing conversation because of difficulties in comprehending typical emotional cues. Similarly, it can be complicated for others to comprehend what such children with ASD may be trying to communicate as their expressions and gestures may not be synchronous with their intentions. Repetitive and stereotyped behaviours may be presented in mild or extreme forms. Involuntary and repeated actions, such as jumping and spinning, by 11 children with ASD on a normal basis were observed by (Kanner, 1943). On top of body motion stereotypes, children with ASD also work best with routine and do not adapt well to changes in their regular

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cycles. This inflexibility requires them to follow a strict regiment, such as always having to take the exact route to school. Research has also led to several theories which have been used to explain the reasons of the certain characteristics of individuals with ASD. Theory of Mind (ToM) is the capacity to internally comprehend and distinguish subjective mental states like expectations and thoughts, of one's own and others' minds (Peterson, 2014). Failure to develop ToM fully is often used to explain the social and communication impairment characteristic of children with ASD. This allows one to understand that their mental states such as emotions and perceptions can be a result or cause of the behaviour and reaction of others. The Theory of Impeded Plasticity explains the abnormality in the development of the brain of children with autism (Fakhoury, 2015). Brain functional and morphological irregularity is associated with a considerable diminution in the long-distance connectivity. Patterns of hypo- and hyper-connectivity were correlated with the age of the child (Keehn, Wagner, Tager-Flusberg, & Nelson, 2013). It was found mutation of genes to be a significant factor related to autism (Chaste & Leboyer, 2012). Higher levels of glutamate have been found in individuals with ASD (Shimmura et al., 2011). Glutamatergic neurons send excitatory inputs while amino butyric acid (GABA)-interneurons send inhibitory inputs. The level of GABAergic has also been found to be altered in the brains of ASD-diagnosed persons (Pizzarelli & Cherubini, 2011).

While there is no cure for ASD, early and regular therapy can help both the child and caregivers to cope in their areas of limitations. Such therapy includes behavioural therapy, occupational therapy and medication. The aim of behavioural therapy is to help the child better understand how one ought to respond in various circumstances. As aforementioned, children with ASD are often unable to pick up social cues and norms, thus reacting in manners that may not be appropriate. This form of therapy targets the behavioural correction to modify undesirable conduct. The other aspect of therapy which cannot be neglected is occupational therapy. This seeks to develop higher levels of independence by the employment of purposeful activities. With the nature of activity and environment in consideration, children learn to cope with daily occupations such as brushing their teeth. Research has shown the importance of active engagement in daily occupations as a crucial contribution to the health and well-being of an individual while giving meaning to life (Law, Steinwender, & Leclair, 1998). Special facilities, schools, centres and associations are also set up so that support is provided for families with loved ones with ASD. Children are given a slower-paced curriculum to learn subjects such as language and mathematics, as well as skills. These are executed in the forms of book learning, role play, and educational toys.

Serious games and VR for children with ASD

In this digital era where technological advancements are at unprecedented rates, the rife of gaming and the use of the internet has emphasized the need to produce various educational methods incorporating the use of (serious) video games (Freitas & Liarokapis, 2011). Consequently, the serious games sector has attracted the interest of steadily rising markets and a greater depth of academic research in diverse fields (Ritterfeld, Cody, & Vorderer, 2009). Serious games are video games modelled for the purpose of learning or solving problems, as opposed to those entirely entertainment focused (Djaouti, Alvarez, & Jessel, 2011). While there are entertainment video games branded as purpose-shifting games which carry secondary underlying motives, serious games are designed specifically for its intended purpose and audience. The use of serious games is common in fields such as the military, medical and educational sectors. The tapping of technology in the education sector is no exception and one aspect of this is the use of serious games. The great array of benefits associated with learning through serious games include the possibility of players to learn effectively about an environment virtually without the need to be present at the actual environment as well as the high motivational factor embedded into learning (Mouaheb, Fahli, Moussetad, & Eljamali, 2012). With the current advancements in technology and greater engagement of electronic gadgets around the world, it is important to tap on the boundless opportunities technology presents to aid the learning of children with ASD (Göbel et al., 2015). The exploration of the incorporation of serious games for an audience of children with ASD is on a progressive ascent today (Densmore, 2007). Educators and researchers are looking to digital teaching for the children to learn various skills from communication, psychomotor training and social behaviour augmentation. Whiz Kid Games (www.whizkidgames.com) is an example of serious games designed to aid children with ASD becoming more independent. It was discovered that learning through simulation games resulted in 11% higher declarative knowledge, 14% higher procedural knowledge and 9% higher retention of training material compared to those who underwent traditional learning methods (Sitzmann, Ely, Bell, & Bauer, 2010). Serious games play increases the entertainment value to the player on top of the educational objectives trained (Csikszentmihalyi, 1990). This can help to deepen the sense of commitment and responsibility to perform well in the character (Yee & Bailenson, 2007).

There is an increasing interest in the recent years on VR technology for autism research. Moore, Cheng, McGrath, and Powell (2005) investigated the collaborative virtual environment technology for people with autism. Austin, Abbott, and Carbis (2008) did a feasibility study with two cases on using VR for ASD. Bellani, Fornasari, Chittaro, and Brambilla (2011) examined the state of the art of VR for autism research. Kandalaft, Didehbani, Krawczyk, Allen, and Chapman (2013) reported the use of VR social cognition training for high-functioning autistic young adults. Cai et al. (2013) described their design and development of a virtual dolphinarium for children with autism. Escobedo, Tentori, Quintana, Favela, and Garcia-Rosas (2014) shared their work on using augmented reality to help children with autism stay focused. Chen, Lee, and Lin (2016) worked on augmented-reality based video-modeling storybook of nonverbal facial cues for children with ASD to improve their perceptions and judgments of facial expressions and emotions.

VR is well known for its relation to sensorial system. ASD, on the other hand, is often referred to sensory processing disorder. It is therefore of interest to look into the possible way to help children with ASD in their learning with the aid of VR technology, particularly VR-enhanced serious games. VR-enhanced serious games can be played by children with ASD multiply times for learning a skill in a simulated real life situation without incurring any physical risks. However, just like physical pilot training cannot be replaced by pilot simulation training, VR-enhanced serious games will play a complementary role to confrontation therapy (or social referencing) which shows positive response for children with ASD (DeQuinzio, Poulson, Townsend, & Taylor, 2016).

This paper reports our effort to assist children with ASD by acquisition and exposure of learning skills through VR serious gaming. We first present our VR enabled pink dolphins game. The idea is to use low cost VR technology for the purpose to help children with ASD in their learning, at the same time avoid the use of physical pink dolphins which is a species endangered. The virtual pink dolphin game has been used to teach children with ASD on topics like numeracy, shape, words, colours, etc. This paper focuses on the discussion and evaluation of the virtual pink dolphins for children with ASD to learn direction following, psychomotor skills and hand-eye coordination. Detail of how to establish VR learning environment for special needs education can be found in (Cai, 2011, 2013; Cai et al., 2013; Cai, Chiew, Nay, Chandrasekaran, & Huang, 2017; Cai & Goei, 2013; Cai, Lu, Zheng, & Li, 2006).

VR enhanced pink dolphins game

The game

Animal-assisted therapy is reported to improve the social and communication skills such as being more receptive to stimuli, and to harness roles of responsibilities in caring for the animals in the case of children with autism (Law & Scott, 1995). In particular, dolphins-assisted therapy for children with ASD has raised public interest in recent years (Nutter, 2011). Typically, children with ASD swim with the dolphins during the therapy which may cast out of risks of children in the actual physical dolphin encounters such as drowning or unpredictable animal behaviour of the dolphins. Moreover, the game provides an alternative to dolphin-assisted therapy which may be harmful to the endangered creatures. The virtual pink dolphin project is an alternative solution aiming to develop innovative VR technology for the purpose to assist children with ASD in their learning, and at the same time substitute live dolphin interactions (Cai et al., 2013, 2017). Initially, the virtual pink dolphin game (Figure 1) is designed for special needs schools to engage children with ASD in their learning of social communication using gesture through immersive and interactive means of 3D virtual reality technology. Table 1 shows the characteristics of the virtual pink dolphin game as a function of serious games according to Breuer and Bente's categorization chart by (Breuer & Bente, 2010).

The game play

Calibration

The player is required for calibrating of the rig system through the raising of both arms while maintaining approximately a constant 2.5 m distance from the Kinect sensor which is used for motion detection.

Figure 1. The main menu of the virtual pink dolphin game.

Table 1. Tag categories for classifying serious games.

Tag category	Exemplary labels
Platform	Virtual reality classroom (Figure 2)
Subject Matter	Dolphin training
Learning Goals	Giving and following directions
Learning Principles	Mirroring, psychomotor skills
Target Player	Children diagnosed with ASD
Interaction Mode(s)	Single player
Application Area	Skills, special needs education
Controls/ Interface	Kinect motion sensor
Common Gaming Labels	Role-play

Game start

The game begins at the main menu with graphics of a dolphin trainer avatar and the dolphins. Then, an animated prelude of a turtle will bring the children to the dolphin lagoon where the actual game play will take place.

Avatar and mirroring

In the game, the children will be dolphin trainers giving directions to the pink dolphins to perform tricks. By mirroring an avatar on the screen, their hand movements will be picked up by the motion sensing input device. There are three stages of the game, together with a warm-up round at the beginning with five sets in every stage. Upon executing the set correctly, the dolphin will perform a trick. The wrong gesture will trigger a prompt displaying "Follow me!" with a buzzer sound. Likewise, the right gesture will result in a green tick, displaying a prompt of encouragement of "Excellent!" and accompanying victory bells ringing.

Warm-up

The warm-up round starts with the avatar and a speech bubble with the exact instructions for the actions required. In the subsequent stages, only the avatar with performing the animated action will be shown without any worded hints.

The game level

"Triangle" stage comprises of 1 action per set. Each set of level 2, or the "Circle" stage, is made up of 2 actions. The third and final stage, the "Square" stage, requires 3 actions in each set (Figure 2). After the warm-up round, the game will officially begin with level 1 Triangle stage, level 2 Circle stage and the final level 3 Square stage. At the end of the game play, the player will be rated on a 3-star scale for their speed and accuracy.

Gestures

The entire game consists of five actions, of which will be permutated in different sets in the Circle and Square stages. These five actions require the various movement of the arms, thus enabling learning using the correct hand and executing the action in the right position (Figure 3).

Game-based learning

3D virtual nature of the game

Firstly, the nature of the dolphin game being a VR game will help children learn actions or skills more effectively as compared to traditional teaching methods through book or whiteboard. The VR platform that the virtual pink dolphin game is conducted in would therefore reap such benefits as well.

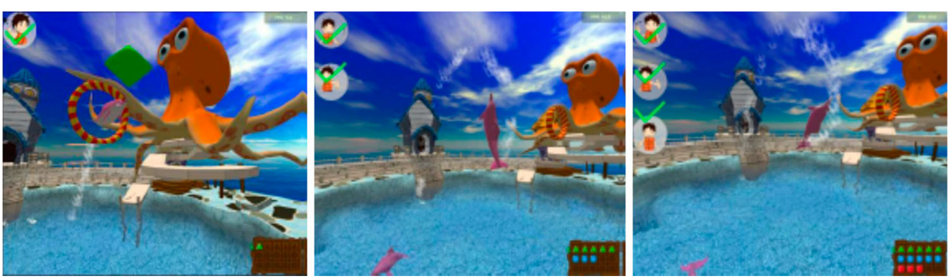

Figure 2. Triangle stage with 1 action each set; Circle Stage with 2 actions each set; and Square Stage with 3 actions each set.

Figure 3. Selected gestures.

Realistic game environment

As the children play the role of the dolphin trainer with realistic graphics of the lagoon and the water splashing sounds and animation (Cai et al., 2013, 2017), the immersion into the environment leads to a greater sense of actuality and a more enjoyable experience (Csikszentmihalyi, 1990). This increases the entertainment value to the player on top of the educational objectives trained. The assumption of the persona of the dolphin trainer avatar helps the children to identify with their role and responsibilities better. This can help to deepen the sense of commitment and responsibility to perform well in the character (Yee & Bailenson, 2007).

Experiential learning method

The hands-on approach involves the children to both follow the directions of the avatar and give directions to the dolphin. This contributes to the experiential learning of communicating through hand gestures. The children will be able to adapt what they have learnt in the game to real life, as well as to have a higher retention of the content.

Underlying learning objectives

The virtual pink dolphin game may also reinforce other underlying learning objectives such as numeracy, colours and shapes. This is done through the subtle means of the game environment. Different colours are being presented in the background graphics such as the blue oceans, the white clouds, and the orange octopus holding the hula hoop. Numeracy can also be practiced through the number of sets the player is left to complete, while the shapes at each stage are also used as the reward objects the dolphin proceeds to catch after each set is successful.

Experiment of VR enhanced pink dolphins games

The main research questions

This experiment is designed to find 1) whether children with ASD are able to learn to follow and give directions in the virtual pink dolphin game? 2) whether this virtual pink dolphin game engages the children with ASD? And 3) what are the teacher impressions of this game?

For this aim, measurements are done through the collection of various data such as the actual game play data and additional tests to compare the difference before and after playing the game. There are two ways to obtain players' game play records: *ex situ* and *in situ* methods. *Ex situ* data is obtained through observation "outside" of the game play. The profile of the players such as the age, survey feedbacks and physical pre-test and post-tests are forms of *ex situ* data. On the other hand, *in situ* data is found from the "inside" of the system, in other words, the data that can be obtained from the internal software programme (Loh, Sheng, & Ifenthaler, 2015).

The effectiveness of the game may also require additional tests to be done, for example, to test the reaction time before and after playing, so as to compare the improvement as a result of playing the game. The theory of pattern matching may also be employed. Pattern matching is an attempt to relate a theoretical pattern with the actual observation. The theoretical pattern may be a hypothesis or a traditional theory derived by the researcher. Upon direct observation and measurements, the extent to which the patterns tally will reflect the support of the theoretical prediction. The pattern match is achieved through calculations of tests of significance like the T-test or ANOVA. The T-test is the examination of the mean of two populations in order to test the legitimacy of the experimental hypothesis drawn and is commonly used when the sample size of the research is small, typically smaller than 30. From the *T*-test, the means will be compared to determine if there is a statistically significant difference. The T-ratio is a measure of the depth of variance in the statistical estimate. The degree of freedom measures the amount of information that can be derived from the data in estimating the unknown parameters and the variability of the estimations. A greater sample size will result in higher degrees of freedom. The difficulties in these methods arise when there may be other factors which contribute to the differences or similarities between the groups in consideration (Trochim, 1989). Psychological tests may also be helpful in indicating the effectiveness of the game through the measurement of improvements to the individual's abilities. For example, information processing for individuals with ASD can be evaluated to investigate games with memory-related objectives. Psychological theories such as the ToM and Weak Central Coherence pertaining to ASD can also be used to support explanations for certain trends and behaviour seen in the experiments (Miller, Odegard, & Allen, 2014).

Experiment design

The experimental design would split the participants into the experimental group (EG) and the control group (CG). Participants in the EG are those who have been exposed to the pink dolphin game before, with the game in their curriculum. On the other hand, the CG would contain those who have not even seen the game before. With an EG and a CG, we are now enabled to directly compare the results of two groups of participants with regards to their circumstance. It lessens the margin for error stemming from particular individuals.

Both the EG and CG will take a test and we will compare their results. Since the objectives of the dolphin game were 1) Follow directions; 2) Communicate by giving directions; and 3) Train psychomotor skills and hand-eye coordination, we designed a test to measure the capabilities of the children in these three aspects. The test is split into two main parts, the "Grid Game" which would encompass the first two objectives, and the "Do As You See" game which would fulfil the last objective.

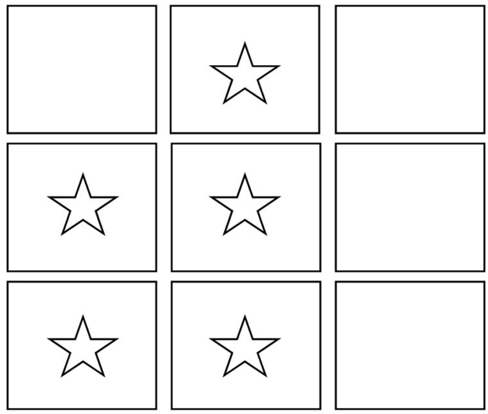

Figure 4. The grid game.

Participants

A total 12 children aged between 8 and 16 from a local special need school participated in the research with 5 for the EG and 7 for the CG. The CG students have been using the Pink Dolphin game in curriculum time to learn numeracy, word, shape, colour, etc. The EG students are totally new to the pink dolphin game. 10 out of the 12 children are ASD and the other two are special need.

Grid game

The game will be set up on paper in a 3×3 grid (Figure 4). The 3 grid side will be facing the instructor with the participants opposite. A toy will be placed in the possession of the participants. By listening to a set of instructions in the directions of "move the toy straight", "turn left", and "turn right", the aim of the game is to reach the other side of the grid following the path chosen (path is fixed for all participants). If a wrong step is taken, they would have to start from the beginning, with the number of attempts being recorded.

Next, the instructor would place sweets on his end of the grids. The participants are supposed to give the instructor instructions to follow to reach other side of the grids in accordance to the path that is marked. The three instructions available to the participants are the same as the previous part. If a wrong instruction was even, the participants would have to start from the beginning. The number of attempts will be recorded and measured for participants.

Do as you see

This game is to test the participants' hand-eye coordination. With the sweets and toys hidden from sight, when they see the sweets, they must raise their right hand. When they see the toy, they must wave their left hand. This will be used to test their hand eye coordination, and they must get it right 3 times. Number of attempts will be recorded and measured. The toy or sweet shown should be fixed to avoid errors. Three different situations will be tested by the instructor, raising the sweets with his left hand, raising the toy with his right hand, and raising the sweets with his right hand. The test will be conducted with the objects hidden behind his back. The reason for the last action is to ensure that the participants do not second guess the answer by looking at which hand is about to be raised.

Table 2. Results recorded of statistical tests.

S/N	Profile	Age	Attempts		Hand-eye coordination
			Following directions	Giving instructions	
EG 1	SPED	13	1	3	2
EG 2	ASD	14	4	4	1
EG 3	ASD	14	6	3	2
EG 4	ASD	8	1	2	1
EG 5	ASD	10	2	1	1
CG 6	ASD	8	15	9	3
CG 7	ASD	11	2	1	1
CG 8	ASD	8	Void (15)	Void (9)	Void (4)
CG 9	ASD	8	Void (15)	Void (9)	Void (4)
CG 10	ASD	16	4	11	4
CG 11	SPED	16	3	1	1
CG 12	ASD	15	1	3	1

Tests

Out of the 12 children available, 2 of them were unable to complete the experiment due to a lack of attention span/ the lack of ability. As such, in order not to affect the experimental samples, they were each allocated the worst results of the respective categories. Table 2 shows the attempt numbers for the CG and EG in terms of following instruction, giving instruction, and hand-eye coordination. Apparently, the attempts for the CG and EG are substantially different for following direction, giving direction and hand-eye coordination. A T-test was done with this small sample size, for CG, $t(7) = 2.13$, $p < 0.036$ which indicates the data is valid with reasonably good result.

Survey

The survey was conducted for the children (EG) who have experience playing with the virtual pink dolphins before. Although this survey was mainly a means to find out if they enjoyed the virtual pink dolphin game and not indicative of the effectiveness of the game in the learning objectives of following and giving directions, it is useful in showing the sustainability of the game play. While fun and entertainment are not the primary objectives of serious games, it is a fundamentally important motivation factor in the making of games for children.

The three questions that were asked were: 1) Do you like playing the game? 2) Which character do you like most? And 3) Which colour in the game do you like most? In the dichotomous style of the first question, the response yielded a 100% positive. The other two questions were also asked to find out what parts of the virtual game they had enjoyed. These questions reflected the observance skills of the players to the virtual surroundings in the pink dolphin game. During the game play itself, many children would point out various features they noticed in the dolphin lagoon such as the hula hoop, the octopus, and the shapes of the gem the dolphin obtained when they were doing the trick. They also noted sound effects such as the countdown timer before each stage began. These showed that the game was helpful to subtly teaching or reinforcing the lessons in shapes and numeracy taught to the children before the game. The connection they drew from what they had learnt previously and in the game scene is a good indication how well a child with ASD can relate reality with virtual games such as the virtual pink dolphin game.

Feedback from the teachers

Feedback was also gathered from the teachers. Some of the questions asked were: 1) Do you think the children enjoyed the game? 2) How well do you think the children learnt from the following game: pointing, colours, numeracy, and shapes? And 3) What was your favourite part of this programme?

The teachers' feedbacks were more useful in measuring the effectiveness of the game qualitatively. One question directly asked for the usefulness in the dolphin game for the children to learn the different skills, and was given a rating of 4 out of 5. The informal feedback given during the game play itself was generally positive, although some areas of improvement were brought up. The most common feedback included making the avatar larger and having more varied actions. These were areas pertaining to the improvement of the software rather than the concept of the game itself. The rationale for the children to play the game was felt to be met, and more could be done for the children to learn more types of directions at one time. Therefore, it can be seen that the game was effective in meeting its objective of teaching direction taking and giving to the children.

On top of the assessments made by the teacher with reference to the objectives, the response to the question of the teacher's favourite part of the programme also highlighted the merits of the virtual games in terms of character development. As the children waited patiently for their turn at the game, they cheered their peers on. Encouraging and sharing the joys of accomplishment with each other is an important aspect in the development of children's character. As known for children with ASD, their emotional sensitivity may not come as naturally. Opportunities and exposure to spaces where values like sportsmanship can be displayed can help to nurture the children. Therefore, on top of the primary objectives of the game, lessons on character development may also be achieved through playing of VR games like the virtual pink dolphin game.

Conclusion

Virtual pink dolphin game is a VR enhanced serious game designed to help children with ASD in learning of social communication and interaction by serving as dolphin trainers. This research looks into the benefits of playing virtual pink dolphin game for children with ASD to learn specifically following directions, giving directions and hand-eye coordination. Through the conduct of the experiment of the virtual pink dolphin game, the statistical analysis based on the experiment data shows that the game has a positive effect in the helping children with ASD learn to follow directions from the avatar and give directions to the dolphins. These directions included pointing with the correct hand.

There, however, were certain limitations in the experimental methods. Though rather common for special needs research with a small sample size, it lowers the reliability of the experiment due to the lack of numbers. The CG and EG were not perfectly controlled. Despite most of the participating children having the same profiles, their age follows a wide distribution (from 8 to 16). This indicates that some of them could have been exposed to directional and instructional tests and lessons for a longer period of time than the rest, giving them an edge over the others. Besides age, the children also came from different classes, meaning the proficiency of the teacher may not be consistent between the participants. Besides, assigning a worst value to "void" results for the respective games seems like a good idea to quantitatively evaluate the results. However, in reality, the "void" results could simply mean an anomaly in the samples. The lack of samples made it impossible for the research to establish if this was an anomaly or that the dolphin game helped to ensure all the children are able enough to participate in the experiments.

In this paper we report our work on virtual pink dolphin assisted learning with a small sample size. More VR-enhanced serious games as future work will be designed and developed to assist children with ASD in life skill learning. Currently, we are in the process of doing research and development on augmented reality games that interweave simulation and reality to assist children with ASD.

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