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The Potential of Augmented Reality to Support the Interest-based Learning of Children with Autism Spectrum Disorder (ASD)

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***Abstract*—Children with autism spectrum disorder (ASD) may encounter the challenge to engage in the inclusive learning due to their naturalistic impairments in social, communication and behavior. The learning disabilities in children with ASD are regarding to the issues of selective attention, lack of motivation, cognitive ability, executive functioning deficits and others. Despite of that, several studies indicate that by incorporating circumscribed interests behavior that appears in most of the children with ASD could improve their academic motivation. With the support of appropriate technology, circumscribed interests could be embedded into interest-based learning strategies for children with ASD. The aims of this paper is to highlight the technical of Augmented Reality, the advantages of Augmented Reality for special education and how Augmented Reality could support interest-based learning for children with ASD. This study was conducted in a form of document reviews. There is a need in understanding the potential of Augmented Reality technology for children with ASD. Therefore, further research could be conducted to design Augmented Reality applications based on interest-based learning strategies for children with ASD.**

***Keywords*—augmented reality; academic motivation; children with ASD; circumscribed interest; interest-based learning.**

I. INTRODUCTION

Children with autism spectrum disorder (ASD) are unique that they exhibits different range of cognitive, communication, social and behavior capabilities than children without disabilities. Difficulties in learning due to the naturalistic conditions of children with ASD are one of the features found in this group. Children with ASD often show little interest in academic task, easily lost focus and get distracted during class lesson, and having less capability to learn by instruction [1]–[3]. Although, various study had shown an implicit learning mechanism in children with ASD where learning occurred without conscious[4],[5].

Despite of that, children diagnosed with ASD often demonstrate fascination with manipulating particular objects or having intense focus on specific topics [6]. They also respond well to part of a relevant cue or topics relates with their interests. Researchers relates these characteristics with circumscribed interests which are often found in children with ASD[7][8]. Circumscribed interests show the affinity of personal interests or individual choice of the children with ASD which they prefer to do with intense focus. According to American Psychiatric Association (APA), circumscribed interests are listed within the domain of restricted and repetitive behavior in the diagnostic criteria for autism. Several studies had shown the positive impact towards the learning interest and motivation of children with ASD if circumscribed interests are embedded in the learning activities [9]–[11]. The incorporation of interest-based child learning could provide more learning opportunities, influencing positive behavioral consequences and improve social engagement [13][14].

Therefore, appropriate approach and intervention strategies are necessary in educating children with ASD especially based on their individual interests. Previous studies had focused on the implementation of various technology in improving the rehabilitation and intervention of children with ASD. Yet, there is a limited study specifically considering on incorporating interest-based learning into special education. A study by da Silva *et al.* [15] focused on the development of a web-based application with customsized content features considering the individual interest of children with ASD. While that, Lucas, Gonc and Silva[16] had implemented user-tuned content customization features in a web application. Through the web application, teachers will have the authority to create different profiles represented in 'My Document' metaphor and assigned to corresponding children with ASD. However, children with ASD need suitable tool or instruments with features that can support the affordance of presence, immediacy and immersion.

As children with ASD are more sensitive to full immersive exposure, Augmented Reality (AR) provides more intuitive interaction techniques that offer the opportunity to interact with 3D objects in real world [17].

The purpose of this paper is to investigate the potential of AR in supporting the interest-based learning approach for children with ASD. The rest of the paper is organized as follows: Section II provides an overview of Augmented Reality; Section III discuss the advantages of Augmented Reality in Autism education; Section IV discuss the proposed approach and finally Section V outlines the main conclusions.

II. Augmented reality

A. Understanding Augmented Reality

Augmented Reality (AR) is a computer technology that has broad potentials and advantages in sustaining many domain areas such as engineering, entertainment, medical, education and others where information are essentials. The technology has been believed can enhance our perception towards our real world experience in a new and enriched way with the assistance of computational models and elements. Although AR has been widely spread and gained much attention, researchers have different views and perspectives on AR. It begins with Azuma [18] who defined AR into three common key concept where (1) it combines real and virtual elements consisting of content or images, (2) able are to perform interactively in real time environment and (3) 3D registration of real and virtual objects.

Aligning AR as an emergent technology, van Krevelen & Poelman [19] viewed AR applications as the *"next generation, reality-based interface".* Ma & Choi [20] also stated their perspective on AR as representing high technologies that challenges the human perception through virtual telepresence, which may possibly affect the human life and cultures. Furthermore, AR also referred as a wide spectrum of technologies that may incorporate any computer-generated sensory input technologies such as sound, video, graphics or GPS data while it is able to *"bridge the gap between the real and virtual objects"* [4][5]. Through AR applications, real objects can be removed from the virtual environment, and replaced by virtual objects which known as *"mediated or diminished reality"* [2][6].

AR allows the process of overlaying and blending computer-generated information with physical objects on reality or real-time in a seamless way [24]. Through AR applications, virtual objects are displayed in the same space with real world objects which can enhance the experience or understanding of the user [6][8]. Described as the most recent development in human computer interaction technology, AR allows content of computer-generated three-dimensional (3-D) or virtual image illusions to be superimposed with the real scene in a non-immersive way [26]–[28].

B. AR System and Technology

AR technologies offers different features depending on cost, accessibility and usability in educational settings [29]. In general, the system and technology that supports AR are categorized into AR tracking technology, AR display technology, AR development tools and AR input and interaction technologies [30]. Vyas & Bhatt [21] had defined three types of AR system which comprises of (1) GPS and compass-based AR system, (2) Marker-based AR system, and (3) Marker-less AR system).

Location-based AR system uses on board GPS and compass to detect user's current location, thus facilitating user's navigation by aligning virtual objects with camera screen. Smith *et al.*[31] had developed a GPS-based AR system as a navigation tool for post-secondary students with intellectual disabilities.

Fig. 1. Screenshot of GPS-based AR system [31]

Marker-based AR system displays 3D related objects or photo by tracking on the visual marker. Marker-based AR use markers that are actually labels containing a colored or black and white pattern, then recognized or registered by the AR application through the camera of the device. For instance, to show a 3D image in the screen of the device located in the same position where the marker is [32]. A study conducted by Samihah *et al.* [33] on the computer-child interaction (CCI), had implemented the use of marker-based AR system as depicted in Fig.2.

Fig. 2. Screenshot of marker-based AR system [33]

Marker-less AR system rely on natural features to perform the object tracking and display the required outputs. Marker-less AR works based on the recognition of the object's shapes. Recent trends in using Microsoft Kinect sensor and similar technology in educational setting, provides some advantages in tracking and registering objects in marker-less AR.

Markers are used in most of the applications developed for educational settings since the tracking process of markers is better and more stable compared to the marker-less tracking techniques [32]. Location-based AR system also a major implementation in educational setting as it allows learning to be occurred beyond geographical limitation.

Mossel, Schönauer, Gerstweiler & Kaufmann [34] describe the key elements of an AR system that comprise of input and output devices for object tracking, a computing platform with a powerful graphics processor and an AR software framework which handling input, output and application functionalities. Camera is necessary as the optical trackers to capture the real environment in vision-based tracking techniques [22][24]. In AR applications, the data received from the real world via the camera or sensors are passed through a process and the resulting image is transferred to the real environment [35]. Available AR software are such as AR Toolkit, Metaio, Vuforia, Layar and Aurasma.

Display technologies are important in AR system. Two types of AR display technologies are monitor-based AR display and video see-through AR display with Head Mounted Display (HMD). In monitor-based AR display, computer system monitor is used as an output for visualization of AR system while in video see-through AR display, HMD is used to support the visual AR output to be viewed by the user [21]. Interaction techniques in AR system are either through tangible AR, collaborative AR or hybrid AR interface [24].

III. Advantages Of Implementing augmented reality in Special Education

Several studies has identified the advantages of AR in education settings. Eight (8) potential skill types that AR helps to build in education [36]:

- Developing spatial imagination
- Supporting creation and understanding of models
- Developing general language and scientific discussion
- Developing the ability to work in team
- Supporting creativity
- Developing decision-making skills
- Supporting the understanding of historical process
- Supporting critical thinking skills

Aligning AR to the potential skill types, a study conducted by McMahon et al. [37] found that AR experience allowed students to view context-relevant prompts in the physical world that effectively supported their decision-making needs in their related study. Another study by Khan, Johnston and Ophoff [38] showed the use of AR mobile application can increased the learning motivation of undergraduate health science students at the University of Cape Town (UCT). Wu *et al.* [39] suggest that the use of AR in educational setting could enable: (1) learning content in 3D perspectives, (2) ubiquitous, collaborative and situated learning, (3) learners' senses of presence, immediacy, and immersion, (4) visualizing the invisible, and (5) bridging formal and informal learning.

Educating special children may need different strategies and aims, which should be aligned to their capabilities. In this context of study, we had reviewed several articles related to the application of AR application to support the learning of children with ASD. Based on the reviews, we categorized the advantages of AR implementation for the learning environment of children with ASD into four (4) features as (1) Learning engagement; (2) Learning interaction; (3) Learning process; and (4) Learning motivation.

TABLE 1 ADVANTAGES OF AR IMPLEMENTATION IN CHILD WITH ASD'S LEARNING ENVIRONMENT

Advantages of AR for Children with ASD	Researchers
Increases engagement	Escobedo & Favela[40], Chen *et al.* [41]
Increase interaction to people and obejct	Nubia *et al.* [42],Lorenzo *et al.* [43], Sahin *et al.* [44],Uzuegbunam *et al.*[45], Kerdvibulvech & Wang [46], Bhatt, de Leon & Al Jumaily [47]
Assist in learning process	Lin *et al.* [48], Vullamparthi et al. [49] Tobar-muñoz, Fabregat & Baldiris[50], Lin *et al.* [51], Lin *et al.* [48],
Increase learning motivation	Brandao *et al.*[52], Lin *et al.* [51], Taryadi & Kurniawan [53] Smith *et al.*[31]

1) *Learning engagement*

AR technologies help learners engage in authentic exploration in the real world and virtual objects through supplementary elements such as texts, videos, and pictures [39]. Furthermore, AR have the ability to catch the children's imagination and to promote their attention [52]. As reported by Escobedo & Favela [40], their AR application known as MOBIS helped to increase the children with ASD to engage with people and objects, which were the main problems encountered by the teachers. While that, an AR application with video modeling storybook developed by Chen *et al.* [41] has attracted the attention of children with ASD to better understand facial expression and emotion of the storybook characters.

2) *Learning interaction*

The AR application developed by Nubia *et al.* [42] increased the verbal language of children with ASD compared to traditional method. A MEBook application developed by Uzuegbunam *et al.* [45], had explored the capabilities of AR in improving the social greetings of children with ASD with others through augmented self-images and gestured-based game. It provides feedback to user as the MEBook application allows to practice the social narrative intervention. Bhatt, de Leon and Al-Jumaily[47] developed two AR based educational games which focus on helping the children with ASD in recognizing other's human emotion and facial expression. Kerdvibulvech & Wang [46] developed a vision-based application based on augmented and mixed reality approaches that assists children with special problems in communication. Some improvement in communication skills among the children with ASD had been shown in a preliminary study of AR as the instruments conducted by

Lorenzo *et al*.[43]. Sahin *et al.* [44] developed Brain Face2Face tool with AR smart glass and the result shows improvement in social motivation and behavior skills.

3) Learning process

AR supports intuitive and interesting learning processes for children with special needs by combining the real and virtual worlds [54]. Children with ASD might views learning context into different perspectives. AR technology would be able to realize the learning content in a context understood by the children with ASD. Such as example, the difficulties in learning mathematic could be simplified by including object of interest that can attract the attention of children with ASD. As concluded by Lorenzo *et al.* [43], AR is an effective tool to explain complex concepts such as emotions to children with ASD which reflect their own feelings and to become more aware of different situations. Mancil & Pearl[55] emphasized that interest-based child learning approach is effective to nurture better academic outcome among children with ASD. A study by Tobar-muñoz, Fabregat & Baldiris[50] shows that AR when integrated with Digital Game based Learning (DGBL) could encouraged the integration of children with special needs into the learning process. Moreover, AR can be used as an effective vocabulary instruction tool and is capable of delivering content inside and outside of the classroom [56].

4) Learning motivation

AR improves learning gain and motivation [57]. Brandão *et al.* [52] created an AR GameBook with focus in helping the children with ASD to recognize facial expressions. The result shows that while developing social skills, the AR GameBook able to increase the children's motivation. Taryadi and Kurniawan [53] showed that AR facilitated the development of motivation or activity interaction through the developed AR system with Picture Exchange Communication System (PECS) technique. In the same way, Lin *et al.* [51] created mobile AR (MAR) application for student with ADHD and reading disabilities. The MAR design could stimulate children's motivation for the learning process because the teaching materials are easy to use.

The findings in this section are important in determining the elements required in creating the Augmented Reality based learning environment.

IV. Augmented Reality to support interest-based learning

Engagement and obsession with an interest that is unusual such as parts of moving objects is commonly observed in children with ASD. Despite of that, the incorporation of circumscribed interest (CI) in the teaching strategies and learning materials could improve academic engagement and outcome of the children with autism [10][54][57] [59][60]. Circumscribed interests or preferred interests among children with ASD may systemized into mechanical (e.g. vehicles), abstract (e.g. number patterns), natural (e.g. the tide) or collectible (e.g. a library classification index) [61]. Klin *et al.*[6] grouped circumscribed interest into (1) facts/ verbal memory and learning, (2) facts and activities/visual memory and learning, (3) sensory behaviors, (4) Math, (5) classifying/ordering information, (6) date and time, (7) hoarding and (8) letters and numbers.

AR provides an extraordinary contribution to special education in the context of controlled environment because the teachers can have more control over the content in the system, according to Wu *et al.* [51]. Without control, even with the incorporation of interest-based learning, children with ASD will have less focus on the instructed learning content. The teachers should have the controlling authority in AR learning environment. Therefore, they could adapt the needs of their students to support interest-based learning.

Furthermore, Wu *et al*.[51] identified the features and affordances of AR that could enable (1) learning content in 3D perspectives, (2) ubiquitous, collaborative and situated learning, (3) learners' senses of presence, immediacy, and immersion, (4) visualizing the invisible, and (5) bridging formal and informal learning. The AR affordance and features identified for each educational purposes are summarized in Table 2.

TABLE 2 AR Affordances And Features For Educational Purposes [51]

Educational Purposes (EP)	AR Affordance and Features
1. Learning content in 3D perspectives	**Features:** • Use of 3D synthetic objects for interaction to enhance learning experiences. • Visualize abstract concept **Affordance:** • 3D imagery/objects • Digital display of printed materials
2. Ubiquitous, collaborative and situated learning	**Features:** • Portability, social interactivity, context sensitivity, connectivity, and individuality **Affordance:** • Use of handheld computers in AR e.g : mobile devices, wireless connection, Kinect • Location-based support
3. Learners' senses of presence, immediacy, and immersion	**Features:** • AR provide a mediated space that gives learners a sense of being in a place with others. • AR brings together learners, virtual objects or information, and characters in a real environment to increase immediacy **Affordance:** • Integration with computer simulations, games, models, and virtual environments
4.Visualizing the invisible	**Features:** • Superimpose of virtual objects or information onto physical objects or environments enables visualization and understanding of invisible concepts, events or phenomena. **Affordance:** • Superimposing virtual objects onto physical objects/environment • Using virtual objects to augment real objects
5. Bridging formal and informal learning	**Features:** • Augment students' visualization, experiments, models and learning experience between the real scenario and the virtual environment. **Affordance:** • Connection between virtual and real environment

The features and affordance of AR might seem overlapping with each other, but there will be various approach required when aligning to each different educational purposes.

Next, it is important to identify how the AR affordance and features could support interest-based learning. Below we suggest suitable AR implementation to support the incorporation of circumscribed interest (CI) into interest-based learning. We adapted circumscribed interests categories identified by Klin *et al.* [6] and mapped each CI categories with suitable AR implementation.

TABLE 3 SUGGESTION OF THE SUITABLE AR IMPLEMENTATION FOR CIRCUMSCRIBED INTEREST (CI) CATEGORIES

Circumscribed Interests (CI) (Klin *et al.* [6].	**AR Implementation**
Facts/verbal memory and learning *(Collection of facts involving verbal memory)*	Marker-based AR to show digital display of models, appliances, equipment, such as car models, electronic appliances, etc.
Facts and activities/visual memory and learning *(Collection of facts or engagement in activities involving visual memory)*	• Game or activity that allows user to group object of preferences according to characteristics, • Block drawing or arrangement such as LEGOS
Sensory behaviors *(Activities related to seeking sensory stimulation, ordering objects, or sameness)*	• Using mobile devices or Kinect for sensing to touch or moving virtual objects such as lining up objects. • Integration with computer simulations, games, models, and virtual environments to create a mediated space .
Math *(Memorization of numerical facts, math procedures, or fascination with abstract shapes)*	• Visualizing numerical facts, math procedures abstract shapes into 3D imagery objects such as Cube counting game, dividing objects game, etc. • Computer simulation showing abstract shapes
Classifying /Ordering Information *(Learning of classification systems or attempts at classifying)*	Game or activity that allows user to group object of preferences according to characteristics.
Date and Time *(Dates of birth, calendars, time concepts)*	• Include calendar, scheduling and time counting in learning content. • Game-based learning with time limits.
Hoarding *(Collection of objects)*	Game or activity that allows user to collect object of preference using GPS based location, time based tasks, reward points or events.
Letters and numbers (Fascination with letters, numbers, reading, decoding)	• Game or activity that allows user to form letters and numbers using object of preferences, simple word spelling, etc. • Marker-based AR to show digital display of letters and numbers.

Vullamparthi *et al.* [49] in their study, found that AR is an effective tool to help children with ASD to understand the abstract concepts by associating with real life objects, household objects and social objects. Added by a study by Constantin *et al.* [62], personalized choice of rewards are important in designing computer based application for children with ASD. Preference for cartoon faces and object of interests can be used as extrinsic reward to reflect the progress of learning task. In this context, we define 'choice of reward' as having same meaning as 'choice of interest' or preferred interest which reflect the circumscribed interest.

Related with this study, instead of 2D images, we suggest that AR could enhance the perspective by creating for example the cartoon in 3D images and superimposing with real environment. Learners could be immersed in a blended physical environment and gained new experienced [41]. As some children with ASD might be more aggressive or physical weaker than normal children, incorporating AR would be an effective approach. The use of marker-less concept and integration with Kinect technology, would prevent direct physical connection with computer system. Children with ASD can interact with AR application in freedom without need to depend on mouse click or mobile touch.

Visualization of 3D objects to represent abstract concept could enhance imaginative function and symbolic play which is lack in children with ASD [63]. In the context of interest-based learning, the interaction of 3D imagery/object representing preferred interest and all the components could cultivate the development of learning process.

V. CONCLUSION

In general, AR has wide potential in supporting the therapy, intervention and education of children with ASD. With recent technological development, the utility and technology of AR provides features and affordance that can assist the teaching and learning process of children with ASD. Through overview of the AR systems and technology, the overall understanding on how AR applications will works were gained. Based on the previous studies, we identify three (3) advantages of AR in autism education which contributes to 1) learning engagement; 2) learning interaction and 3) learning process. Next, we proposed how AR can support the interest-based learning for children with ASD by determining the suitable AR implementations based on its affordance and features. Each circumscribed interests' categories of the children with ASD were mapped with the proposed AR implementations. This can be useful guidelines in designing and developing the AR application to support interest-based learning for children with ASD.

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REFERENCES

[1] K. C. M. Gunn and J. T. Delafield-butt, "Teaching children with autism spectrum disorder with restricted interests : a review of evidence for best practice," *Rev. Educ. Res.*, pp. 1–23, 2015.

[2] M. Dawson, L. Mottron and M. A. Gernsbacher, “Learning in autism,” *Autism*, pp. 759–772, 2008.

[3] N. Sparapani, L. Morgan, V. P. Reinhardt, C. Schatschneider, and A. M. Wetherby, “Evaluation of classroom active engagement in elementary students with autism spectrum disorder,” *J. Autism Dev. Disord.*, vol. 46, no. 3, pp. 782–796, 2016.

[4] D. Nemeth , J. Karolina, B. Virag, L. Zsuzsa, M. Robert, F. Marta, J. Szilvia, D. Izabella and V. Agnes, “Learning in autism: implicitly superb,” *PLoS One*, vol. 5, no. 7, pp. 1-7, 2010.

[5] F. Foti, F. De Crescenzo, G. Vivanti, D. Menghini, and S. Vicari, “Implicit learning in individuals with autism spectrum disorders : a meta-analysis,” *Psychol. Med.*, vol. 45, pp. 897–910, 2015.

[6] A. Klin, J. H. Danovitch, A. B. Merz, and F. R. Volkmar, “Circumscribed interests in higher functioning individuals with autism sSpectrum disorders: an exploratory study,” *Res. Pract. Pers. with Sev. Disabil.*, vol. 32, no. 2, pp. 89–100, 2007.

[7] O. E. Parsons, A. P. Bayliss, and A. Remington, “A few of my favorite things: circumscribed interests in autism are not accompanied by increased attentional salience on a personalized selective attention task,” *Mol. Autism*, vol. 8, no. 1, p. 20, 2017.

[8] S. Parsons, “Authenticity in virtual reality for assessment and intervention in autism: a conceptual review,” *Educ. Res. Rev.*, vol. 19, pp. 138–157, 2016.

[9] B. A. Boyd, S. G. Mcdonough, and J. W. Bodfish, “Evidence-based Behavioral Interventions for Repetitive Behaviors in Autism,” *J. Autism Dev. Disord.*, no. 42, pp. 1236–1248, 2012.

[10] M. A. Winter-messiers, C. M. Herr, C. E. Wood, A. P. Brooks, M. A. M. Gates, T. L. Houston, K. I. Tingstad, “How far can Brian ride the dylight 4449 express? a strength-based model of asperger syndrome based on special interest areas,” *Focus Autism Other Dev. Disabl.*, vol. 22, no. 2, pp. 67–79, 2007.

[11] K. C. M. Gunn and J. T. Delafield-Butt, “Teaching children with autism spectrum disorder with restricted interests: a review of evidence for best practice,” *Rev. Educ. Res.*, vol. 86, no. 2, pp. 408–430, 2016.

[12] C. K. Reutebuch, F. El Zein, and G. J. Roberts, “A systematic review of the effects of choice on academic outcomes for students with autism spectrum disorder,” *Res. Autism Spectr. Disord.*, vol. 20, pp. 1–16, 2015.

[13] C. J. Dunst, C. M. Trivette, and T. Masiello, “Exploratory investigation of the effects of interest-based learning on the development of young children with autism,” *Autism*, vol. 15, no. 3, pp. 295–306, 2011.

[14] S. Jung and D. M. Sainato, “Teaching games to young children with autism spectrum disorder using special interests and video modelling,” *J. Intellect. Dev. Disabil.*, vol. 40, no. 2, pp. 198–212, 2015.

[15] M. L. Da Silva, D. Gonçalves, T. Guerreirob, and H. Silva, “A web-based application to address individual interests of children with autism spectrum disorders,” *Procedia Comput. Sci.*, vol. 14, no. Dsai, pp. 20–27, 2012.

[16] M. Lucas, D. Gonc, and H. Silva, “User-tuned content customization for children with autism spectrum disorders,” *Procedia Comput. Sci.*, vol. 27, pp. 441–448, 2014.

[17] E. Richard, V. Billaudeau, P. Richard, and G. Gaudin, “Augmented reality for rehabilitation of cognitive disabled children: a preliminary study,” *2007 Virtual Rehabilitation*, no. 2, pp. 102–108, 2007.

[18] R. T. Azuma, “Survey of augmented reality,” *Presence*, vol. 6, no. 4, pp. 355–385, 1997.

[19] D. W. F. van Krevelen and R. Poelman, “A survey of augmented reality technologies, applications and limitations,” *Int. J. Virtual Real.*, vol. 9, no. 2, pp. 1–15, 2010.

[20] J. Y. Ma and J. S. Choi, “The virtuality and reality of Augmented Reality,” *J. Multimed.*, vol. 2, no. 1, pp. 32–37, 2007.

[21] D. A. Vyas and D. Bhatt, “Augmented Reality (AR) applications : a survey on current trends, challenges & future scope,” *Int. J. Adv. Res. Comput. Sci.*, vol. 8, no. 5, pp. 2724–2730, 2017.

[22] F. Manuri and A. Sanna, “A Survey on applications of augmented reality,” *Adv. Comput. Sci.*, vol. 5, no. 1, pp. 18–27, 2016.

[23] R. Azuma, R. Behringer, S. Feiner, S. Julier, and B. Macintyre, “Recent advances in augmented reality,” *IEEE Comput. Graph. Appl.*, pp. 34–47, 2001.

[24] F. Zhou, H. B. Duh, and M. Billinghurst, “Trends in augmented reality tracking, interaction and display : a review of ten years of ISMAR,” *ISMAR '08 Proceedings of the 7th IEEE/ACM International Symposium on Mixed and Augmented Reality*, pp. 193–202, 2008.

[25] D. R. Berryman, “Augmented Reality : A Review,” *Med. Ref. Serv. Q.*, vol. 31(2), no. December 2014, pp. 212–218, 2012.

[26] M. Billinghurst, A. Clark, and G. Lee, “A Survey of Augmented Reality,” *Found. Trends® Human–Computer Interact.*, vol. 8, no. 2–3, pp. 73–272, 2015.

[27] G. Kipper, “What Is Augmented Reality?,” *Augment. Real.*, pp. 1–27, 2013.

[28] S. Prince, A. D. Cheok, T. Williamson, N. Johnson, F. Farbiz, M. Billinghurst and H. Kato, “Live 3-dimensional content for augmented reality,” *IEEE Trans. Multimed.*, vol. 7, no. 3, pp. 514–523, 2005.

[29] M. Akcayir and G. Akcayir, “Advantages and challenges associated with augmentedreality for education: A systematic review of the literature,” *Educ. Res. Rev.*, pp. 1–38, 2016.

[30] M. Billinghurst, H. Kato, and S. Myojin, “Advanced interaction techniques for augmented reality applications,” *Third Int. Conf. Virtual Mix. Real.*, vol. 5622 LNCS, pp. 13–22, 2009.

[31] C. C. Smith, D. F. Cihak, B. Kim, D. D. McMahon, and R. Wright, “Examining augmented reality to improve navigation skills in postsecondary students with intellectual disability,” *J. Spec. Educ. Technol.*, vol. 32, no. 1, pp. 3–11, 2016.

[32] J. Bacca, S. Baldiris, R. Fabregat, and S. Graf, “Augmented reality trends in education : a systematic review of research and applications,” *Educ. Technol. Soc.*, vol. 17, no. 4, pp. 133–149, 2014.

[33] C. Samihah, C. Dalim, A. Dey, T. Piumsomboon, M. Billinghurst, and S. Sunar, “TeachAR : an interactive augmented reality tool for teaching basic english to non-native children,” in *IEEE International Symposium on Mixed and Augmented Reality Adjunct Proceedings*, 2016, pp. 82–86.

[34] A. Mossel, C. Schönauer, G. Gerstweiler, and H. Kaufmann, “ARTiFICe-augmented reality framework for distributed collaboration,” *Int. J. Virtual Real. (presented Work. Off-The-Shelf Virtual Reality, IEEE VR, USA, 2012)*, vol. 11, no. 3, pp. 1–7, 2012.

[35] R. Cakir and O. Korkmaz, “The effectiveness of augmented reality environments on individuals with special education needs,” *Educ. Inf. Technol.*, vol. 24, no. 2, pp. 1631–1659, 2018.

[36] M. Wójcik, “Potential use of augmented reality in LIS education,” *Educ. Inf. Technol.*, vol. 21, no. 6, pp. 1555–1569, 2015.

[37] D. McMahon, D. F. Cihak, and R. Wright, “Augmented reality as a navigation tool to employment opportunities for postsecondary education students with intellectual disabilities and Autism,” *J. Res. Technol. Educ.*, vol. 47, no. 3, pp. 157–172, 2015.

[38] T. Khan, K. Johnston, and J. Ophoff, “The Impact of an augmented reality application on learning motivation of students,” *Adv. Human-Computer Interact.*, pp. 1–14, 2019.

[39] H.-K. Wu, S. W.-Y. Lee, H.-Y. Chang, and J.-C. Liang, “Current status, opportunities and challenges of augmented reality in education,” *Comput. Educ.*, vol. 62, pp. 41–49, Mar. 2013.

[40] L. Escobedo and J. Favela, “Using augmented reality to help children

with autism stay focused," *Pervasive Comput.*, pp. 38–46, 2014.

[41] C. H. Chen, C. Y. Huang, and Y. Y. Chou, "Effects of augmented reality-based multidimensional concept maps on students' learning achievement, motivation and acceptance," *Univers. Access Inf. Soc.*, no. 1, pp. 1–12, 2017.

[42] R. M. Nubia, G. R. Fabian, R. A. Wilson, and P. B. Wilmer, "Development of a mobile application in augmented reality to improve the communication field of autistic children at a neurorehabilitar clinic," in *2015 Workshop on Engineering Applications - International Congress on Engineering (WEA)*, pp. 1–6, 2015.

[43] G. Lorenzo, M. Gómez-puerta, G. Arráez-vera, A. Lorenzo-lledó, and G. Lorenzo, "Preliminary study of augmented reality as an instrument for improvement of social skills in children with autism spectrum disorder," *Educ. Inf. Technol.*, vol. 24, no. 1, pp. 181–204, 2019.

[44] N. T. Sahin, R. Abdus-Sabur, N. U. Keshav, R. Liu, J. P. Salisbury, and A. Vahabzadeh, "Augmented reality intervention for social communication in autism in a school classroom : rated by teachers and parents as effective and usable in a controlled, longitudinal pilot study," *PsyArXiv*, pp. 1–10, 2018.

[45] N. Uzuegbunam, W. H. Wong, S.-C. S. Cheung, and L. Ruble, "MEBook multimedia social greetings intervention for children with autism spectrum disorders," *IEEE Trans. Learn. Technol.*, pp. 1–17, 2016.

[46] C. Kerdvibulvech and C. Wang, "A new 3D augmented reality application for educational games to help children in communication interactively," in *ICCSA 2016*, vol. 2, pp. 465–473, 2016.

[47] S. K. Bhatt, N. I. De Leon, and A. Al-Jumaily, "Augmented reality game theraphy for children with autism spectrum disorder," in *International Journal on Smart Sensing and Intelligent Systems*, vol. 7, no. 2, pp. 519–536, 2014.

[48] C. Lin *et al.*, "Using free augmented reality app in teaching programs for children with disabilities," *Displays*, pp. 2–5, 2015.

[49] A. J. Vullamparthi, S. C. B. Nelaturu, D. D. Mallaya, and C. S, "Assistive learning for children with autism using augmented reality speaking albums and visual auditory schedulers," in *2013 IEEE 5th International Conference on Technology for Education*, pp. 43–46, 2013.

[50] H. Tobar-muñoz, R. Fabregat, and S. Baldiris, "Augmented reality game-based learning for mathematics skills training in inclusive contexts," *Inf. Educ.*, pp. 39–51, 2015.

[51] C. Lin, W. Yu, W. Chen, C. Huang, and C. Lin, "The effect of literacy learning via mobile augmented reality for the students with ADHD and reading disabilities," in *International Conference on Universal Access in Human-Computer Interaction*, pp. 103–111, 2016.

[52] J. Brandão, P. Cunha, J. Vasconcelos, V. Carvalho, and F. Soares, "An augmented reality gamebook for children with autism spectrum disorders," in *The International Conference on E-Learning in the Workplace 2015*, pp. 1–6, 2015.

[53] Taryadi and I. Kurniawan, "Multimedia augmented reality with picture exchange communication system for autism spectrum disorder," *Int. J. Comput. Sci. Technol.*, vol. 7, no. 4, pp. 102–106, 2016.

[54] C-Y. Lin, H-C. Chai, J-Y.Wang, C-J. Chen, Y-H. Liu, C-W. Chen, C-W. Lin and Y-M. Huang, "Augmented reality in educational activities for children with disabilities," *Displays*, vol. 42, pp. 51–54, 2016.

[55] G. R. Mancil and C. E. Pearl, "Restricted interests as motivators: improving academic engagement and outcomes of children on the autism spectrum," *Teach. Except. Child. Plus*, vol. 4, no. 6, p. 15, 2008.

[56] D. D. McMahon, D. F. Cihak, R. E. Wright and S. M. Bell, "Augmented reality for teaching science vocabulary to postsecondary education students with intellectual disabilities and autism," *J. Res. Technol. Educ.*, vol. 1523, no. February, pp. 38–56, 2016.

[57] J. Garzón, J. Pavón, and S. Baldiris, "Augmented reality applications for education: Five directions for future research," *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, vol. 10324 LNCS. pp. 402–414, 2017.

[58] M. Winter-Messiers, "From tarantulas to toilet brushes," *Remedial Spec. Educ.*, vol. 28, no. 3, pp. 140–152, 2007.

[59] T. S. Brown and T. Stanton-Chapman, "Strategies for teaching children with autism who display or demonstrate circumscribed interests," *Young Except. Child.*, vol. 18, no. 4, pp. 31–40, 2015.

[60] L. K. Koegel, A. K. Singh, and R. L. Koegel, "Improving motivation for academics in children with autism," *J. Autism Dev. Disord.*, vol. 40, no. 9, pp. 1057–1066, 2010.

[61] C. L. Caldwell-Harris and C. J. Jordan, "Systemizing and special interests: characterizing the continuum from neurotypical to autism spectrum disorder," *Learn. Individ. Differ.*, vol. 29, pp. 98–105, 2014.

[62] A. Constantin, H. Johnson, E. Smith, D. Lengyel, and M. Brosnan, "Designing computer-based rewards with and for children with autism spectrum disorder and / or intellectual disability," *Comput. Human Behav.*, vol. 75, pp. 404–414, 2017.

[63] Z. Bai, "Augmented reality interfaces for symbolic play in early childhood," *Technical Report published by the University of Cambridge Computer Laboratory*, issue 874, pp. 1-292, 2014.