Design and Development of a Virtual Dolphinarium for Children With Autism

Yiyu Cai, Noel K. H. Chia, Daniel Thalmann, Norman K. N. Kee, Jianmin Zheng, and Nadia M. Thalmann

***Abstract*—The recent proliferation of virtual reality (VR) technology applications in the autism therapy to promote learning and positive behavior among such children has produced optimistic results in developing a variety of skills and abilities in them. Dolphin-assisted therapy has also become a topic of public and research interest for autism intervention and treatment. This paper will present an innovative design and development of a Virtual Dolphinarium for potential autism intervention. Instead of emulating the swimming with dolphins, our virtual dolphin interaction program will allow children with autism to act as dolphin trainers at the poolside and to learn (nonverbal) communication through hand gestures with the virtual dolphins. Immersive visualization and gesture-based interaction are implemented to engage children with autism within an immersive room equipped with a curved screen spanning a 320° and a high-end five-panel projection system. This paper will also report a pilot study to establish trial protocol of autism screening to explore the participants' readiness for the virtual dolphin interaction. This research will have two potential benefits in the sense of helping children with autism and protecting the endangered species.**

***Index Terms*—Autism, dolphins, immersive and interactive learning, nonverbal communication, virtual reality (VR).**

I. Introduction

A. Autism Spectrum Disorder

RECENTLY, more media attention has been drawn on the increase of autism with the international prevalence rate of 60 per 10 000 applied across cultures [1], [2]. An average of 1 in 88 children in the United States is identified to have autism, while an estimated prevalence of autism in China is 5 per 10 000 [3]. In Singapore, the estimated prevalence rate of individuals with autism in the population of 4 million is 1 per 166 [4]. However, no sound scientific evidence indicates that the increasing number of diagnosed cases of autism arises from anything other than purposely broadened diagnostic criteria, coupled with deliberately greater public awareness and intentionally improved case finding [5]. We became interested to do research for possible help of these children with the state-of-the-art of intervention and treatment for autism.

Although Bleuler [6] first coined the term *autism*, our understanding of the disorder with its various subtypes comes from the pioneering works of Kanner [7] and Asperger [8]. Today, the DSM-IV-TR [9] provides the most widely used definition of autism. It is based on twelve diagnostic criteria categorized under three areas describing autism as a disorder of neural development characterized by impaired social interaction and communication, and by restricted and repetitive behavior. Overt symptoms from the age of six months are manifested by age two or three. These symptoms tend to continue through adulthood, though often in a muted form. As said, autism is distinguished not by a single symptom, but by a characteristic triad of symptoms. Autism is also a highly variable neurodevelopmental disorder first appearing during infancy or childhood. Generally, it follows a steady course without remission. The DSM-IV-TR has classified autism as one of the five pervasive developmental disorders. The current diagnosis of autism is based on the manifested behavior as described in the DSM-IV-TR, not the cause or the mechanism.

Currently, there are several major theories and perspectives on the causes of autism. For instance, the empathizing-systemizing theory explains that an individual with autism has affective or empathizing deficits. According to Myers *et al.* [10], empathizing involves two major steps: 1) the ability to attribute mental states to other people as a natural way of understanding them, and 2) having an automatic appropriate emotional response to other people's mental states that makes one care about their feelings [10, p.57]. However, such an individual may have intact or even superior cognitive ability, known as systemizing, to analyze and build systems so as to understand and predict the functional behavior of impersonal events or inanimate or abstract entities. Executive dysfunction is another theory depicting autism as a form of perseveration or result of an inability to shift attention presumably to arise from some form of frontal lobe brain damage. It explains that people with autism lack the control over conation (or conscious effort to carry out self-determined acts) and thus, they cannot plan [11]. The theory of weak central coherence, however, claims the preference of a person with autism for local detail over global processing. A fourth example is the theory of sensory integration deficits. It is based on the premise that adequate processing and integration of sensory information by the central nervous system plays a significant role in an individual's ability to participate in daily activities [12], [13]. Sensory processing difficulties have been reported to

Manuscript received March 09, 2012; revised July 04, 2012, September 14, 2012; accepted November 11, 2012. Date of publication January 24, 2013; date of current version March 07, 2013. This work was supported by the Institute for Media Innovation under the Seed Grant Scheme. Y. Cai and N. K. H. Chia are first authors of the paper with no order difference.

Y. Cai, D. Thalmann, and N. M. Thalmann are with the Institute for Media Innovation, Nanyang Technological University, 637553 Singapore (e-mail: myycai@ntu.edu.sg; danielthalmann@ntu.edu.sg; nadiathalmann@ntu.edu.sg).

N. K. H. Chia and N. K. N. Kee are with the National Institute of Education, 637616 Singapore (e-mail: khchia@nie.edu.sg; knkee@nie.edu.sg).

Y. Cai is with the School of Mechanical and Aerospace Engineering, Nanyang Technological University, 639798 Singapore (e-mail: myycai@ntu.edu.sg).

J. Zheng is with the School of Computer Engineering, Nanyang Technological University, 639798 Singapore (e-mail: jmzheng@ntu.edu.sg).

Digital Object Identifier 10.1109/TNSRE.2013.2240700

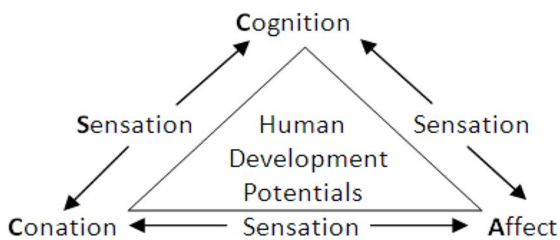

Fig. 1. CCAS Model.

TABLE I
FUNCTIONAL DEVELOPMENTAL LEARNING AND BEHAVIOR

Domains	Skills
Noesis (Cognitive functions)	• Thinking & learning skills • Communication skills
Orexis (Conative-affective functions)	• Body movement skills: Physical development and motor skills • Relating to self and others: Social-emotional development skills • Self-care and daily living skills: Adaptive development skills
Senses (Sensory functions)	• Vision, hearing and touch (including sensory integration and discrimination)

occur in up to 15% of children in the general population [14] and in over 90% of children with autism [15]. However, these are cognitive psychological theories that do not explain the causes of autism in terms of neurobiology or pathophysiology.

In view of some of the theories discussed earlier, we searched for a suitable framework that can accommodate them and decided to settle on the CCAS model [16]. According to Poland [17], human development potentials consist of **C**ognition (for learning) and **C**onation (for conscious action) and **A**ffect (for feeling or emotion) all interlinked by **S**ensation (for sensory processes) (see Fig. 1). It encompasses the three domains (Table I) of functional developmental learning and behavior: noesis, orexis, and senses [18]. The theory underlying the framework describes the learning and behavioral challenges of a child with autism are the results of deficits in cognition, conation, affect, and/or sensation. For instance, affective deficits impair the ability of a child with autism to empathize, but his/her cognitive strength may lie in the ability to systemize. We will investigate the multiple senses (vision, and hearing, and body movement) to better understand these children's communication and learning.

B. Intervention and Treatment for Children With Autism

Current resources in terms of intervention and treatment (I&T) methods [19] for children with autism are rare and costly, often involving a trained therapist or allied professionals to work with such individuals in one-on-one or small group sessions for a 40 hours per week therapy. The two terms intervention and treatment used here refer to different forms of autism therapy. The first term *intervention* for autism (e.g., Applied Behavior Analysis) must be understood as a method of interposition or interference to modify a process, situation or condition, while the second term *treatment* for autism (e.g., **T**reatment and **E**ducation of **A**utistic and related **C**ommunication handicapped **CH**ildren or TEACCH for short) refers to the way a process, situation or condition is being handled, managed, or conducted. Any claim suggestive of *curing* autism is often treated with skepticism and dismissed as a pseudoscientific treatment [20]. In one way or another, I&T methods in autism therapy serve to manage or cope with an abnormality or deficit in functional development learning and behavior. However, the development of I&T methods for children with autism is still lagging behind the advancement made in the design of better screening procedure and public education through talks, forums and seminars for both professionals and parents.

TABLE II
CLASSIFICATION OF I&T METHODS IN AUTISM THERAPY

Five Categories of I&T Methods	
I&T Methods	**Examples**
Interpersonal relationship methods	• Play-oriented strategies • Pet/Animal assisted therapy
Skill-based methods	• Applied behavior analysis • Discrete trial teaching • Pivotal response training
Cognitive-based methods	• Cognitive behavioral modification • Social stories
Physiological, biological and/or neurological methods	• Pharmacology • Sensory integration
IDM-based methods	• VR-based therapies • Game-based learning • Robot dolls

The classification of I&T methods for children with autism is shown in Table II which is mostly based on Simpson [21]. The category #5 is renamed as interactive and digital media (IDM) based methods to better represent the emerging research with efforts using games, robots and virtual reality.

C. Dolphin-Assisted Autism Therapy

Dolphin-assisted autism therapy has become a topic recently of public and research interest. It involves encounters between dolphins and children with autism. Typically, such children spend the initial times (usually for the first three sessions) on out-of-pool activities (e.g., watching video on dolphins, listening to audio records of dolphin sounds, touching and feeling a model dolphin made of fiberglass) to prepare them for the encounter with real dolphins, but subsequently, significant times are spent engaging in poolside activities (e.g., touching or patting a dolphin as it swims past the poolside, hand gesturing to the dolphin to perform certain tricks) and towards the last five sessions of the program, swimming in the pool with dolphins. Claims of benefits from this form of autism therapy include better attention [22], [23], an increased somatic awareness of the surrounding environment [24], improvement in gross and fine motor skills [25] and nonverbal communication, especially in using hand gestures that can progress to teach functional sign language at a later stage [26].

However, the dolphin-assisted therapy may not be always available or affordable to many. While pro-animal activists urge caution for the sake of the endangered species with dolphin-assisted therapy, there exist risks [27] in putting weak children in water for therapy and in contact with the strong animals even though they are well trained. Further, critics claim that the therapy has potential for causing harm to participants since there have been reports of injuries during dolphin-swim programs [28].

D. IDM-Enabled Autism Therapy

There is proliferation of VR technology applications in autism therapy specially designed to promote learning and positive behavior among such children. Studies [29]–[32], [48] have suggested that VR technology application has shown optimistic results in developing a variety of skills and abilities (e.g., social and life skills, joint attention and communication) in children with autism. Weiss *et al.* [33] presented an interesting game Join-In Suite for children with autism using a multi-user tabletop shared active surface. According to Alers and Barakova [34], children with autism like technological gadgets or contraptions and logical thinking since they are stimulated and challenged to communicate using them [16], [35], [36]. One explanation for their technophilic behavior is these children with autism may possess strong visual modality that accounts for their fascination with and propensity for learning from videos and computer games [37]–[39] delivered through electronic screen display [44], [40]. Another explanation can be found in the high systemizing ability of these children with autism [10], perhaps with particular preferences for mechanical (e.g., machines and tools) and abstract (e.g., mathematics or computer programs) systems.

E. Research Objectives

VR research has been promoted positively in the recent years for the purpose to assist learning of children with autism. Dolphin-assisted therapy has also become a topic of public and research interest for autism intervention and treatment. To our best knowledge, there is no research reported on the use of virtual dolphins to help children with autism to learn. In particular, instead of emulating the swimming with dolphins, we are interested in the design and development of Virtual Dolphinarium to assist children with autism to learn nonverbally communication through gesturing. As an initial effort, a virtual dolphin interaction (VDI) will be designed allowing children with autism to act as dolphin trainers at the poolside. Immersive visualization and gesture-based interaction will be developed to engage children with autism to establish joint attention and to learn (nonverbal) communication. The trial protocol of autism screening from a pilot study will be reported with a small number of children with autism to explore their readiness for this VDI. The potential benefits of the research include 1) the elimination of the risks of children with autism in the physical dolphin encounters; 2) protection of the endangered species by introducing virtual dolphins in alternative dolphin-assisted therapy. Eventually, we hope to have the VDI in the Virtual Dolphinarium as a new and effective method to aid children with autism in their functional development learning and behavior.

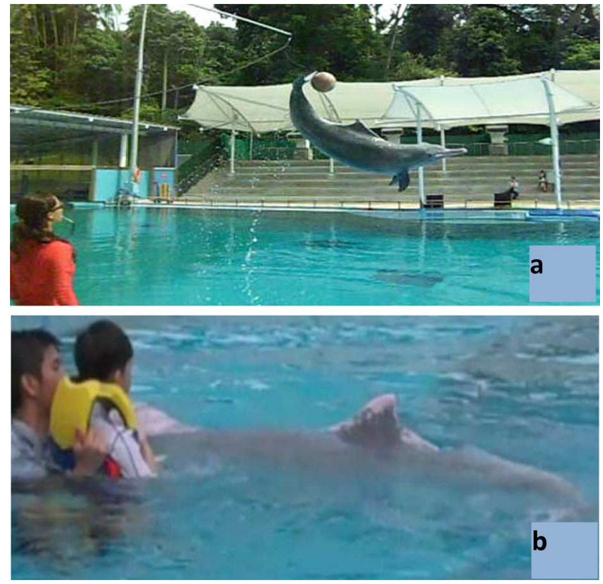

Fig. 2. (a) Dolphin show at UWS Dolphin Lagoon and (b) UWS Pink Dolphin Encounter Program.

F. Organization of the Paper

This paper is organized as follows. Section II gives a brief description of Pink Dolphin Encounters and its limitations before shifting to the Virtual Dolphinarium and VDI. Section III describes the virtual pink dolphin assisted learning in the immersive environment through gesture-based playing. Section IV presents a pilot study. Section V concludes this research.

II. From Physical Dolphin Encounter to Immersive Virtual Dolphin Interaction

A. Physical Dolphin Lagoon and Pink Dolphin Encounter

Indo-pacific humpback dolphins, or commonly known as pink dolphins, is an endangered species. These dolphins start off life grey and gradually become pink as they mature. They can be found only off the coast of China, Singapore, Thailand, and Vietnam. Pink Dolphin Encounter is a special program designed for children with autism and conducted at the Dolphin Lagoon by trained dolphin therapists from the Underwater World Singapore (UWS). It is a unique form of autism therapy using pink dolphins in the Dolphin Lagoon (Fig. 2). The program offered children with autism a chance to interact with these marine creatures; and to boost the self-confidence of these children when they physically encounter the pink dolphins in the lagoon [42]. Research based on this program suggested that there was a good reduction in stereotyped behavior with a slight improvement in their awareness of the surroundings [43], [24].

However, the program has its limitations. From 2007 to 2011, only 32 children with autism were admitted to undergo this therapy. The program was only open to such children of local residents. All these children took turns to have one-to-one encounter with one or two dolphins. As the Dolphin Lagoon is in outdoor area, the program may be affected by the weather conditions. There were also risks to put those children with poor health or physiological challenges in water. Also dolphins are after all animals with nonhuman behavior and they are not easy to be manipulated to meet the special needs of children with autism. Most importantly, the pink dolphins are endangered species.

From local or the region, there is an increasing interest from persons with autism or their families to participate in the Pink Dolphin Encounter Program. In Singapore, there are 5472 children with autism of ages 19 or below according to the Academy of Medicine Singapore and Ministry of Health (AMS-MOH) [7]. Each year about 400 new cases of children with autism are diagnosed. So given limited number of pink dolphins available the physical Pink Dolphin Encounter program is not scalable. This motivates us to develop an alternative solution.

B. Virtual Dolphinarium and Virtual Dolphin Interaction

The idea to design this 3-D Virtual Dolphinarium (or virtual dolphin lagoon) is to create a virtual environment for children with autism to learn through interaction (including play) with virtual dolphins. The Virtual Dolphinarium is designed as a "simulated" dolphin lagoon.

The Virtual Dolphinarium is developed inside the Immersive Room [Fig. 3(a)] with the Institute for Media Innovation (IMI) at Nanyang Technological University (NTU). Hosted by IMI, the Immersive Room is a newly established infrastructure designed for all NTU researchers to visualize and simulate any objects or processes in Engineering, Science, and Arts for learning and research purposes. This Immersive Room is equipped with latest immersive graphics hardware and software. A spherical 3-D screen spanned 320° is used to display images from five projectors which are ceiling mounted. Each of the projectors produces a pair of images swapping at a high speed to produce active stereographic effect. The five pairs of projected images are synchronized to form a seamless view for stereographic visualization using a software edge blending technique. Five graphics workstations are linked together in a local area network to support high performance graphic computing. Electromagnetic 6 degree-of-freedom (DOF) tracking is incorporated in the Immersive Room to capture viewers' motions in terms of position and orientation changes. Microsoft Kinect devices are installed in the room for human gesture recognition. Physically, we simulate dolphin motions and dolphin performance. For this, we implement real-time collision avoidance and collision detection algorithms. Graphically, we simulate water wave, water splashing, fountains, clouds, balloons, etc. To enable physical and graphical simulation, we do geometrical modeling on top of the digital represented geometry of dolphins, underwater environments, dolphin lagoon, etc. [Fig. 3 (b) and (c)].

The Virtual Dolphin Interaction program is developed based on the Virtual Dolphinarium. Instead of emulating the swimming with dolphins, the program allows these children to act as dolphin trainers at the poolside. As an initial implementation, immersive visualization and gesture-based interaction were developed to engage children with autism to learn nonverbal communication through hand gesture control with the virtual dolphins.

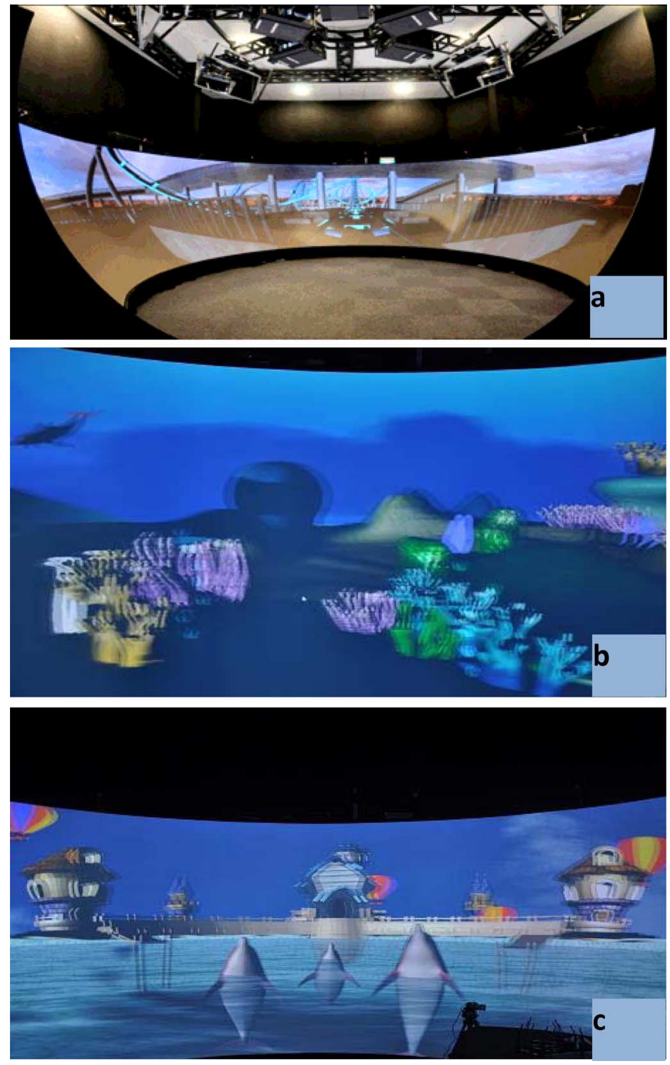

Fig. 3. (a) The immersive room, (b) Virtual Underwater World visualized on the 3-D screen, and (c) Virtual Dolphinarium visualized on the screen.

III. Virtual Pink Dolphin Assisted Learning Through Immersive and Interactive Playing

Children with autism display impairments in communication and social interaction, and lacking flexibility. However, they may possess strong visual modality and high systemizing ability. We hope the Virtual Dolphinarium we designed can help them improve their communication, and social interaction and learning. As an initial effort, our VDI program designed will have a focus on the learning of nonverbal communication.

A. Motivating Children With Autism to Learn Through Play as Dolphin Trainers

Dolphins are highly intelligent marine mammals. Captive dolphins in oceanariums are always popular among children. Typically, those dolphins are trained by instructors to follow their gestures for performance in public. Motivated by dolphin show which is mostly controlled by gesture-based instruction, we have, in the Virtual Dolphinarium, all virtual pink dolphins modeled with gesture recognition functions. A video of the real dolphin training and dolphin performance is shown to the

Fig. 4. (a) A professional instructor training a real dolphin in the UWS Dolphin Lagoon and (b) a child with autism acting as a dolphin trainer in the Virtual Dolphinarium.

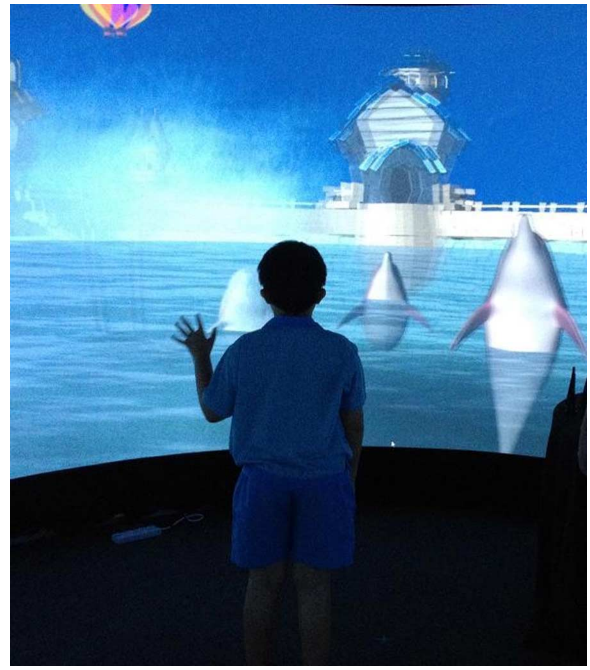

Fig. 5. Engaging a child with autism through 3-D immersive visualization and hand gesturing.

children with autism before they are invited to the immersive room. Meantime, they are given chances to do practice on gesturing for the purpose of better preparing them for the VDI program. All these warm-ups help them get familiar with the dolphin training process. The program has a learning element embedded. Through gesturing and dolphin training, children with autism can improve their nonverbal communication skills.

Fig. 4(a) shows a professional dolphin instructor training a real dolphin in the UWS Dolphin Lagoon and Fig. 4(b) shows a child with autism imitating to be a dolphin trainer within the Virtual Dolphinarium.

B. Engaging Children With Autism by Immersive Visualization

Dolphin lagoon, dolphins and dolphin shows are always attractive to children. Our Virtual Dolphinarium models the dolphins and the lagoon in a great detail. Supported by a 320° curved 3-D screen, immersive visualization is developed to simulate virtual dolphins with an emphasis on its fidelity and real-time interaction. Children with autism participating in the program each will wear a pair of 3-D shutter glasses to enable an active stereographic view during the interactive program. They imitate dolphin trainers to use different hand gestures to communicate nonverbally with virtual dolphins. Unlike the limited number of hand gestures acquired to communicate with real dolphins, one big advantage of using virtual dolphins is that more functional hand gestures can be created or programmed and taught to improve the nonverbal communication capacity of children with autism. At a higher level, such hand gestures can be extended to incorporate functional sign language for various learning purpose.

It has been reported that many children with autism have good visual modality. In this initial study, 3-D stereographic visualization implemented with the Virtual Dolphinarium helps to engage children with autism. They gain high quality immersive visual and interactive experience through the VDI program with the Virtual Dolphinarium. In Fig. 5, a child with autism is interacting with the virtual pink dolphins in the Virtual Dolphinarium to learn to communicate with appropriate hand gestures.

C. Increasing Nonverbal Communication Through Hand Gesturing

Selected hand gestures used by the dolphin trainers with the UWS Dolphin Lagoon are implemented to enable hand gesture control with the virtual pink dolphins. The gesture is fairly easy to learn and its design is in consistent with many gesture controlled games supported by Microsoft Kinect.

To act as dolphin trainers, children with autism can stand in an area close to the screen of the immersive room and the graphics will visualize on the 3-D screen the Virtual Dolphinarium immersively and allow them doing gesturing at poolside. Each time, when they successfully command a dolphin for an action; several effects will be activated including dolphin sounds, water wave and splash, etc. Typically, a specific gesture activated dolphin show will last about 30–60 s. After the completion of an interaction cycle, they can try other gesture options for different dolphin interaction. The options of the gestures can be single or mixed input based. These children can combine two hand gestures to initiate mixed dolphins shows.

Together with the Microsoft Kinect hardware device, the latest Natural Interface Programming is applied in this project to facilitate hand gesture detection and recognition for children with autism to act as dolphin trainers in the Virtual Dolphinarium. Fig. 6(a) shows a hand gesture of greeting and Fig. 6(b) shows a child with autism using the greeting gesture to communicate with a virtual pink dolphin. Fig. 7 shows another child

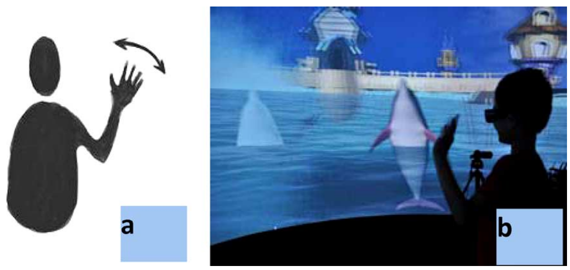

Fig. 6. (a) Greeting with left hand waving and (b) a virtual pink dolphin responding by spraying water to the greeting of a child with autism.

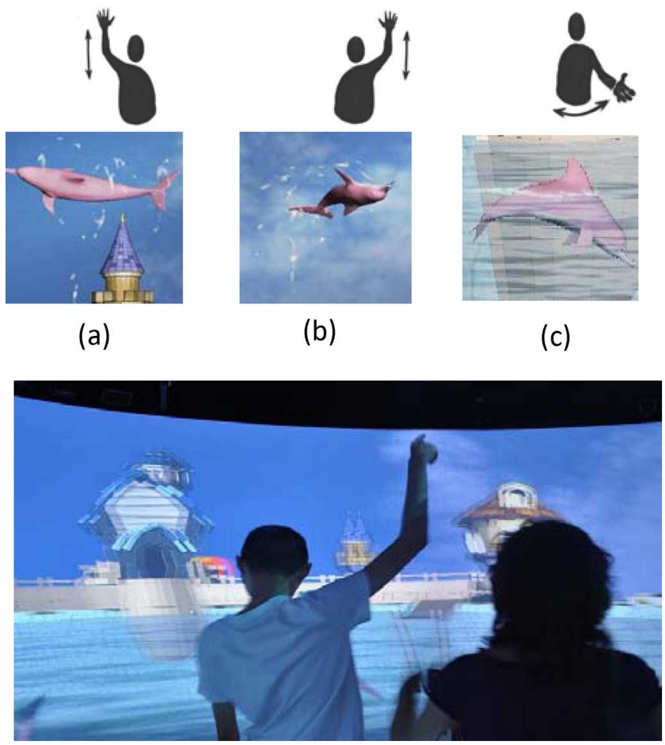

Fig. 7. A child with autism gesturing to control a virtual dolphin in the Virtual Dolphinarium. (a) Gesture for dolphin to spin. (b) Gesture for dolphin to leap. (c) Gesture for dolphin to swim.

with autism serving as a dolphin trainer with hand gesture to control a dolphin show.

IV. Pilot Study

As the immersive room is a very new facility established in IMI, this paper will report only the initial study of the Virtual Dolphinarium research.

A. Participants

The initial study involved a random selection of 15 participants from a cohort of 32 children with autism who had taken part in the dolphin-assisted therapy between 2007 and 2011. Their ages ranged from 6 to 17 years old at the time of this study. All were formally diagnosed by psychologists to have autism since 3–4 years of age. Among the 15 participants, two were twin sisters while the remaining were boys. Of the 15 participants, seven are nonverbal, another three are with limited speech and the remaining five are verbal and could hold a decent conversation with others though rather egocentric. Parents or guardians of these selected children were informed and their written consents were obtained.

B. Two Tests

All 15 participants were administered the Test of Nonverbal Intelligence-Third Edition (TONI-3) [44] to determine their respective intellectual levels in terms of Nonverbal Intelligence Quotient (NIQ). TONI-3 is one of the better language-free IQ tests that can be easily administered on nonverbal children with autism [45]. This norm-referenced nonlinguistic problem solving ability assessment tool is administered to identify if a participant has intellectual impairment or cognitive, language or motor impairments due to neurological conditions. Anyone with an NIQ of below 80 is considered as having intellectual deficiency.

At the same time, the parents of these participants were given the questionnaire from the Gilliam Autism Rating Scale (GARS) [46] to complete. The GARS would provide the research team the Autism Quotient (AQ) of each participant. Higher AQ means the child has a more severe form of autism. The GARS uses a 42-item parent-report behavior checklist intended to help identify those who have a high likelihood of autism. Each subtest raw score is converted to a standard score with a mean of 100 and a percentile rank. In addition, subtests are summed to generate an overall GARS total score which is converted into a standardized Autism Quotient and overall percentile rank.

C. Six Tasks

Six tasks are identified to screen for Functional Development Learning and Behavioral Suitability for VDI. They consist of the following:

Task 1: Identifying parts of a dolphin: The participant was to point to different parts of the toy dolphin as named by the assessor: eye, tail, flipper, fin, blowhole, mouth (rostrum). Total score was five. To pass the test/task, the participant must give at least four correct responses.

Task 2: Identifying shapes traced on palm: The assessor would trace one shape or sign at a time on the participant's palm. The participant would point to the correct shape/sign given on the stimulus chart. Total score was six. To pass the test/task, the participant must give at least four correct responses.

Task 3: Geometric shape copying: The participant had to copy all the four shapes into the empty boxes below each of the shapes. The total score was four. To pass the test/task, the participant must be able copied at least three shapes correctly. An extension to this task required every participant to match each of the four 2-D shapes with its correct 3D object: e.g., a circle is matched correctly with a sphere/ball; a square is matched correctly with a cube/box. To pass the test/task, the participant must be able to match three 2-D shapes with their respective 3-D objects.

Task 4: Copy-drawing of a dolphin: The participant had to copy-draw the dolphin shown on the opposite side of the blank space for drawing. To pass the test, the participant must copy-

TABLE III
RESULTS OF NVIQS AND AQS

Participants	NVIQ	AQ	Degree of autistic severity	Level of performance during VDI
1M	110	76	Mild	PA
2M	95	70	Mild	PA
3F	81	83	Moderate	EM
4F	67	98	Severe	TU
5M	110	81	Moderate	PA
6M	76	96	Severe	EM
7M	107	98	Severe	HD
8M	99	115	Very severe	HD
9M	72	117	Very severe	TU
10M	75	113	Very severe	HD
11M	62	129	Very severe	HD
12M	72	117	Very severe	EM
13M	84	113	Very severe	HD
14M	65	126	Very severe	TU
15M	66	122	Very severe	TU

M –Male; F – Female; EM – Emerging; HD – Highly Dependent; PA – Passing; TU – Totally Unable

TABLE IV
SCREENING RESULTS FOR FUNCTIONAL DEVELOPMENTAL LEARNING AND BEHAVIORAL SUITABILITY OF THE VDI

PPT	PD	SP	GC	CD	M	WC	6T	6TR	VO
1M	5 (P)	6 (P)	4 (P)	P	P	P	6	P	2
2M	5 (P)	6 (P)	4 (P)	P	P	P	6	P	2
3F	4 (P)	0 (F)	4 (P)	F	F	F	2	F	1
4F	0 (F)	0 (F)	0 (F)	F	F	F	0	F	0
5M	5 (P)	3 (F)	4 (P)	P	P	P	5	P	2
6M	5 (P)	6 (P)	4 (P)	P	P	P	6	P	2
7M	5 (P)	4 (P)	3 (P)	P	F	F	4	P	1
8M	5 (P)	3 (F)	4 (P)	P	P	P	5	P	2
9M	5 (P)	2 (F)	2 (P)	F	F	F	1	F	1
10M	5 (P)	2 (F)	0 (F)	F	F	F	1	F	1
11M	2 (F)	0 (F)	0 (F)	F	F	F	0	F	1
12M	5 (P)	2 (F)	4 (P)	P	F	P	4	P	1
13M	2 (F)	0 (F)	4 (P)	P	F	P	3	F	1
14M	0 (F)	0 (F)	0 (F)	F	F	F	0	F	0
15M	0 (F)	1 (F)	0 (F)	F	F	F	0	F	0

PPT-Participants (M-Male, F-Female) P-Pass; F-Fail

Six Screening Tasks for VDI Readiness

1. PD – Pointing to dolphin parts (Pass score 3-5);
2. SP – Sensory Palm Drawing (Pass score 4–5);
3. GC – Geometric Shape Copying (Pass score 3-4);
4. CD – Copy a Dolphin (QS: Qualitative scoring of Pass or Fail)
5. M – Maze (QS);
6. WC – Write name & sentence copying (QS)
7. 6TR – 6 Tasks for VDI Readiness
8. VO – Video Observation (Additional)

draw an identifiable dolphin and not just to produce mere scribbles.

Task 5: Dolphin maze: The participant was required to draw a line to lead the dolphin through the maze to coral reef located in the middle of it. If the participant just drew a line cutting across the barriers, he/she was considered to have failed the test/task.

Task 6: Name writing and sentence copying: The participant was asked to write his/her name in the provided four-line space and also to copy a sentence. As long as the participant was able to write his/her name or copy the sentence in the four-line space provided, he/she was considered to have passed the test/task. Meaningless scribbles or illegible handwriting would not be accepted. The four-line space served as guides for the correct formation of a letter, especially for those letters with descending or ascending strokes.

D. Immersive Virtual Dolphin Interaction

After the two tests and six tasks, each participant was shown a video of real pink dolphins performance show conducted in the UWS Dolphin Lagoon. This video was to give the participants an idea on the hand gesture control in the real dolphin shows. They were then given each at one time a short tutorial on how to interact with virtual dolphins using their own hand gestures. Once the participant knew what he/she was required to perform, he/she was led to the immersive room to do the same task using hand gestures that he/she had learnt.

In the immersive room, each participant was given 20 min to play with the virtual pink dolphins serving as a dolphin "trainer." His/her interaction with the virtual dolphins as well as his/her behavioral response was observed.

E. Initial Results

Table III shows the NIQ, AQ, degree of autistic severity, problem with 3-D classes and the level of performance during the VDI. The 15 participants have NIQ scores ranging between 67 and 110. According to Brown *et al.* [44], NIQ below 85 suggests the participant could be mentally, cognitively or visually challenged. In terms of AQs, all 15 participants scored between 70 and 129. Higher AQ of a participant likely indicates more severe form of autism with the participant displaying symptoms pertaining to the triad of impairments in autism.

Table IV shows the results based on six screening tasks to determine the functional developmental learning and behavioral suitability of the 15 participants in preparation for the VDI.

In this study, the 15 participants demonstrated different levels of interests to interact with the virtual pink dolphins. Eight male participants had no problem with wearing 3-D glasses and they showed strong interest with enthusiasm and volunteering throughout the whole session of VDI. While one of the twin girls (Participant 4F) was totally not interested and refused to enter the immersive room even with her parent's mediation, the other twin girl (Participant 3F) showed initial interest after her parent's mediation and interacts with the virtual dolphins. She was amenable to wear the 3-D glasses for about 5 min to interact with the dolphins. In terms of performance, Participants 1M, 2M, and 5M were able to actively learn and function with minimal supervision; Participant 3F, 6M, and 12M were able to learn and function but required prompting or some mediation from time to time. Participants 7M, 8M, 10M, 11M, and 13M were overwhelmed by the VR experience and high parental mediation was needed in order for them to be able to learn and function throughout the session. Participants 4F, 9M, 14M, and 15M were overwhelmed by the VR experience such that even with parental mediation, they refused to cooperate and were unable to learn and function (see also Table V).

V. DISCUSSION AND CONCLUSION

This article starts with an introduction on autism spectrum disorder followed by a review on intervention, treatment and therapy for children with autism. The ***CCAS*** conceptual framework is used in this research. VR has been studied as a new

TABLE V
OBSERVATION SCORING FOR BEHAVIOR IN LEARNING AND FUNCTIONING DURING THE VDI

Score	Level of Performance	Description of Participant's Behavior
0	Totally unable despite adult mediation (TU)	Child is overwhelmed by VR experience and even with mediation from parents; still unable to learn and function.
1	High dependent on adult mediation (HD)	Child is overwhelmed by VR experience but with high mediation by parents; able to learn and function to some extent.
2	Emerging (EM)	Child shows emerging ability to learn and function in VR immersive environment; requires prompting or some mediation from time to time.
3	Passing (PA)	Child is able to learn and function in the VR environment with minimal supervision.

TABLE VI
PHYSICAL DOLPHIN ENCOUNTER VERSUS VDI

Item	Physical Dolphins Encounter	Virtual Pink Dolphin Interaction
Activity	Swimming with real dolphins	Commanding virtual dolphins with gesturing
Site	Inside-pool	Poolside
Water	Real	3D virtual, dynamic and visual Sound of water wave
Dolphins	Real	3D virtual
Lagoon	Real	3D virtual
Senses & Gesture	Visual, hearing, tactile and haptic	Visual, hearing and hand gesture
Experience	Real and tangible	Virtual, immersive and interactive
Learning	Non-verbal communication	Gesture-based non-verbal communication
Risks	Weak children, and water and strong wild animal	No physical water and no real animal

media to administer autism intervention and treatment. An innovative design of Virtual Ddolphinarium was presented to engage children with autism for nonverbal communication through gesturing. Multiple senses such as vision and hearing, and hand gesture etc. built in the Virtual Dolphinarium were discussed. A pilot study whose tests require the use of skills of ***C***ognition, ***C***onation, ***A***ffect, and ***S***ensation was also discussed. The relation between the pilot results and the ***CCAS*** conceptual framework can be easily inferred. Table VI shows a comparative view between physical dolphin encounter and VDI. As can be seen from the table, the VDI and the physical dolphin encounter are somehow complementary.

A. Novelty

We have developed a Virtual Dolphinarium providing a participating child with autism the sense of being totally immersed into simulated dolphin lagoon. Children with autism could interact in real-time with Pink Dolphins within the Virtual Dolphinarium. Emphasis was placed on teaching these children hand gesture-based communication in a fun way by enabling them to play the role of a "dolphin trainer." This research also explores the use of stereographic visualization and hand gesturing as a way to engage children with autism in poolside activities. The Virtual Dolphinarium has advantages of controllability, replicability, and being programmable for such children to play with the virtual dolphins. In other words, the VDI program allows instruction to be delivered with consistency and can be repeated an infinite number of times without degradation of fidelity which is difficult for physical dolphin encounters to achieve. Besides, VR technology is capable of providing a wide range of situations and scenarios that can be used to teach or impart certain basic hand gestures that form functional sign language to children with autism. Also VR technology can simulate scenarios that are too risky or impractical especially for children with autism to experience in real life. Hence, it provides ample opportunities for them to practice without having to worry of being hurt or injured.

B. Limitation and Future Work

As an ongoing project, we are keen to explore the use of the Virtual Dolphinarium for other autism related researches such as sign language learning, life skill learning, etc. The current pilot study allowed one child with autism per time to interact with the virtual pink dolphins. We are interested in the autism collaborative learning [47]. In fact, the circular Immersive Room designed is suitable for multiple participants such as children with autism. Some children with autism had problems with the 3-D glasses partially because that the active shuttering glasses used in this project are designed for adults. Lighter weight 3-D glasses for kids should be sought for children with autism. Glass-free stereographic visualization might be an alternative solution.

Calibration is required for each participant to have gesture recognized. Due to the limitations of the Kinect hardware and calibration software, some children with autism may take a long time for this process to complete. Future work will include developing calibration free or easier calibration methods for gesture recognition.

The observation in this pilot study was based on a small sample size. In terms of I&T research, there are several topics (e.g., stimuli, intervention, and outcomes) we are yet to study with the VDI.

ACKNOWLEDGMENT

The authors would like to thank M. X. Wu, D. J. Lu, B. Y. Yang, and many others for their helps in this project. The project team would also like to thank the support from the Underwater World Singapore and A. G. T. Ng, the principal therapist from the LDcentre, who has kindly arranged for parents of those children from the Pink Dolphin Encounter for Special Children program to participate in the study.

REFERENCES

[1] L. A. Carpenter, L. Soorya, and D. Halpern, "Asperger's syndrome and high-functioning autism," *Pediatric Ann.*, vol. 38, no. 1, pp. 30–37, 2009.

[2] N. K. N. Kee and B. C. M. L. Loh, , N. K. H. Chia and M. E. Wong, Eds.*, Autism Spectrum Disorders: Characteristics and Intervention Strategies*, ser. Series on Special Educational Needs in Mainstream Schools. , Singapore: Pearson Education/Prentice Hall, 2009, pp. 1–38.

[3] V. C. N. Wong and S. L. H. Hui, "Epidemiological study of autism spectrum disorder in China," *J. Child Neurol.*, vol. 23, no. 1, pp. 67–72, 2008.

[4] Autism Resource Centre, Frequently asked questions—On autism Dec. 12, 2011 [Online]. Available: http://autism.org.sg/main/faq.php?cat=autism

[5] M. A. Gernsbacher, M. Dawson, and H. H. Goldsmith, "Three reasons not to believe in an autism epidemic," *Current Direct. Psychol. Sci.*, vol. 14, no. 2, pp. 55–58, 2005.

[6] E. Bleuler, "Die prognose der dementia praecox (Schizophreniegruppe)," *Allgemeine Zeitschrift für Psychiatrie und Psychischgerichtliche Medizin*, vol. 65, pp. 436–464, 1908.

[7] L. Kanner, "Autistic disturbances of affective contact," *Nervous Child*, vol. 2, pp. 217–250, 1943.

[8] H. Asperger, , U. Frith, Ed., "Autistic psychopathy in children," in *Autism and Asperger's Syndrome*. Camrbridge, U.K.: Cambridge Univ. Press, 1944, pp. 37–92.

[9] *Diagnostic and Statistical Manual of Mental Disorders*, 4th ed. Washington, DC: DSM-IV-TR, 2000, Am. Psychiatric Assoc..

[10] P. Myers, S. Baron-Cohen, and S. Wheelwright*, An Exact Mind: An Artist With Asperger Syndrome*. London, U.K.: Jessica Kingsley, 2004.

[11] E. L. Hill, "Evaluating the theory of executive dysfunction in autism," *Developmental Rev.*, vol. 24, no. 2, pp. 189–233, 2004.

[12] A. J. Ayres*, Sensory Integration and Learning Disorders*. Los Angeles, CA: Western Psychol. Services, 1972.

[13] A. J. Ayres*, Sensory Integration and the Child*. Los Angeles, CA: Western Psychol. Services, 1979.

[14] R. R. Ahn, L. J. Miller, S. Milberger, and D. N. McIntosh, "Prevalence of parents' perceptions of sensory processing disorders among kindergarten children," *Am. J. Occupat. Ther.*, vol. 58, pp. 287–293, 2004.

[15] S. D. Tomchek and W. Dunn, "Sensory processing in children with and without autism: A comparative study using the short sensory profile," *Am. J. Occupat. Ther.*, vol. 61, pp. 190–200, 2007.

[16] N. K. H. Chia, N. K. N. Kee, and M. M. Y. Shaifudin, "Identifying and profiling autistic learning and behavioral difficulties in children," in *Practical Tips for Teaching Children With Mild/Moderate Autism in Mainstream Schools*. Singapore: Cobee Publishing House, 2010.

[17] R. G. Poland*, Human Experience: A Psychology of Growth*. Saint Louis, CO, USA: C. V. Mosby, 1974.

[18] Center Improvement Child Caring, Functional development definition: Introduction about child development. North Hollywood, CA, USA, 2004.

[19] , K. Siri and T. Lyons, Eds.*, Cutting-Edge Therapies for Autism 2011–2012*. New York, NY, USA: Skyhorse, 2011.

[20] A. Polenick and S. R. Flora, "Sensory integration and autism: Science or pseudoscience?," *Skeptic*, vol. 17, pp. 28–35, 2012.

[21] R. L. Simpson*, Autism Spectrum Disorders: Interventions and Treatments for Children and Youth*. Thousand Oaks, CA, USA: Corwin, 2005.

[22] L. N. Lukina, "Influence of dolphin-assisted therapy sessions on the functional state of children with psychoneurological symptoms of diseases," *Human Physiolog.*, vol. 25, pp. 676–679, 1999.

[23] V. Servais, "Some comments on context embodiment in zootherapy: The case of the autidolfijn project," *Anthrozoos*, vol. 12, pp. 5–15, 1999.

[24] N. K. H. Chia and N. K. N. Kee, "Dolphin as a psychopomp: An alternative window into the psycho-space of children with autism," *Unlimited Human*, no. 3, pp. 40–44, 2010.

[25] D. E. Nathanson, "Long-term effectiveness of dolphin-assisted therapy for children with severe disabilities," *Anthrozoos*, vol. 11, pp. 22–32, 1998.

[26] T. L. Humphries, "Effectiveness of dolphin-assisted therapy as a behavioral intervention for young children with disabilities," *Bridges*, vol. 1, no. 6, pp. 1–9, 2003.

[27] C. Williamson, "Can swimming with dolphins be a suitable treatment?," *Develop. Med. Child Neurol.*, vol. 50, no. 6, p. 477, 2008.

[28] Humane Soc. U.S., Swim-with-dolphins attractions Sep. 25, 2009 [Online]. Available: http://www.humanesociety.org/issues/captive_marine/facts/swim_dolphins.html

[29] D. W. Austin, J. M. Abbott, and C. Carbis, "The use of virtual reality hypnosis with two cases of autism spectrum disorder: A feasibility study," *Contemp. Hypnosis*, vol. 25, no. 2, pp. 102–109, 2008.

[30] U. Lahiri, Z. Warren, and N. Sarkar, "Design of a gaze-sensitive virtual social interactive system for children with autism," *IEEE Trans. Neural Syst. Rehabil. Eng.*, vol. 19, no. 4, pp. 443–452, 2011.

[31] D. Moore, Y. Cheng, P. McGrath, and N. J. Powell, "Collaborative virtual environment technology for people with autism," *Focus Autism Other Develop. Disabil.*, vol. 20, no. 4, pp. 231–243, 2005.

[32] B. A. Mineo, W. Ziegler, S. Gill, and D. Salkin, "Engagement with electronic screen media among students with autism spectrum disorders," *J. Autism Develop. Disorders*, vol. 39, pp. 172–187, 2009.

[33] P. L. Weiss, S. Cobb, E. Gal, L. Millen, T. Hawkins, T. Glover, D. Sanassy, S. Eden, L. Giusti, and M. Zancanaro, "Usability of technology supported social competence training for children on the autism spectrum," in *Int. Conf. Virtual Rehabil.*, Zurich, Switzerland, Jun. 27–29, 2011, pp. 1–8, 2011.

[34] S. H. M. Alers and E. I. Barakova, "Multi-agent platform for development of educational games for children with autism," in *Proc. Int. IEEE Consum. Electron. Soc. Games Innovat. Conf.*, U.K., Aug. 25–28, 2009, pp. 47–53.

[35] J. W. Jacobson, R. M. Foxx, and J. A. Mulick*, Controversial Therapies for Developmental Disabilities: Fad, Fashion and Science in Professional Practice*. Mahwah, NJ, USA: Lawrence Erlbaum, 2005.

[36] "Committee on Educational Interventions for Children with Autism. Division of Behavioral and Social Sciences and Education," in *Educating Children With Autism*. Washington, DC, USA: Nat. Acad. Press, 2001.

[37] N. K. N. Kee and N. K. H. Chia, , Y. Cai, Ed., "Mediated and engaged learning using COTS video games in ASD special education," in *IDM and Virtual Reality for Education in Virtual Learning Environment*. New York, NY, USA: Nova Sciences, 2010, pp. 140–159.

[38] M. Heiman, K. E. Nelson, T. Tjus, and C. Gilberg, "Increasing reading and communication skills in children with autism through an interactive multimedia program," *J. Autism Develop. Disorders*, vol. 25, no. 4, pp. 459–480, 1995.

[39] B. Nally, B. Houlton, and S. Ralph, "The management of television and video by parents of children with autism," *Autism*, vol. 4, pp. 331–337, 2000.

[40] T. Buggey, "Video self-modeling applications with students with autism spectrum disorder in a small private school setting," *Focus Autism Other Develop. Disabil.*, vol. 20, pp. 52–63, 2005.

[41] H. C. Shane and P. D. Albert, "Electronic screen media for persons with autism spectrum disorders: Results of a survey," *J. Autism Develop. Disorders*, vol. 38, no. 8, pp. 1499–1508, 2008.

[42] K. Watanabe and J. Lee, Dolphin encounter for special children (DESC): Proposal for standard procedures: Special dolphin program for children with autism, down syndrome, and physically disability, Underwater World Singapore, Singapore, 2004.

[43] N. K. H. Chia, N. K. N. Kee, K. Watanabe, and P. T. C. Poh, "An investigation on the effectiveness of 'dolphin encounter for special children' (DESC) program for children with autism spectrum disorder," *J. Am. Acad. Special Ed. Professionals*, no. 3, pp. 57–87, Fall 2009.

[44] L. Brown, R. J. Sherbenou, and S. K. Johnsen*, Test of Nonverbal Intelligence*, 3rd ed. San Antonio, TX, USA: Pearson, 1997, (TONI-3).

[45] B. Siegel*, The World of the Autistic Child: Understanding and Treating Autistic Spectrum Disorders*. New York, NY, USA: Oxford Univ. Press, 1996.

[46] J. Gilliam*, Gilliam Autism Rating Scale Examiner's Manual*. Austin, TX, USA: Pro-Ed, 1995.

[47] S. Cobb, S. Parsons, L. Millen, R. Eastgate, and T. Glover, "Design and development of collaborative technology for children with autism: COSPATIAL," presented at the Int. Technol., Edu. Develop. Conf., Valencia, Spain, Mar. 8–10, 2010.

[48] S. Parsons, P. Mitchell, and A. Leonard, "The use and understanding of virtual environments by adolescents with autistic spectrum disorders," *J. Autism Develop. Disorder*, vol. 34, no. 4, pp. 449–466, 2004.

Yiyu Cai is Associate Professor with the College of Engineering, Nanyang Technological University (NTU), Singapore. He has a joint appointment with NTU's Institute for Media Innovation. He has been doing interdisciplinary research especially at the intersection of interactive and digital media, and biomedical sciences.

Noel K. H. Chia is Assistant Professor with the Early Childhood and Special Needs Education Academic Group, National Institute of Education, Nanyang Technological University, Singapore. He is board certified in educational therapy and special education with the Association of Educational Therapists and the American Academy of Special Education Professionals, respectively.

Dr. Chia was elected into *Omega Gamma Chi* Honour Society, an integral part of the National Association of Special Education Teachers, in recognition of his outstanding scholastic achievement and excellence in special education, in 2012.

Daniel Thalmann is Ph.D. Program Coordinator with the Institute for Media Innovation, Nanyang Technological University, Singapore. He has been the Founder of The Virtual Reality Lab (VRlab) at EPFL, Lausanne, Switzerland. He is co-Editor-in-Chief of *Computer Animation and Virtual Worlds* (Wiley) and Associate Editor of six other journals. He is a Pioneer in virtual humans. His research interests include computer animation, crowd simulation, virtual humans, and virtual rehabilitation.

Norman K. N. Kee is a Lecturer with the Early Childhood and Special Needs Education Academic Group, National Institute of Education, Nanyang Technological University. He is a Board Certified Special Education Professional with American Academy of Special Education Professionals. His research interests include special needs education, training for parents with special needs children, and autism spectrum disorders.

Jianmin Zheng is currently Associate Professor with the School of Computer Engineering, Nanyang Technological University, Singapore. His research interests include computer graphics, visualization, geometric modeling, CAD, multi-level and multi-resolution shape modeling, and interactive digital media.

Nadia M. Thalmann is currently Professor and Director of the Institute for Media Innovation, Nanyang Technological University, Singapore. She is also the Founder and Director of the MIRALab, an interdisciplinary lab in human computer animation, University of Geneva, Geneva, Switzerland. She is Editor-in-Chief of the journal *The Visual Computer* (Springer-Verlag). Her research area is the modelling of Virtual Humans and Social Robots including mixed realities.

Prof. Thalmann has received many artistic and scientific awards, among them, the 2012 Humboldt Research Award, and two Doctor honoris Causa (from University of Hanover in Germany and from the University of Ottawa in Canada).