

THE EFFECTIVENESS OF MIXED REALITY-BASED INTERVENTION FOR CHILDREN
WITH AUTISM SPECTRUM DISORDERS: A META-ANALYSIS AND SINGLE-CASE
STUDY

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DEDICATION

To my wife

Sungsoon Yoon, *the love of my life*

my son

Ethan Kim, *my everything*

and my parents

Jean-ho Kim and Jungsun Choi, *the best people of my life*

Thank you all for your love!

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Remember how the Lord your God led you all the way
in the desert these forty years, to humble you and to test you
in order to know what was in your heart, whether or not
you would keep his commands.
He humbled you, causing you to hunger and then feeding you
with manna, which neither you nor your fathers had known,
to teach you that man does not live on bread alone
but on every word that comes from the mouth of the Lord.
Your clothes did not wear out and your feet did not swell
during these forty years.
Know then in your heart that as a man disciplines his son,
so the Lord your God disciplines you.
Observe the commands of the Lord your God,
walking in his ways and revering him.

Deuteronomy 8:2-6

ABSTRACT

The development of technology has led to the development of various software and application as well as computer-based devices, and is extending its influence even to the mixed reality domain. These technologies are being used actively in the education field for students without disabilities as well as for students with disabilities. In recent years, the instructional application of technology has been accelerated by the development and dissemination of hand-held smart devices. These technologies are increasingly promoting the participation of students with ASD in education and rehabilitation programs. Currently, the number of apps developed as interventions for students with ASD is consistently on the rise, and researchers are presenting findings through various experimental studies showing whether these technologies can effectively educate and involve students with ASD in a learning process. The purpose of this dissertation was to investigate the effects of mixed reality-based intervention studies to date and to provide evidences for teaching effectiveness from examining the areas less covered by researchers.

TABLE OF CONTENTS

CHAPTER 1: UNDERSTANDING MIXED REALITY AS AN INTERVENTION TOOL FOR CHILDREN WITH AUTISM SPECTRUM DISORDERS	1
PROBLEM STATEMENT	1
PURPOSE OF STUDY	6
<i>Key Terms</i>	<i>8</i>
CONCEPTUAL FRAMEWORK	10
<i>Technology Use and Self-Directed Learning.....</i>	<i>10</i>
<i>Motivation and Play</i>	<i>11</i>
CHAPTER 2: LITERATURE REVIEW	17
MIXED REALITY: VIRTUAL REALITY	17
<i>Understanding Virtual Reality</i>	<i>17</i>
<i>Virtual Reality Intervention for Students with ASD.....</i>	<i>18</i>
MIXED REALITY: AUGMENTED REALITY	20
<i>Understanding Augmented Reality</i>	<i>20</i>
<i>Definition of Augmented Reality.....</i>	<i>20</i>
<i>Characteristics of Augmented Reality.....</i>	<i>22</i>
EDUCATIONAL STRENGTHS OF AUGMENTED REALITY AND LEARNING-PROMOTING FACTORS	24
<i>Educational Strengths of Augmented Reality.....</i>	<i>25</i>
<i>Learning-Promoting Factors.....</i>	<i>26</i>
PRACTICES AND/OR STRATEGIES USED IN EARLY INTERVENTION AND EARLY CHILDHOOD SPECIAL EDUCATION TO SUPPORT LANGUAGE DEVELOPMENT FOR CHILDREN WITH AUTISM SPECTRUM DISORDERS	29
<i>Defining Autism Spectrum Disorders</i>	<i>29</i>
<i>Communication Characteristics of Children with ASD</i>	<i>30</i>
<i>Echolalia</i>	<i>32</i>
AUTISM SPECTRUM DISORDER AND VOCABULARY ACQUISITION	33
<i>Vocabulary Acquisition of Children with ASD.....</i>	<i>33</i>
<i>Vocabulary Intervention Method</i>	<i>36</i>
<i>Vocabulary Intervention in Previous Studies</i>	<i>36</i>
<i>Teaching Science Vocabulary</i>	<i>38</i>
PURPOSE OF RESEARCH	40
RESEARCH QUESTIONS	41
CHAPTER 3: DOES MIXED REALITY WORK FOR STUDENTS WITH AUTISM SPECTRUM DISORDERS?: EVIDENCE FROM A META-ANALYSIS.....	43
METHODS.....	47
<i>Identification of Studies.....</i>	<i>47</i>
<i>Evaluation of the Quality of the Studies</i>	<i>50</i>
<i>Data Coding and Target Variables.....</i>	<i>50</i>
<i>Data Analysis Procedures.....</i>	<i>52</i>
RESULTS	56
<i>Summary of Selected Mixed Reality-Based Intervention Studies.....</i>	<i>56</i>
<i>Meta-Analysis of Mixed Reality-Based Intervention: Group Design Studies</i>	<i>75</i>
<i>Meta-Analysis of Mixed Reality-Based Intervention: Single-Case Design Studies</i>	<i>84</i>

DISCUSSION.....	91
<i>Limitations</i>	94
<i>Future Studies</i>	95
CHAPTER 4: AUGMENTED REALITY AS AN INSTRUCTIONAL TOOL FOR TEACHING SCIENCE VOCABULARY AND LIFE-CYCLE TO PRESCHOOL CHILDREN WITH AUTISM SPECTRUM DISORDERS.....	97
METHODS.....	101
<i>Participants</i>	101
<i>Settings</i>	104
<i>Materials</i>	104
<i>Variables and Data Collection</i>	107
<i>Design</i>	107
<i>Procedures</i>	108
<i>Maintenance</i>	109
<i>Data Analysis Procedures</i>	110
<i>Interobserver Agreement and Procedural Reliability</i>	111
<i>Social Validity</i>	112
RESULTS	112
<i>Social Validity and Teacher's Opinion Results</i>	115
DISCUSSION.....	116
<i>Limitations</i>	118
<i>Future Studies</i>	119
CHAPTER 5: IMPLICATIONS FOR THE FUTURE OF MIXED REALITY IN SPECIAL EDUCATION	121
<i>Motivation and Learning</i>	122
<i>Meta-Analysis of Mixed Reality-Based Intervention</i>	123
<i>Science Education for Children with Disabilities</i>	124
LIMITATIONS	125
FUTURE RESEARCH	126
REFERENCES.....	128
APPENDICES.....	176
APPENDIX A. ESSENTIAL QUALITY INDICATORS OF GROUP DESIGN STUDIES.....	177
APPENDIX B. ESSENTIAL QUALITY INDICATORS OF SINGLE-CASE DESIGN STUDIES.....	181
APPENDIX C. DATA COLLECTION INSTRUMENT: STUDY 2 LANGUAGE INTERVENTION	185
APPENDIX D. TREATMENT INTEGRITY CHECKLIST: STUDY 2 LANGUAGE INTERVENTION.....	188
APPENDIX E. SOCIAL VALIDITY QUESTIONNAIRE FOR CHILDREN: STUDY 2 SCIENCE VOCABULARY INTERVENTION	189
APPENDIX F. SOCIAL VALIDITY QUESTIONNAIRE FOR TEACHERS: STUDY 2 SCIENCE VOCABULARY INTERVENTION	190
VITA	191

LIST OF TABLES

TABLE 2.1. EDUCATIONAL BENEFITS OF AUGMENTED REALITY	28
TABLE 3.1. CODING DATA FOR MODERATORS.	51
TABLE 3.2. SUMMARY OF THE FEATURES OF SELECTED STUDIES FOR GROUP DESIGNS	58
TABLE 3.3. QUALITY ASSESSMENT FOR GROUP DESIGNS	65
TABLE 3.4. SUMMARY OF THE FEATHERS OF SELECTED STUDIES FOR SINGLE-CASE DESIGNS.....	67
TABLE 3.5. QUALITY ASSESSMENT RESULTS FOR SINGLE-CASE DESIGNS	73
TABLE 3.6. AVERAGE EFFECT SIZE OF THE SELECTED GROUP DESIGN STUDIES	76
TABLE 3.7. GROUP DESIGN EFFECT SIZES BY OUTCOMES	77
TABLE 3.8. GROUP DESIGN EFFECT SIZES BY MODERATORS.....	79
TABLE 3.9. GROUP DESIGN EFFECT SIZES BY INSTRUCTIONAL TIME AND SESSIONS	80
TABLE 3.10. GROUP DESIGN EFFECT SIZES BY GENDER.....	81
TABLE 3.11. ADJUSTED GROUP DESIGN EFFECT SIZES BY DUVAL AND TWEEDIE'S TRIM-AND-FILL	83
TABLE 3.12. AVERAGE EFFECT SIZE OF THE SELECTED SINGLE-CASE DESIGN STUDIES	84
TABLE 3.13. EFFECT SIZES OF SINGLE-CASE DESIGN BY OUTCOMES	86
TABLE 3.14. EFFECT SIZES OF SINGLE-CASE DESIGN BY ASD TYPES	87
TABLE 3.15. EFFECT SIZES OF SINGLE-CASE DESIGN BY INSTRUCTIONAL TIME AND SESSIONS...	88
TABLE 3.16. EFFECT SIZES OF SINGLE-CASE DESIGN BY GENDER	89
TABLE 3.17. ADJUSTED SINGLE-CASE DESIGN EFFECT SIZES BY DUVAL AND TWEEDIE'S TRIM- AND-FILL	91
TABLE 4.1. CHARACTERISTICS OF PARTICIPANTS	102
TABLE 4.2. TEACHERS' RESPONSES TO THE OPEN-ENDED QUESTIONS	116

LIST OF FIGURES

FIGURE 1.1. CONCEPTUAL FRAMEWORK MODEL	15
FIGURE 2.1. REALITY-VIRTUALITY CONTINUUM	22
FIGURE 3.1. PRISMA FLOWCHART FOR STUDY IDENTIFICATION AND SELECTED PROCESS FOR THIS STUDY	49
FIGURE 3.2. RESULTS OF THE OVERALL EFFECT SIZE OF GROUP DESIGN STUDIES	75
FIGURE 3.3. REGRESSION ON HEDGES'G ON GENDER OF GROUP DESIGN STUDIES	82
FIGURE 3.4. FUNNEL PLOT OF PRECISION BY HEDGES'G OF GROUP DESIGN STUDIES	83
FIGURE 3.5. RESULTS OF THE OVERALL EFFECT SIZE OF SINGLE-CASE DESIGN STUDIES	85
FIGURE 3.6. REGRESSION ON POINT ESTIMATE OF SINGLE-CASE DESIGN ON GENDER	90
FIGURE 3.7. FUNNEL PLOT OF PRECISION BY POINT OF ESTIMATE	91
FIGURE 4.1. EXAMPLE OF AR-BASED INTERVENTION	110
FIGURE 4.2. PARTICIPANTS' PERCENTAGE OF CORRECT RESPONSES	114

CHAPTER 1

UNDERSTANDING MIXED REALITY AS AN INTERVENTION TOOL FOR CHILDREN WITH AUTISM SPECTRUM DISORDERS

Problem Statement

Modern society can be defined as being more high-tech and marked by overall change faster than any time in the past (Izatt et al., 2014; Ku, Liao, & Hsing, 2005). Along with the rapid progress of technologies, our daily life is also changing rapidly. For example, people check emails, read newspapers, and invest in stocks through their mobile devices. High-tech devices have not only changed daily life but also have changed education in many ways. One of change in education field is the use of Assistive Technology (AT).

AT is defined by the Individuals with Disabilities Education Act (IDEA) as “any item, piece of equipment, or product system, whether acquired commercially off the shelf, modified, or customized, that is used in increase, maintain, or improve functional capabilities of a child with a disability” (IDEA 2004 U.S.C. 1401(1)). Thus, IDEA (2004) also requires educators to consider using AT devices and services for children with disabilities. For this requirement, high-tech AT devices and services are used for various types of disabilities in 21st century (Campbell, Milbourne, Dugan, & Wilcox, 2006; Flanagan, Bouck, & Richardson, 2013).

The development of technology has facilitated the development of AT devices and programs in educational settings, which in turn led to various changes in teaching contents, materials, and methods (Reichle, 2011). Similarly, the development of AT has created interests in the engineering approach to special education, and thus, the development of AT devices and use of various software for students with disabilities have become an essential task (Campbell et al., 2006; Reichle, 2011).

With the active development and dissemination of smart learning in recent years, the advantages of high-tech AT devices are considered as an alternative to address the problems facing students with Autism Spectrum Disorders (ASD) (Stasolla et al., 2015; Still et al., 2014). In many cases, students with ASD have various complicated difficulties in learning skills, including communication and social skills, while they show their abilities and strengths in many different ways (Armstrong, 2012; Simpson et al., 2005).

In general, children with ASD face challenges in the domains of communication, social skills, and behavior problem (Johnson & Myers, 2007); and educational supports for them are provided in such context. Because researchers have shown that children with ASD are very strong visual learners (Brian, Tipper, Weaver, & Bryson, 2003; Meadan et al., 2011; Trembath, Vivanti, Iacono, & Dissanayake, 2015), providing them with visual supports are essential and can be an effective strategy (Ganz, Boles, Goodwyn, & Flores, 2014; Van Laarhoven et al., 2010; Rao & Gagie, 2006). Thus, high-tech AT devices providing visual stimulation, such as photos, pictures, and videos, can be recommended as effective education instruments to support the development of communication, social skills, and positive behavior of children with ASD. One of the most promising AT devices, for educating of children with ASD, is Mixed Reality.

Mixed reality is a continuum in the field of three dimensional (3D) virtual technology that describes the intersection of the real-world and virtual world (Milgram, Takemura, Utsumi, & Kishino, 1994). This continuum includes both virtual reality (VR) and augmented reality (AR), which augments the real-world with synthetic electronic data (Tamura, Yamamoto, & Katayama, 2001).

VR as an AT is a fully artificial digital environment using 3D graphics in which a user interacts with the educational resources existing in various cyber spaces (Delwich, 2006;

Fairfield, 2001; Lee & Kim, 2010). VR provides a 3D simulation of a real or virtual environment through a computer of virtual device (Cobb, Kerr, & Glover, 2001) and is also referred to as a virtual environment, virtual world, or artificial reality (Lee & Kim, 2010; Yang, Lee, & Suh, 2017). VR is divided into a single-user virtual environment (SVE) and a collaborative virtual environment (CVE). Both types allow users to interact freely with an individual avatar in a virtual environment (Gerhard, Moore, & Hobbs, 2004). SVEs, however, have limited interaction with the user's virtual environment and can only provide pre-programmed responses (Cobb et al., 2002), while CVEs have the difference that a user can interact with one or more avatars simultaneously and receive real-time responses (Cheng, Chiang, Ye, & Cheng, 2010; Moore, Cheng, McGrath, & Powell, 2005).

VR-based intervention for children with ASD can be discussed in four aspects. First, it facilitates learning because it utilizes the strength of children with ASD who are good at processing information on visual stimuli. Second, it can alleviate the selection problem from over-stimuli in children with ASD and increase their attention. Third, it creates stable and predictable educational environments for children with ASD. Lastly, it provides a learning environment where children with ASD can practice repeatedly and easily generalize what they learn (Yang et al., 2017). With these reasons, studies applying VR-based interventions for children with ASD are increasing in many areas such as social communication (Cheng & Huang; 2012; Cheng et al., 2010; Moore et al., 2005), development and maintenance of social relations (Cheng & Ye, 2010; Ke & Im, 2013; Mitchell, Parsons, & Leonard, 2007; Parsons, Leonard, & Mitchell, 2006; Stichter et al., 2014), cognitive interventions (Lorenzo et al., 2016; Strickland et al., 2013), and teaching safety skills (Self, Scudder, Webbe, & Ma, 2007; Strickland et al., 2013).

A type of mixed reality, AR is a combined word of ‘augmentation’ and ‘reality’, and refers to a computer graphic technique that combines a virtual object or information with the actual environment, making it look like an object in the original environment (Billinghurst & Kato, 2002). It is a technique that provides users with various form of meaningful information on a real-time basis by augmenting the information entered through video sensors with computer to vivid 3-Dimensional (3D) information and content in the actual environment (Shelton, 2003). This technique can not only provide additional knowledge or pleasure to users, but also enhance motivation and flow, which are important factors in education, because contents are combined with the actual environment in a sophisticated manner (Bower et al., 2014; Bressler & Bodzin, 2013).

AR is a technique that provides enhanced learning flow and presence to users by seamlessly combining the actual world with the virtual world on a real-time basis (Azuma, 1997), and has a significant educational potential, in that it can provide an experience-based learning environment to learners. In this regard, Shelton (2003) found that the educational application of AR can promote active learning, empirical learning, intentional learning, actual learning, and cooperative learning of learners. In addition, AR is expected to be a next generation learning model for improving learning effects, because it has overcome the problems of existing smart learning contents, such as failures to motivate and interest learners and the limitations of interaction, and can establish a more realistic, authentic, engaging, and fun learning environment (Kirkely & Kirkely, 2004).

As such, AR can provide a high level of presence, offer learning flow, in which users feel as if they were in actual places (Oh, 2012). For these reasons, AR can be used much effectively in special education contexts, where realistic experiences and repetition are required. In

particular, considering that classes for students with ASD require an intuitive instructional design in which concrete materials are operated and routine experiences are offered (Scruggs & Mastropieri, 1994), AR allows educators to simultaneously provide customized multimedia materials and modeling materials with various subjects to be effectively used in class for children with ASD.

Currently, AR is used in various fields, including broadcasting, medicine, and education, with a proven level of effectiveness (Takatalo, Nyman, & Laaksonen, 2008). Studies on AR are conducted in the general education field, as well as special education area. In fact, the number of apps developed specifically for students with ASD have continued to increase (Seeton, 2009), and several experimental studies have presented the bases for the effective ways of teaching students with ASD and helping them participate in the education processes (Friedlander & Besko-Maughan, 2012; Seeton, 2009). For example, McMahon, Cihak, and Wright (2015) conducted a study to compare the effects of navigation using AR and paper-based navigation with students with ASD. They found that all participants could travel more successfully using AR compared to paper-based map. Fecich (2014) conducted a study using AR books in order to enhance vocabulary acquisition for students with disabilities. She found that AR books increased vocabulary acquisition scores from before the activity to after the activity. Although various approaches to AR have been investigated in special education, unfortunately, few studies have been conducted on language skills of children with ASD.

One of the biggest challenges that children with ASD face is language (American Psychiatric Association: APA, 2013; Parlade & Iverson, 2015; Shumway & Wetherby, 2009). The major characteristics of students with ASD in language include deficiency in communication, delay in language development, use of repetitive and rigid language, and

problem in starting and maintaining conversation (APA, 2013; Matson & Neal, 2010; Parlade & Iverson, 2015; Wetherby & Prinzant, 2000). However, children with ASD have the advantage of processing visual information (Cohen & Sloan, 2007; Litras, Moore, & Anderson, 2010; Ozonoff & Cathcart, 1998), not just the difficulties mentioned above.

Words are the basis for living and learning, vocabulary acquisition is essential among language skills for the independent life of children with ASD (Heflin & Alaimo, 2007). Because language deficiencies in children with ASD are a comprehensive problem affecting many other areas, not single area (e.g., academic area) (Parlade & Iverson, 2015; Shumway & Wetherby, 2009). Especially, vocabulary knowledge of scientific terms is important to understanding science. However, students with disabilities have difficulty learning science vocabulary and concepts. In addition, they have difficulty understanding the textbook material in a structured way, or they find it difficult to grasp the causal relationships (Mastropieri, Scruggs, Boon, & Carter, 2011). To improve their science vocabulary knowledge, what is needed is not textual information processing but a comprehensive approach using their strengths. For children with ASD, considering that they tend to have a visual strength, in which they recall an image when they think and understand a concept (Brian et al., 2003; Meadan et al., 2011), AR is also anticipated to be very effective in educating children with ASD like VR.

Purpose of Study

The purpose of this dissertation is to evaluate the effectiveness of mixed reality-based intervention including VR and AR by conducting a meta-analysis, and to empirically examine the effectiveness of AR for science vocabulary acquisition for children with ASD.

Study 1

The purpose of this study is to examine the effectiveness of mixed reality-based intervention and confirm the validity of practical application by conducting a meta-analysis on mixed reality-based intervention studies performed on students with ASD. In order to achieve the purpose of this study, the following research questions:

1. What are the general characteristics of mixed reality-based intervention studies for students with ASD?
2. What is the overall effect size of mixed reality-based intervention for students with ASD?
3. What is the effect of the moderators on the size of the effect of mixed reality-based intervention?
4. Is there a publication bias in mixed reality-based studies?

Study 2

The purpose of this study is to evaluate the effectiveness of augmented reality-based intervention to teach children with ASD science related vocabulary words:

1. What are the effects of augmented reality-based intervention on the acquisition of science vocabulary words of children with ASD?
2. What are the effects of augmented reality-based intervention on the acquisition of life-cycle knowledge of children with ASD?
3. Do children with ASD find augmented reality-based vocabulary intervention to learn new science vocabulary words socially acceptable?
4. What are the teachers' opinion of using augmented reality-based vocabulary intervention?

Key Terms

Augmented Reality: Augmented reality as part of mixed reality is a combined word of ‘augmentation’ and ‘reality’, and it refers to a computer graphic technique that combines a virtual object or information with the virtual object or information with the actual environment, making it look like an object in the original environment (Billinghurst & Kato, 2002).

Virtual Reality: A fully artificial digital environment using 3D graphics in which a user interacts with the educational resources existing in various cyber spaces (Delwich, 2006; Fairfield, 2001; Lee & Kim, 2010).

Mixed Reality: A continuum in the field of 3D virtual technology that describes the intersection of the real-world and virtual world (Milgram et al., 1994). This continuum includes both virtual reality and augmented reality, which augments the real-world with synthetic electronic data (Tamura et al., 2001).

Random-effects Model: A statistical model that includes both within-group sampling error and between-study variance in the computation of mean effects and confidence intervals (Littell, Corcoran, Pillai, 2008, p. 177).

Fixed-effects Model: An approach for estimating mean effects that assumes all studies come from a population in which there is one true effect that does not vary (Littell et al., 2008, p.175).

Heterogeneity: The extent of variation in a distribution of effect sizes. Includes differences between studies in terms of outcomes (statistical heterogeneity), populations (clinical heterogeneity), and methods (methodological differences) (Littell et al., 2008, p. 175).

Meta-regression: A statistical analysis in which the potential impact of one or more continuous variables is assessed on a dependent variable (i.e., effect size in meta-analysis)

(Littell et al., 2008, p. 176).

Meta-Analysis of Variance (ANOVA): A statistical analysis in which the potential impact of one or more categorical variables is assessed on a dependent variable (i.e., effect size in meta-analysis) (Borenstein, Hedges, Higgins, & Rothstein, 2009; Littell et al., 2008).

Forest Plot: A visual display of effect sizes and confidence intervals from one or more studies (Littell et al., 2008, p. 175).

Funnel Plot: A graphical method for detecting publication bias, other sources of bias, and small sample effects; based on the assumption that study effect sizes are normally distributed around the mean effect (Littell et al., 2008, p. 175).

Conceptual Framework

Children with ASD deal with various complex problems in regards to communication, social skills, and learning skills all the while also expressing various abilities and advantages (Simpson et al., 2005). Despite these challenges, children with ASD have the advantage and ability to understand signals throughout the environment visually rather than through language, they are also referred to as strong visual learners (Cafiero, 1998; Rao & Gagie, 2006). Here I argue that this research will draw on that strength via the use of visual digital technologies to enhance children learning, while also fostering motivation and engagement.

Technology Use and Self-Directed Learning

Generally, children with ASD are reported to process visual support with ease compared to other communication method (Quill, 1995). Also, visual supports allow those with ASD to focus, understand language, and allow them to organize and make connections regarding the environment (Hodgdon, 1995). Thus, according to Hodgdon (1995), by providing visual supports as a scaffolding tool to allow one to focus, visually process information, and develop organization skills, he asserts that children with ASD will benefit in terms of reduced problem behaviors and increasing positive behaviors, by communicating through visual support.

There is not one single best approach for the education of children with ASD, but because they are very strong visual learners (Meadan et al., 2011), providing learning supports similar to smart learning could be an effective strategy in helping them to understand and process the big picture (Armstrong, 2012; Cohen & Sloan, 2007; Rao & Gagie, 2006).

Promoting efficacy and efficiency are important elements for successful education. Educators can produce successful outcomes if they effectively use resources at hand. Using children's strengths are good way to improve education effectiveness. For this reason, IDEA

(2004) mandates educational programs should be “based on the individual child’s needs, taking into account the child’s strengths, preferences, and interests” (§300.42(a)(2)). As I mentioned above, students with ASD have typically visual strengths, and AT can be a good approach for visual supports. Additionally, IDEA (2004) requires that educators including teachers and/or researchers consider using AT devices and services to children with disabilities.

Recently, there has been a considerable rise in adaptation of mobile technology in education for children with ASD with concurrent development in technology such as iPod and tablet PC. According to Traxler (2007), the benefits of mobile technology in education are as such: First, the learner’s needs are met virtually anywhere due to ubiquity. Due to the nature of mobile technology as being free from the constraints of location and time, learning can be achieved immediately, thus the efficiency and effectiveness of learning can be maximized. Second, self-directed learning is possible. The learner can choose the content to fit their needs while being able to adjust one’s speed and quantity of learning. Third, in the process of self-directed learning the student can benefit from the feedback provided by AT thus enhancing one’s educational performance. Also, mobile devices are an attractive medium because mobile devices are fairly commonplace for the younger generations (Zickuhr, 2011), its use can help the social integration of children with disabilities and lessen the repulsion of children without disabilities towards those with disabilities (Lim & Park, 2012). Lastly, AT can maximize the visual information processing strengths of students with ASD.

Motivation and Play

Education for children with ASD needs to draw attention and interest in such visual education and requires an instructional approach that can help the students retain what they learn. Of various approaches in this regard, mixed reality has been frequently used in recent years. The

greatest potential of mixed reality is that it can enhance learning motivation of children with ASD by maximally utilizing their visual advantages. Although learning motivation varies depending on the personal traits of learners, intentionally promoting and sustaining motivation has significance in education. In this regard, Keller (1983) proposed ARCS model as a strategy to design learning based on the motivation theory, so that learners can have learning flow and interest in learning and sustain the learning.

According to Keller's ARCS model, learning motivation is improved by promoting the main areas of attention, relevance, confidence, and satisfaction. Attention means that learners are interested and focused by learning stimulation. Relevance means that learners perceive the need for learning. Confidence refers to a belief that learners can successfully finish learning assignments. Satisfaction is achieved when learners have a positive feeling as they are pleased with their performance (Keller, 1983). The ARCS model with these factors are used as a theoretical and/or conceptual model in studies using mixed reality in the AT area, because mixed reality is very appropriate method to satisfy A (Attention), R (Relevance), C (Confidence), and S (Satisfaction) (Bolliger, Supanakom, & Boggs, 2010; Chyung, 2001; Lee, Sim, Kim, & Lee, 2010).

As mixed reality usually uses visual stimulations, it can be very suitable for drawing attention of children with ASD (Escobedo et al., 2014). Such attention allows children with ASD to focus on learning and study on their own, and moreover, provides them more opportunities to complete their learning assignment. When children with ASD finish their assignments, they can feel a sense of achievement, which in turn can give a positive feeling on learning to them. Through this process, children with ASD can have continuing motivation to learn, and are

expected to make a positive change in participation in future learning (Chen, Lee, & Lin, 2015; Escobedo et al., 2014; Vullamparthi, Nelaturu, Mallaya, & Chandrasekhar, 2013).

Motivation is an important element in learning (Linnenbrink & Pintrich, 2002), and it is identically applied to children with disabilities as well (Siegel, 2003). One of the behavioral characteristics appearing in children with ASD is the qualitative difference from children without disabilities, in motivation, which may be explained by the fact that children with ASD may be focused on something but at the same time do not want to share it with others and that they may not be motivated to explore new environments (Simpson & Myles, 2011).

When teaching new skills to children with ASD, reinforcement is an element that is necessarily required. Social reinforcements (e.g., compliments, smiles) are sufficient motivators in themselves for children without disabilities to carry out subsequent behaviors, but to children with ASD, who have difficult understanding non-verbal cues, such social reinforcements are insufficient as motivators (Aspy & Grossman, 2011). Siegel (2003) asserted that social motivation may not be important to children with ASD, so for the motivation of children with ASD, the environment must be restructured in a way that procures meaningful rewards. Additionally, using special interests and/or strengths are important for teaching children with ASD. According to Park (2012), teachers who have experience in teaching children with ASD mentioned in interviews that they recognized the limited repeat behavior and interest of children with ASD as a special talent, and reported that such special interest may be used as an intervention element aimed at transitioning to adequate behavior or social interaction.

Such grounds have recently become a basis for strength-based approach in special education. According to Gardner (2006; 2011), individuals have different areas of intellect where their strengths lie, and also have different developmental paths, so children with disabilities are

not disabled in all area of the intellect but have some areas that have strengths. A strength-based approach model depending on a special interest area has been introduced to children with ASD, and the special interest displayed in children with ASD can be integrated into the activities that are carried out in schools, families, and societies as well as applied to behaviors, curriculums, and learning methods in a variety of ways (Armstrong, 2012; Cosden et al., 2006; Mancil & Pearl, 2008; Winter-Messier et al., 2007). Also, an integrated intervention program that expects long-term and comprehensive results emphasizes reinforcement as a necessary element, and may use interest and attention as elements to promote motivation (Myles et al., 2012).

An element that must necessarily be considered in the learning of children along with motivation is play. Just as in the concept ‘Homo-Ludens’, which means human are being that play, play is an important element to humans (Huizinga, 2014). Especially, play is the medium by which children can make contact with their surrounding world, and is the best method for children to effectively learn because they learn through play (Broadhead, Howard, & Wood, 2010; Whitebread, Coltman, Jameson, & Lander, 2009). Due to this reason, when children’s learning assumes the form of play, it can be most ideally accomplished, and such a concept may be applied to children with disabilities as well. One of the reasons mixed reality is receiving attention as a next-generation education program is that it is ‘fun’ (Dunleavy, Dede, & Mitchell, 2009; Nilsson & Johansson, 2007). Considering that joyfully playing is an important element in children’s learning, mixed reality is referred to as a suitable material for education or intervention which targets children because mixed reality can be provided as play to children (Boden, Dekker, Viller, & Matthews, 2013; De Freitas & Oliver, 2006; Kadomura, Tsukada, & Siio, 2013).

Considering from the bases of such theories and concepts, it is most adequate to use the external environment or internal strengths to motivate children with ASD. Mixed reality is an ideal medium that can draw out motivation toward activities because it applies special interest areas and visual strengths that are recognized as advantages for children with ASD as joyful external stimulation. Based on these concepts, figure 1.1 shows the conceptual model for this study.

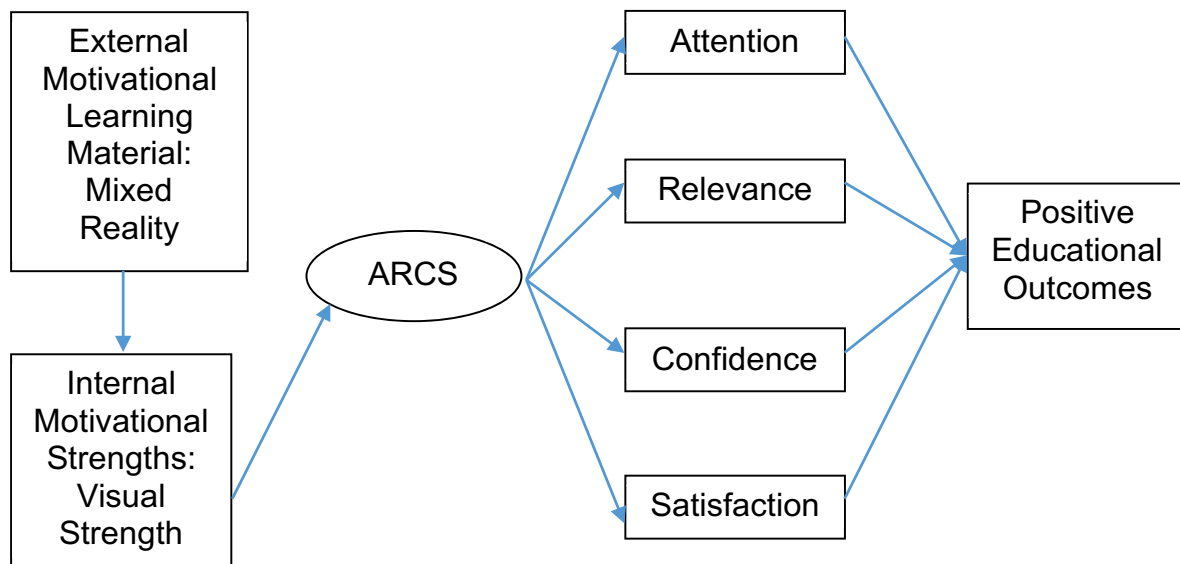


Figure 1.1. Conceptual Framework Model

In conclusion, the rapid development of mobile devices that have features that can implement mixed reality, require a directional shift toward mobile-based content that goes beyond the limitation of content learning using wired networks (e.g., desktop computer) in the area of AT. Mobile devices are convenient because they are portable. In addition, because mobile devices can access networks wirelessly, they have fewer limitation in time and place. In

summary, AT with mixed reality is used to enhance the visual advantage of children with ASD, it can increase learning motivation, and thus more positive educational outcomes can be expected.

CHAPTER 2

LITERATURE REVIEW

Mixed Reality: Virtual Reality

Understanding Virtual Reality. Mixed reality is the next generation technology for information processing that maximizes the usability and utility of information by mixing the information created in the virtual world with the objects in the real world on a real-time basis and allowing users to interact (Billinghurst & Kato, 1999; Milgram & Kishino, 1994; Ohta & Tamura, 2014). Mixed reality is divided into VR and AR based on the type of information processing in the real world (Milgram & Kishino, 1994). VR, a type of mixed reality, is a method of creating a real or virtual environment with 3D simulation using a computer (Cobb, Kerr, & Glover, 2001), and is referred to as virtual environment, virtual world or artificial reality (Lee & Kim, 2010; Lee & Suh, 2017).

VR is categorized into single-user virtual environments (SVE) and collaborative virtual environments (CVE) (Neale, Cobb, & Wilson, 2002). Both types allow users to interact in the virtual environment by using individual avatars (Gerhard, Moore, & Hobbs, 2004). However, while SVE lets users have limited interactions with the virtual environment and can provide only pre-programmed responses (Cobb et al., 2002), CVE allows users to have interactions with a single or multiple avatar simultaneously and can provide real-time responses (Cheng, Chiang, Ye, & Cheng, 2010; Moore, Cheng, McGrath, & Powell, 2005).

Hew and Cheng (2010) analyzed empirical studies on VR in an inductive manner. They presented the following three bases for analyzing the direction of VR studies: application method of VR, research methodology of VR studies, and subjects and/or effects of VR studies (Lee & Kim, 2010). They divided VR into ‘communication space’, ‘simulation space’, and experiential

space' according to its application method (Hew & Cheng, 2010). The communication space refers to a form of applying a virtual world to exchange information among participants in a verbal and non-verbal manner. The simulation space means a form of providing learners with opportunities to look around and experience the spaces provided in the virtual world. The experiential space means providing users with opportunities to immerse themselves in the virtual world through avatars (Lee & Kim, 2010).

Virtual Reality Intervention for Students with ASD. Recently, an increasing number of studies have been applying VR, as an intervention for students with ASD. VR as an intervention for students with ASD can be discussed in four aspects. First, VR can have a facilitating effect on learning because it can utilize the strength of students with ASD, who are good at processing information on visual stimuli. As an intervention using visual clues, such as texts, photos, pictures, and videos, visual supports have been reported to be an effective intervention for students with ASD (Quill, 1995). In particular, when students with ASD, who have difficulties in building concepts, are taught with visual supports, they can easily remember information depending on how the concepts are presented (Williams, Goldstein, & Minshew, 2006). This is attributable to the fact that they tend to have visual thinking where they are reminded of the images when they think and understand certain concepts (Brian, Tipper, Weaver, & Bryson, 2003).

Second, VR can alleviate the selection problem from over-stimuli in students with ASD and increase their attention to the tasks. Excessive stimuli can have a negative effect on learning in students with ASD because they respond to only a few clues given in a learning situation (Baron-Cohen, 2004; Mandy & Skuse, 2008; Yang et al., 2017). VR can create a structured environment with simple stimuli.

Third, VR creates a stable and predictable education environment for students with ASD. They have difficulties in emotional communication with others due to a deficiency in social interaction (Cheng & Ye, 2010; Klin et al., 2002). Students with ASD also experience emotional problems, such as withdrawal, fear, and concern, from those who they are not familiar with (Tantam, 2002). VR allows students with ASD to learn in an emotionally stable situation by minimizing the social interaction problems arising in the real world, which is the biggest difficulty for them (Yang et al., 2017).

Finally, VR provides a learning environment where students with ASD can repeatedly practice and easily generalize what they learn. Students with ASD have difficulties in generalizing the skills they have learned in a new condition (Deitchman, Reeve, & Progar, 2010; Ferraioli, Hughes, & Smith, 2005). However, there are difficulties in creating the situations and conditions in which students with ASD perform their tasks due to spatial, physical, financial, and safety limitations. Overcoming such limitations, VR enables students with ASD to indirectly experience the real world or situation that they have never experienced by providing them with a very similar virtual situation with the real situation (Yang et al., 2017).

VR-based interventions for students with ASD are actively pursued in various areas including social attention (Aresti-Bartlome & Garcia Zapiain, 2015; Jung et al., 2006; Wallace, Parsons, & Bailey, 2017), social recognition (Bekele et al., 2014; Didehbani et al., 2016; Hopkins et al., 2011; Lorenzo, Lledó, Pomares, & Roig, 2016), executive functions (Grynszpan, Martin, & Nadel, 2008; Parsons, Mitchell, & Leonard, 2004), learning outcomes (Bouck, Satsangi, Doughty, & Courtney, 2014; Root, Browder, Saunders, & Lo, 2017), and living skills (Cihak et al., 2016).

Mixed Reality: Augmented Reality

Understanding Augmented Reality. The rapid development and expansion of digital technology has increased the options for learning in education, along with innovative changes (Beetham & Sharpe, 2013; Collins & Halverson, 2009). With the changes in the educational environment from the development of wireless network technology, education using various media can be offered in diverse settings, and new teaching methods with new technologies are now actively introduces. Among new teaching methods, educational research on the 3D virtual world is rapidly increasing in its volume (Merchant et al., 2014; Wang, Kim, Love, & Kang, 2013).

At the very beginning, educational research on the virtual world had been suggested as a supplement to the existing online education (Delwiche, 2006). Recently, however, educational research on 3D Virtual Reality (VR), including actual interaction using 3D graphics and free hyperlinks with the educational resources existing in various cyber spaces, is now a hot topic as a new educational environment (Delwiche, 2006; Fairfield, 2011; Lee & Kim, 2010). VR is also positively accepted, as it is an educational method that can satisfy the rapidly changing need of the internet generation (Lee & Kim, 2010; Thorne & Reinhardt, 2008). Among virtual realities using 3D VR, Augmented Reality (AR) is an assistive technology media that has drawn the most attention.

Definition of Augmented Reality. Numerous researchers have identified AR variously. Milgram and colleagues (1994) defined AR by a broad and a restricted approach (Wu, Lee, Chang, & Liang, 2013). In the broad approach, AR means “augmenting natural feedback to the operator with simulated cues” (Milgram, Takemura, Utsumi, & Kishino, 1994, p. 283). Whereas, the restricted approach refers to “a form of virtual reality where the participant’s head-mounted

display is transparent, allowing a clear view of the real world” (Milgram et al., 1994, p. 283). In these regards, Klopfer (2008) argued that the term of AR should not be defined narrowly because it could not only be applied to head-mounted devices, but also hand-held devices (e.g., iPad, iPhone, etc.) that mix real and virtual information.

Azuma’s definition of AR is widely used; he describes AR as a tool that provides seamlessly overlay or superimposition of virtual objects in the real-world settings on a real-time basis (Azuma, 1997). This may allow for enhanced learning flow and presence to users compared to more traditional virtual realities, which do not allow simultaneous interaction of the virtual and the real (Bower et al., 2014; Lee, 2012). Azuma (1997) argued that the following three characteristics are used in defining AR. First, the images of real-world elements need to coexist and be combined with virtual images. Second, AR needs to interact with real-time users. Third, the virtual objects need to be represented in the real-world with 3D.

As part of mixed reality, Billinghurst and Kato (2002) identified AR as a combined ‘augmentation’ and ‘reality’, and it refers to a computer graphic technique that combines a virtual object or information with the actual environment, making it look like an object in the original environment. Shelton (2003) described AR as a technique that provides users with various forms of meaningful information on a real-time basis by augmenting the information entered through video sensors, such as camera, with a computer to vivid 3D information and content in the real world.

As a technology positioned between VR and real world, AR is based on virtuality, like VR (Bower et al., 2014; Milgram et al., 1994). AR and VR share the common aspect of including a virtual situation, which often makes AR and VR confusing. However, while VR is a technology that makes users immerse in the virtual space established by a computer, AR is a

technology that improves presence by adding virtual information with the actual environment of users being a trigger (Chang, Morreale, & Medicherla, 2010; Lee, 2012; Liu, Cheok, Mei-Ling, & Theng, 2007). Since AR maintains the existing information in the actual environment held by the users, it differs from VR, which completely replaces the actual environment with the environment generated by a computer (Chang et al., 2010; Lee, 2012). Figure 2.1 shows mixed reality position on the mixed reality visual display.

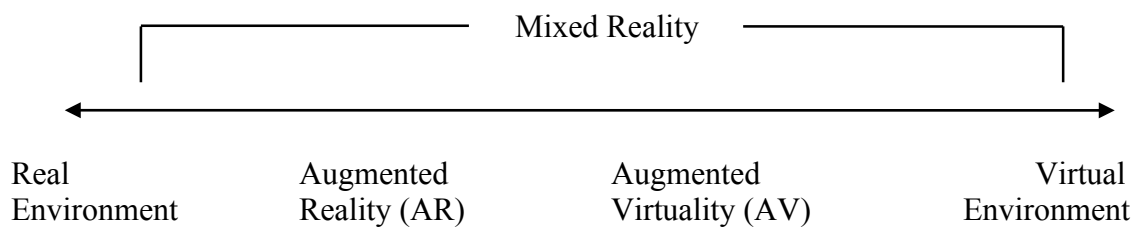


Figure 2.1. Reality-Virtuality Continuum (Milgram et al. 1994)

Characteristics of Augmented Reality. Kye and Kim (2008) described characteristics of AR that are (a) providing 3D type multi-sensory information (McLellan, 1996; Rosenblum, 2000; Ternier, Klemke, Van Ulzen, & Specht, 2012), (b) enhanced operability through tangible user interface, and (c) combination between real and virtual world throughout seamless interface.

AR provides information with a sense of reality through multi-dimensional objects in 3D that support diverse senses. The realistic experience is attributable to perceptualization in which various senses are included (McLellan, 1996). AR creates a sensory immersion of information by improving the perceptivity of humans through the expression method based on the multi-senses (Rosenblum, 2000; Ternier et al., 2012).

As a concept suggested first by Csikszentmihalyi (2000), immersion is defined as a mental and physical excitement that people feel when they behave in a completely immersed condition. Immersion is the result of the consecutive responses facilitated by interactivity and has the characteristic of voluntary reinforcement, along with fundamental fun (Novak & Hoffman, 1997). The concept is extended to the area of interaction with computers and defined as recognition by users who consider the interaction with a media playful and exploratory (Kye & Kim, 2008). Based on this definition, sensory immersion into the virtual world is defined as the extent to which the attention of users is paid to information of the virtual world.

Unlike VR, where sensory immersion is an immersion into a new world beyond the real world, AR allows users to feel a sensory immersion in virtual objects in the context of the real world (Kye & Kim, 2008). In addition, the 3D expression in AR helps understand the phenomena occurring in the physical space (Bower et al., 2014; Lee, 2012; Wu et al., 2013). Since AR has the characteristic of using virtual objects, it not only enables the simulation of the real world, but also materializes the experience that is not possible in the real world using various sensory organs (Kye & Kim, 2008). AR provides enhanced operability through Tangible User Interfaces (TUIs). TUIs refer to an “interface that is concerned with providing tangible representations to digital information and controls, allowing users to quite literally grasp data with their hands” (Shaer & Hornecker, 2009, p.4).

Furthermore, AR offers a combination between real and virtual world throughout a seamless interface. AR users maximize interaction with 3D interface that responds on a real-time basis, during which they develop a sense of reality, just like in the real world (Azuma, 1997; Azuma et al., 2001). The sense of reality is well perceived when recognition and behavior of users are efficiently connected with the virtual environment (Bower et al., 2014; Billinghurst,

Kato, & Poupyrev, 2001). AR makes it ambiguous to distinguish the actual environment from the virtual screen by overlapping the realistic images that users are watching with 3D virtual images (Azuma et al., 2001).

VR has a disadvantage that it cannot see the real environment as it makes users immerse into the contents of the virtual environment. In contrast, AR allows users to use the real environment by mixing the actual environment with virtual objects, so that they could feel a better sense of reality and be additionally provided related information (Bower et al., 2014; Chang et al., 2010; Liu et al., 2007). In AR, the volume of the real environment augmented by virtual images depends on an AR app. Therefore, AR can provide a transitional interface so that users naturally move from the pure real world to the pure virtual world in accordance with the intention of a designer (Billinghurst, 2002; Kye & Kim, 2008).

Educational Strengths of Augmented Reality and Learning-Promoting Factors

With the recent development of ubiquitous computing, a variety of media that apply new technologies are under development. Among others, AR draws a lot of attention as a new educational media that can extend the learning experience of learners by providing information with a sense of reality through 3D stereoscopic images that support various senses and allows learners to implement direct operation (Billinghurst, 2002; Bower et al., 2014; Change et al., 2010; Kye & Kim, 2008; Liu et al., 2007).

AR can not only provide additional knowledge or pleasure to users, but also enhances motivation and immersion, which are important factors in education, because contents are combined with the actual environment in a sophisticated manner. Based on the merits of AR, empirical research studies are increasingly undergoing worldwide, beyond conceptual and

theoretical researches (de Freitas & Veletsianos, 2010; Hew & Cheung, 2010; Lee & Kim, 2010).

Educational Strengths of Augmented Reality. The biggest reason that attention is paid to AR, unlike the existing educational media, that it has a unique method providing learning information in which AR can provide digitized information to users as they watch actual objects (Kesim & Ozarslan, 2012; Shelton, 2003; Yuen, Yaoyuneyong, & Johnson, 2011). In addition, AR can increase the context awareness of learning scenes, as well as the authenticity of observers and promote learning activities by providing additional information on the subjects or places that the learners are observing (Martin et al., 2011; Tarnng & Ou, 2012). AR supports learning by experiencing in the authentic environment with contextuality – learning by doing – by providing TUIs, where a user manipulates and interacts with physical objects, and natural interface, where a user can cross reality and the virtual space (Kaufmann & Schmalstieg, 2003).

There was a debate on the merits of AR. Billinghurst (2002) presented the technological advantages of AR by exploring a collaborative AR in shared spaces. AR provides a smooth and natural interaction that connects the real world with the virtual world and increases presence. It also provides spatial information to participants in collaboration and supports TUIs using metaphors. Shelton (2003) found that the educational application of AR can promote active learning, actual learning, empirical learning, intentional learning, and cooperative learning of learners.

The development of contents based on VR requires modeling work. In other words, virtual objects need to be created using Computer Aided Design (CAD) (Chu, Dani, & Gadh, 1997), and the creation of contents may be very difficult when there are many virtual objects (Cruz-Neira, Sandin, & DeFanti, 1993). In addition, a lot of time and cost are needed to create

models similar with actual objects. Also, the lack of reality in VR may reduce the effect of the contents (Cruze-Neira et al., 1993; Kaiser, 1996; Pierce & Aguinis, 1997).

On the contrary, since AR uses real objects as they are, it is very easy to model them and create virtual objects using an app (Carmigniani et al., 2011; Rekimoto & Ayatsuka, 2000). This can be a significant advantage to teachers who create and provide contents by themselves. Since AR is an actual environment, it enhances reality and gives familiarity in interaction. It also provides easy access to various educational resources though hyperlinks (Harrington & Vallino, 2002; Pence, 2010). These advantages allow AR to be combined with the educational field in a much easier manner, compared to VR.

Learning-Promoting Factors. AR not only provides a learning environment similar to a game to learners at a lower cost, but also offers an educational function accompanied by pleasure (Lee & Kim, 2010). The reason for AR to facilitate learning is that it accompanies actual operation activities for learning objects (Kye & Kim, 2008). Since the contents of learning developed by the behaviors of learners, such behaviors prompt exploratory activities again, and lead further to meaningful learning. These operation activities can provide a sense of achievement and satisfaction to students by improving the learning experience of students, creating immersion in learning scenes, and enhancing a sense of control over learning contents (Kye, & Kim, 2008; Rosenblum, 2000; Ternier et al., 2012). In summary, applying AR in the development of teaching materials can be an effective alternative to enhance learning motivation, because it is an engaging and efficient replacement for potentially expensive equipment otherwise necessary for experiments and practice. In addition, AR provides a high level of presence, offering sensory immersion, in which students feel as if they were in actual places, and it provides education services at lower costs than in actual educational settings (Oh, 2012). For

these reasons, AR can be used much more effectively in the special education field because students with disabilities need realistic experiences and its repetition.

Seamlessly connecting the real world with the virtual world, AR can contribute to the improvement of learning effects as it naturally connects reality with virtual learning information (Azuma, 1997; Azuma et al., 2001; Bower et al., 2014; Lee, 2012). This technology makes it possible to express a task similar with the actual problematic situation. Emphasizing the authenticity of learning by maintaining the environment of the real world, AR has the effect of improving application ability, beyond acquiring or understanding simple concepts by facilitating problem-solving and high-dimensional thinking activities in the actual learning situation (Bower et al., 2014; Kerawalla, Luckin, Seljeflot, & Woolard, 2006; Kye & Kim, 2008). It also can help users increase concentration by allowing them to experience the problems in the actual context.

In addition, AR can enhance the interactivity of users through TUI. An interface using real objects brings out a natural affordance in the learning situation, enabling a more natural interaction suitable for the situation of learners (Kye & Kim, 2008). Especially, in interaction between students and contents, AR, unlike VR, has an advantage that users can have a direct and intuitive interaction with virtual contents or services in the real world (Azuma et al., 2001). Such interaction was found to be more effective when a sense of reality was higher (Steuer, 1992). Yilmaz (2016) divided educational benefits from previous studies into the following 10 benefits. Table 2.1 shows educational benefits of AR.

Currently, AR is used in various fields, including broadcasting, medicine, and education. Also, its effectiveness was proven as well (Takatalo et al., 2008). Based on educational strengths of AR and its learning-promoting factors, researchers in education try to develop a technological educational environment using AR.

Table 2.1. Educational Benefits of Augmented Reality (Yilmaz, 2016, p. 242)

Educational benefits	References
Enhancing attention	O'Brien and Toms (2005); Sumadio and Rambli (2010)
Providing attractive and effective learning	Duenser and Hornecker (2007); Lester et al., (1997); Oh and Woo (2008); Wojciechowski and Cellary (2013); Zho, Cheok and Pan (2004)
Enhancing motivation	O'Brien and Toms (2005); Sumadio and Rambli (2010); Serio, Ibanez, and Kloss (2013)
Enriching interaction	Azuma (2004); Bujak et al. (2013); Ivanova and Ivanov (2011); Kerawalla et al. (2006); Wojciechowski and Cellary (2013); Wu et al. (2013)
Facilitating learning	Ivanova and Ivanov (2011); Nunez et al. (2008)
Enhancing engagement	Bujak et al. (2013); Ivanova and Ivanov (2011)
Providing cooperation	Yuen, Yaoyuneyong and Johnson (2011)
Triggering creativity	Klopfer and Yoon (2004); Yuen et al. (2011); Zhou et al. (2004)
Developing imagination	Klopfer and Yoon (2004); Yuen et al. (2011)
Enhancing spatial ability	Bujak et al. (2013); Cheng and Tsai (2012); Wojciechowski and Cellary (2013)

Practices and/or Strategies Used in Early Intervention and Early Childhood Special Education to Support Language Development for Children with Autism Spectrum Disorders

Defining Autism Spectrum Disorders. Turnbull and her colleagues (2015) described two major definition of Autism Spectrum Disorders (ASD) defined by IDEA and the Diagnostic and the Statistical Manual of Mental Disorders, fifth edition (DSM-V). According to IDEA (2014), ASD is defined as a disability that significantly impacts communication and social interaction before the age of three, and must negatively impact on the educational performance (Turnbull, Turnbull, Wehmeyer, & Shogren, 2015). The term ‘spectrum’ refers to the disabilities associated with ASD and fall on a range from mild to severe (Hallahan, Kauffman, & Pullen, 2014). According to the previous version of the DSM manual (DSM-IV-TR), autism was referred to as pervasive developmental disorders not otherwise specified (PDD-NOS). It included five distinct categories that are autistic disorder, Rett syndrome, Asperger syndrome, childhood disintegrative disorder, and PDD-NOS (Turnbull et al., 2015). These categories were combined into the term ASD, in the DSM-V (APA, 2013). The standard for defining autism, the DSM-V also employs the term ‘spectrum’ (APA, 2013; Hallahan et al., 2014).

The DSM-V divides ASD into two general domains: Social-communication impairments and repetitive, restrictive behaviors and interests (APA; 2013; Hallahan et al., 2014; Turnbull et al., 2015). Turnbull et al. (2015) mentioned that these two domains must occur in the early childhood and will be challenges in a child’s daily life.

The prevalence rate for ASD has dramatically increased in the past decade. An official announcement of the U.S. Center for Disease Control and Prevention (CDCP, 2013), reported the rate for ASD was at 1 in 150 by 2000, and the rate has increased to 1 to 88 by 2011. CDCP

(2013) also reported that 1 in 54 boys and 1 in 252 girls are diagnosed with ASD. The rate is almost 5 times higher for boys than girls. According to the IDEA Data Accountability Center (2013), the rate of students who are 6 to 21 years identified as having ASD doubled from 2005 to 2011.

Caucasians are more likely identified as having ASD than African American and Latino, unlike other disabilities (CDCP, 2013). For this phenomenon, Volkmar and colleagues (2012) speculated that according to the DSM-V, some individuals with milder forms of ASD and normal intelligence are less likely to meet the criteria for ASD, compared with DSM-IV (Turnbull et al., 2015). However, exact causes are not well revealed.

Communication Characteristics of Children with ASD. Autism is a disability with the symptoms of verbal or non-verbal complex communication problems, lack of social skills, difficulties with pretend play and behavioral disorder with the limited range of repetition, complicated with cognitive intelligence and neurobehavioral problems (APA, 2013). Among these problems, communication is the most challenging problem in the development process of children with ASD, as the problem in communication significantly affects their other problems (Hallahan et al., 2014; Parlade & Iverson, 2015; Shumay & Wetherby, 2009; Turnbull et al., 2015).

In general, communication starts to develop at 4-18 months, a pre-linguistic period. While communicative functions in this period are mostly to regulate the behaviors of others, they are extended to other functions to maintain communication with others, such as joint attention, as they get older (Bruner, 1981; Halliday, 1975; Wolfberg, 2003; Owens, 2010). Children without disabilities show the changes in their means of delivering their intention to others with the increased and diversified communication methods. In the beginning, children without disabilities

frequently use gestures as non-verbal means and then gradually combine words with gestures, and eventually their gestures decrease as they use verbal language (Bates, O'Connel, & Shore, 1987; Wetherby, Cain, Yonclas, & Walker, 1988). In other words, children without disabilities' communication skills change from non-verbal forms to verbal forms as they get older. (Gim, Choi, & Lee, 2015).

Unlike children without disabilities, children with ASD commonly show communication problems in both verbal and non-verbal regardless of their age or language level (Vulchanova et al., 2012; Wing, 2001; Wolfberg, 2003). They also differ from children without disabilities in the functions and means of communication behaviors as well as the frequency of communication (Chiang, Soong, Lin, & Roger, 2008; Parlade & Iverson, 2015; Shumay & Wetherby, 2009).

As for communication deficits in children with ASD, even though they can produce spontaneous communication, they are less perfect compared to children without disabilities. In addition, they have deficits in learning categorical vocabularies and synonyms and lack skills to recognize communication rules or learn and use languages in social contexts (Heflin & Alaimo, 2007).

Most children with ASD are significantly delayed even at the starting point of leaning language. Rutter (1978) reported that 50% of children with ASD learn verbal language at the age of 5 and Beukelman and Mirenda (1995) found that 25-61% of children with ASD fail to develop verbal expressions. Lord and Paul (1997) reported that at least 30-50% of children with ASD never learn conventional language at all. Most recently, Zager, Wehmeyer, and Simpson (2012) found that approximately 40-50% of children with ASD never develop functional utterance. In addition, Bondy and Frost (1994) investigated children with ASD under the age of 5 who entered the Delaware Autistic Program (DAP) and reported that approximately 80% of them did not have

communication skills. However, the range of communication and language deficits in children with ASD is varied from those who are not able to speak to those who use spontaneous communication (Lord et al., 2000; Thurm, Load, Lee, & Newschaffer, 2007).

More specifically, communication deficits of children with ASD include deficiencies in recognizing the other of communication (Mundy & Sigman, 1989; Sigman & Kasari, 1995), skills to draw attention when starting conversation (Heflin & Alaimo, 2007; McArthur & Adamson, 1996; Wolfberg, 2003), lack of using social languages (Scheuermann & Webber, 2002), recognizing the position or emotion of other people, and understanding non-verbal expressions (Chiang et al., 2008; Georgescu et al., 2014). These deficits lead to the obstacles in overall development, creating problems in ordinary social life after growing up (Hallahan et al., 2014; Heflin & Alaimo, 2007; Shumay & Wetherby, 2009; Turnbull et al., 2015).

Echolalia. Echolalia is also a common linguistic characteristic of children with ASD (Scheuermann & Webber, 2002). It is a phenomenon of repeating verbalizations made by another person and is largely divided into immediate echolalia and delayed echolalia (Prizant & Duchan, 1981; Prizant & Rydell, 1984). Immediate echolalia refers to an utterance produced within a short period of time immediately after the utterance of the model, while delayed echolalia refers to an utterance made after certain time passed (Prizant & Duchan, 1981; Prizant & Rydell, 1984; Scheuermann & Webber, 2002). Echolalia has been considered non-functional, but there is a study suggesting that it is used for several communicative functions, including request, resistance, and acceptance (Prizant & Duchan, 1981). This is a change from the view where echolalia is considered a simply non-functional and deviant linguistic characteristic.

In a study on echolalia, Prizant and Rydell (1984) suggested that echolalia has the communicative functions of request, answer, self-control, labeling and naming in it. In this

regard, it was found that children with ASD use the linguistic strategies different from those of children without disabilities to maintain social relationships using their limited linguistic system (Prizant & Duchan, 1981; Prizant & Rydell, 1984). Thus, the authors of existing literature regarding echolalia have not come to consensus as to whether echolalia ought to be viewed as a positive function or a negative detriment to communication.

Autism Spectrum Disorder and Vocabulary Acquisition

It is typical that humans face various surrounding environments as soon as they are born. They soon start learning the language of the society to which they belong. Acquisition of the language of the societies they belong is identical with acquisition of shared vocabularies in the society. Vocabularies help realize communication between humans and pass down experiences through representation of specific objects or images, selection of their characteristics, and generalization and categorization of objects and images (Loewenstein, Ocasio, & Jones, 2012; Suddaby & Greenwood, 2005).

Vocabulary acquisition, as a part of language development, renders significant effect on general language development, even though it cannot be an index for overall development of the child. In particular, vocabulary acquisition serves to form the basis of the initial language development and takes a considerable role in language development (Stahl, 2005). It is thus required to understand and express vocabulary to communicate to each other. Lack of vocabulary will lead to communication challenges as well as hindrance to reading, writing, speaking, and listening (Jahromi & Marzban, 2015; Nagy & Townsend, 2012; Snow & Kim, 2007). Therefore, vocabulary is most fundamental to communication.

Vocabulary Acquisition of Children with ASD. The most typical linguistic problem found from children with ASD lies in their pragmatics, a problem in communication, but they

also have defects in understanding and expression of meaning or concepts. Fay and Schuler (1980) presented that the children with ASD experience difficulties in processing of concepts and meanings due not only to their pragmatic defect which is one of linguistic problems, but also to defects in acquisition of basic conceptual knowledge that include meaning. They also use only limited range of vocabulary they already know and are not interested in using proper and various words according to contexts.

Tager-Flusberg and Thurber (1993) suggested that children with ASD have the same vocabulary competency as children without disabilities but show inferior competency in the number of words they understand. Also, vocabulary usage by children with ASD is limited compared to the communication ability using appropriate words for context they are given and the most fundamental precondition in the linguistic intervention is vocabulary acquisition.

The characteristics in vocabulary acquisition of children with ASD lie in their challenges in acquisition of receptive and expressive language (Howard et al., 2005). Children with ASD have defects in language reception. Even when they are acquiring colloquial languages, their linguistic competence for understanding is not as good as that for expression. It is because they have defects in linguistic reception due to lack of metacognition before language development (Najdowski, Gould, Lanagan, & Bishop, 2014; Whitebread et al., 2010). This factor leads to difficulties in understanding others' intention, emotion, or thought and results in problems in reception of the language.

Children with ASD also have defects in expressive language. They have difficulty in acquiring vocabulary for emotional expressions in expressive language. Approximately 50% of children with ASD fail to develop their expressive language (Paul, 1987). Children without disabilities start to distinguish and express their emotions such as pleasure, sadness, and anger in

their infancy, basic emotion between 2.5 and 7 months of age, and complex emotions from 2 years.

Children with ASD have defects in acquisition of relational words. Acquisition of relational words requires simultaneous analyses of linguistic information and contextual information of each word, but children with ASD are prone to use vocabulary in an integral and absolute way (Prizant & Schuler, 1987). Since they do not recognize alternation of speaker and listener very well, they sometimes experience difficulties in understanding and production of vocabulary according to parts of speech or properties of children with ASD (Tager-Flusberg, Paul, & Load, 2005).

Vocabulary acquisition is very important for independent lives of children with ASD (Heflin & Alaimo, 2007). Thus, language-oriented educational programs have to be suggested in early childhood and preschool period in the educational course for them (Bernstein & Tigerman-Farber, 2009). Although lexical development is a necessary mediating variable area for communication, because it serves not only as a foundation for syntactic development but also as an essential element for language fluency (Wood, 2001), interventions retain difficulties due to children with ASD's defect in sociality, lack of motivation, behavioral problems, and so on. Because of those problems, vocabulary acquisition receives less attention than the area of communication. Furthermore, negative prediction of teachers that teaching would not incur any changes is a reason of that phenomenon (Downing, 2005).

Therefore, it is important to help children with ASD acquire vocabulary through selection of learning content in which they may be interested to enhance their learning motivation. In particular, it would be effective to carry out play-based intervention if preschool children are

selected as subjects. At the same time, it should be accompanied by lowering teachers' prejudice against language education for children with ASD.

Vocabulary Intervention Method. The existing traditional linguistic intervention programs for children with ASD are based on operational behavior shaping and they demand language acquisition and development according to structuralized stages until reaching specific goals. Since the operational method is useful for teaching simple concepts or general theories, but the endeavor of skillful experts receives emphasis and the demand of interventionist is in most cases unidirectional regardless of needs of children, it is known that it is not easy to generalize into natural context (Alpert & Kaiser, 1992; Mancil, 2009; Mancil, Conroy, Nakao, & Alter, 2006; Yoder & Warren, 2002).

Recognizing those limits of the intervention method and seeking for social and functional linguistic intervention methods, context-centered linguistic intervention was developed and has been applied to many subject children. Furthermore, other intervention techniques are being applied using a symbol system of sign language or pictures, eye-gaze frame, PECS, books, high-tech communication devices, and assistive technology tools such as computer (Heflin & Alaimo, 2007).

Vocabulary Intervention in Previous Studies. Coleman-Martin et al. (2005) conducted a study that examined the use of a computer-assisted instruction (CAI) and the non-verbal reading approach (NRA) to teach word identification for three students with disabilities including ASD. The target words were presented either by index cards or by the computer. CAI was carried by the guided practice component of the NRA, and words were shown using the PowerPoint slides during CAI. Each slide included a visual and auditory stimulus. The words for this study were selected based on the students' teacher's suggestions. Each teacher recommended

a list of at least twenty-five possible words, and the researcher removed words that were not ordinary or words that could not be decoded. Throughout the selection process, a total of fifteen words were chosen and divided into three sets of five. A multiple condition design with drop-down baselines was employed for this study, and the researchers evaluated three conditions to examine the effects of teaching word identification using the NRA: a) teacher instruction only, b) teacher and CAI, and c) CAI only. The researchers measured the percentage of vocabulary words identified correctly. Results indicated that all participants did increase word identification which means the NRA can be effectively used through CAI to teach vocabulary.

More recently, Coleman and her colleagues (2012) conducted a study to compare the effects of teacher-directed and computer-assisted constant time delay intervention for students with moderate intellectual disability including ASD. The target words consisted of eleven functional cooking words (i.e., pour-spoon, bowl-tomato, refrigerator-microwave, pudding-pepperoni, etc.), and printed at 96-point font on a 4 X 6 inch card for teacher-directed constant time delay intervention. Also, selected words were presented on a PowerPoint slideshow to the participants during the computer-assisted constant time delay intervention. First, each target word that contained a picture of the corresponding text was presented, and then the card was presented without the picture. Teacher and computer asked the participant “what is the word?” for each stage, and a 4 second wait occurred between the request and the presentation of the correct response. The researchers conducted a preferred constant time delay condition and faded picture stimulus condition. In addition, each participant read the words in order to prepare a snack during the generalization phase through the six-step task. An alternating treatment design was used and the researchers employed an event recording and permanent product recoding procedure for data collection. The data calculated the percentage of accuracy. Results indicated

that both instructions were effective, but two out of three participants learned words more efficiently during the teacher-directed intervention.

Teaching Science Vocabulary. The recent trends in the scientific education are ‘science for all’ where, through the study of science based on daily life experience, all learners amass the kind of experience that can be applied in society (Mastropieri et al., 2006). This implies that science education has to target not just a specific group of people but all people. The National Research Council (NRC, 2011) also asserted that all students should have STEM (science, technology, engineering, and Mathematics) literacy, saying that it is one of the objectives of education. Accordingly, science is being seen as an important area of education for all students.

Students with disabilities can’t be excluded from this either, who have not been able to work on the skills, knowledge, and problem solving abilities people absolutely need in society because they have not had the same extent of experience that others have enjoyed (Kim, 2015). So, science is one of the most important and valuable areas in the entire curriculum that students with disabilities could learn (Browder et al., 2012; Spooner et al., 2011), in that it can teach them the theory and practice concerning natural phenomena and give them the ability to problem solve in their daily life through causality (Hwang & Taylor, 2016; Salend, 1998).

The most basic element when it comes to understanding science is the understanding of scientific terms and principles (Young, 2005). Accordingly, there have been constant attempts to teach science vocabulary to students with ASD. McMahon et al. (2016) conducted a study to investigate the effectiveness of an AR to teach science vocabulary words to postsecondary education students with intellectual disabilities and autism. The target words were selected to evaluate students’ knowledge on three science-related vocabulary lists including human bones, human organs, and cell biology. Each vocabulary domain consisted of twenty items that included

two questions for each of the ten words. One question called “the definition question” was developed to assess the ability of the participant to appropriately match a definition to the vocabulary. Another question was designed for investigating the vocabulary to label either a diagram or a figure with the appropriate vocabulary. The mobile AR app, Aurasma, was employed, and the researchers developed video contents (ranged from 25 to 30 sec.) for each vocabulary using this AR app. The AR contents presented the participants a view of the vocabulary card and overlaid digital information including video and audio information to teach the definition of the science vocabulary. A multiple probe design across three sets of science vocabulary and the researchers employed an event recording for data collection. Results indicated that all participants did increase knowledge for the science vocabulary.

Smith et al. (2013) conducted a study to investigate the use of a computer-assisted instruction to teach science vocabulary to students with ASD. The twelve science-related target words (e.g., organ, chromosomes, mitosis, homeostasis, etc.) were selected and taught using slideshow presentation through the iPad. Each presentation delivered instruction on a set of three science terminologies per unit, and offered a written direction paired with an identical verbal direction and four response options consisting of one correct and three incorrect options. The participants had five seconds to answer a response option. A multiple probe design across participants was employed and only correct responses were graphed. Results indicated that all participants acquired the science vocabulary through the iPad-based instruction. In addition, various interventions, such as using explicit instruction (e.g., Knight, Smith, Spooner, & Browder, 2012), systematic instruction and graphic organizers (e.g., Knight et al., 2013), and one to one embedded instruction (Jameson et al., 2007; McDonnell et al., 2006), have been attempted to teach science vocabulary to students with ASD.

Although, there have been intervention studies to teach science vocabulary to students with ASD, there has only been one study that used AR for the intervention. Considering the educational value of AR, there should be more intervention studies using AR going forward.

Purpose of Research

Previous research has shown that mixed reality-based intervention is effective for students with ASD. Despite the increased volume of studies on mixed reality-based intervention for students with ASD, there is a possibility of errors in decision making for selecting an intervention because there might be repeated studies on the same concept and subject, and due to the diversity in variables or environments for studies. Therefore, a more comprehensive review needs to be performed using a meta-analysis, which is an evidence-based scientific approach centered on literature for the effect of mixed reality-based intervention in students with ASD. The purpose of this study is to verify the effectiveness of mixed reality-based intervention and confirm the validity of practical application by conducting meta-analysis on mixed reality-based intervention studies performed on students with ASD.

Furthermore, as shown earlier AR provides educational benefits, such as enhancing attention, motivation, engagement, and interaction. Based on the merits of AR, empirical studies are increasingly undergoing worldwide, beyond conceptual and theoretical studies. Comparing to other field of education, however, researchers in special education fields need to be actively engaged and empirically examining the effects of AR for students with disabilities to improve educational outcomes. Especially, research involving young children with disabilities is needed. The purpose of this study is to examine empirically the use of portable AR technologies for young children with autism spectrum disorders (ASD). The single-case research study in this

paper are empirically examinations of this field of augmented reality on mobile devices as a tool for children with ASD.

Research Questions

The purpose of study 1 is to investigate the effectiveness of mixed reality-based intervention program for students with ASD through meta-analysis, and study 2 uses a single-case design method in order to empirically examine the use of AR technologies and acquiring vocabulary words for children with ASD.

Study 1. The purpose of this study is to verify the effectiveness of mixed reality-based intervention and confirm the validity of practical application by conducting a meta-analysis on mixed reality-based intervention studies performed on students with ASD. In order to achieve the purpose of this study, the following research questions:

1. What are the general characteristics of mixed reality-based intervention studies for students with ASD?
2. What is the overall effect size of mixed reality-based intervention for students with ASD?
3. What is the effect of the moderators on the size of the effect of mixed reality-based intervention?
4. Is there a publication bias in mixed reality-based intervention studies?

Study 2. The purpose of this study is to examine the effects of augmented reality-based intervention to teach children with ASD science vocabulary words. Specific research questions include:

1. What are the effects of augmented reality-based intervention on the acquisition of science vocabulary words of children with ASD?

2. What are the effects of augmented reality-based intervention on the acquisition of life cycle knowledge of children with ASD?
3. Do children with ASD find augmented reality-based vocabulary interventions to learn new science vocabulary words socially acceptable?
4. What are the teachers' opinion of using augmented reality-based vocabulary intervention?

CHAPTER 3

DOSE MIXED REALITY WORK FOR STUDENTS WITH AUTISM SPECTRUM

DISORDERS?: EVIDENCE FROM A META-ANALYSIS

The interest in the media has always existed, even before the emergence of advanced modern media, and efforts have been continuously made to link the media with education. The fundamental question of ‘will assistive technologies improve education capabilities?’ has been expanded to ‘how will assistive technologies change the form of education?’ (Banathy, 1991; Reigeluth, 1991). With the development of technology, the educational environment for students with disabilities has been also experiencing significant changes. The key to the changes in the education for students with disabilities lies in how to use computers, the internet, and virtual environment in this ubiquitous era. This, as a new feature of the digital era, reflects the fact that special education is changing from the analogue context to the digital one.

The most notable change in special education with the development of technology is the educational application of the virtual environment. In recent years, the change in the educational environment due to the development of mixed reality technology makes it possible to provide education using various forms of media in various places (Grynszpan, Weiss, Perez-Diaz, & Gal, 2014; Merchant et al., 2014), not just limited to possibly applying mixed reality to education (Kirkley & Kirkely, 2004; Pan et al., 2006). New forms of teaching-learning methods using mixed reality have been actively introduced, which in turns has changed the form of education. As the mixed reality environment evolves from its connection with computers to the development of head mounted display (HMD) and related apps, the application of mixed reality has increasingly drawn attention in the educational environment (Kesim & Ozarslan, 2012; Yuen, Yaoyuneyong, & Johnson, 2011).

Mixed reality is used as a term that encompasses virtual reality (VR) and augmented reality (AR). Mixed reality refers to “the incorporation of virtual computer graphics objects into a real three-dimensional scene, or alternatively the inclusion of real world elements into a virtual environment.” (Pan et al., 2006, p.20). In the case of the former, it is generally referred to as AR, the latter as VR (Pan et al., 2006; Tamura, Yamamoto, & Katayama, 2001).

The mixed reality-based virtual environment can be applied to the education and intervention situations where a safe learning environment needs to be provided (Bellani, Fornasari, Chittaro, & Brambilla, 2011). It also has the advantage of being able to effectively, provide learning that requires cognitive and behavioral practice in the virtual environment because mixed reality can remove confusing stimuli in the social context (Stichter, Laffey, Galyen, & Herzog, 2014). Since the virtual environment usually uses visual stimuli, it is known to be an effective intervention for students with autism spectrum disorders (ASD) who have visual strength (Aresti-Bartolome & Garcia-Zapirain, 2015; Fornasari et al., 2013; Yang, Lee, & Suh, 2017).

Considering the characteristics of mixed reality environment and ASD, the suitability of mixed reality as an intervention for student with ASD can be discussed in four aspects. First, mixed reality can have a facilitating effect on learning because it can utilize the strength of students with ASD who are good at processing information on visual stimuli. As an intervention using visual clues, such as texts, photos, pictures, and videos, visual supports have been reported to be an effective intervention for students with ASD (Quill, 1995). In particular, when students with ASD, who have difficulties in building concepts, are taught with visual supports, they can easily remember information depending on how the concepts are presented (Williams, Goldstein, & Minshew, 2006). This is attributable to the fact that they tend to have visual thinking where

they are reminded of the images when they think and understand certain concepts (Brian, Tipper, Weaver, & Bryson, 2003).

Second, mixed reality can alleviate the selection problem from over-stimuli in students with ASD and increase their attention to the tasks. Excessive stimuli can have a negative effect on learning in students with ASD because they respond to only a few clues given in a learning situation (Baron-Cohen, 2004; Mandy & Skuse, 2008; Yang et al., 2017). Mixed reality can create a structured environment with simple stimuli.

Third, mixed reality creates a stable and predictable education environment for students with ASD. They have difficulties in emotional communication with others due to the deficiency in social interaction (Cheng & Ye, 2010; Klin et al., 2002). Students with ASD also experience emotional problems, such as withdrawal, fear and concern, from those whom they are not familiar with (Tantam, 2002). Mixed reality allows students with ASD to learn in an emotionally stable situation by minimizing the social interaction problems arising in the real world, which is the biggest difficulty for them (Yang et al., 2017).

Finally, mixed reality provides a learning environment where students with ASD can repeatedly practice and easily generalize what they learn. Students with ASD have difficulties in generalizing the skills they have learned in a new condition (Deitchman, Reeve, Reeve, & Progar, 2010; Ferraioli, Hughes, & Smith, 2005). However, there are difficulties in creating the situations and conditions in which students with ASD perform their tasks due to spatial, physical, financial, and safety limitations. Overcoming such limitations, mixed reality enables students with ASD to indirectly experience the real world or situation that they have never experienced by providing them with a very similar virtual situation with the real situation (Yang et al., 2017).

Previous studies reported that interventions in virtual environments using mixed reality were effective for students with ASD. As for VR, there was a study on communication between students with ASD and therapists through avatars (Moore et al., 2005). In addition, VR intervention programs regarding how to express emotions to students with ASD were developed and applied (Cheng & Ye, 2010). Many previous studies have shown that students with ASD can learn social skills and generalize them in a social situation through VR interventions (Parsons, Mitchell, & Leonard, 2005). Intervention studies were also conducted to address the difficulties in risk situations and learning situations due to the lack of cognitive ability (Lorenzo, Pomares, & Lledo, 2012; Self, Scudder, Webber, & Ma, 2007). It was also reported that intervention effects included not only supported academic and behavioral performance, but also increased the participation and motivation of students with ASD (Finkelstein, Nickel, Barnes, & Suma, 2010; Yang et al., 2017).

As for AR, Chen et al. (2015) conducted a study to promote the emotional expression and social skills of adolescents with ASD using AR-based self-facial modeling. Chen-Hsu et al. (2016) used AR-based video modeling storybook for students with ASD to improve perceptions and judgments of facial expressions and emotions. Cihak et al. (2016) evaluated AR to complete a chain task for children with ASD. These intervention studies suggest that mixed reality-based intervention is an effective approach to education for students with ASD.

As such, a majority of studies reported that mixed reality has a significant effect on intervention for students with ASD. However, there is a limitation in objectively understanding such effect. Despite the increased volume of studies on mixed reality-based intervention for students with ASD, there is a possibility of errors in decision making for selecting an intervention because there might be repeated studies on the same concept and subject, and due to

the diversity in variables or environments for studies. Therefore, a more comprehensive review needs to be performed using a meta-analysis, which is an evidence-based scientific approach centered on literature for the effect of mixed reality-based intervention in students with ASD. The purpose of this study is to verify the effectiveness of mixed reality-based intervention and confirm the validity of practical application by conducting a meta-analysis on mixed reality-based intervention studies performed on students with ASD. In order to achieve the purpose of this study, the following research questions:

1. What are the general characteristics of mixed reality-based intervention studies for students with ASD?
2. What is the overall effect size of mixed reality-based intervention for students with ASD?
3. What is the effect of the moderators on the size of the effect of mixed reality-based intervention?
4. Is there a publication bias in mixed reality-based intervention studies?

Methods

Identification of Studies

A systematic search was conducted to select empirical mixed reality-based intervention studies, particularly for students with ASD. A list of search terms and combinations of those terms (“mixed reality”, “virtual reality”, “virtual environment”, “augmented reality”, “augmented environment”, “autism”, “ASD”, “Asperger”, “pervasive developmental disorder”, “PDD”) were generated to identify target studies. The terms were entered into PsycInfo, EBSCO

databases, ERIC, and Google Scholar. Through the initial searching process, a total, 2,048 articles were founded.

Following the initial location of studies, inclusion/exclusion criteria were developed based on the PICOS (Population, Intervention, Comparison, Outcomes, and Study designs) framework (Methely et al., 2014) to determine the eligibility of selected studies for the meta-analysis. Six criteria to locate a set of studies were as follows: (a) the study includes the mixed reality-based intervention including VR and AR as an independent variable; (b) the study involves the use of an experimental, quasi-experimental, randomized control trial (RCT), or single-case design; (c) are published in peer-reviewed journal articles in English; (d) are published between 2000 and 2017; (e) includes participants aged from preschool to K-12 with ASD; and (f) excludes studies that used AB design because it doesn't show a functional relationships (i.e., cause-effect as a function of mixed reality-based intervention; Gast & Ledford, 2014). Through the identification process, a total of 25 studies (14 group designs and 11 single-case designs) met the criteria and were included in the final set of studies for current meta-analysis. Figure 3.1 summarizes PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-analysis; Moher et al., 2015) flowchart for study identification and selection process for this study.

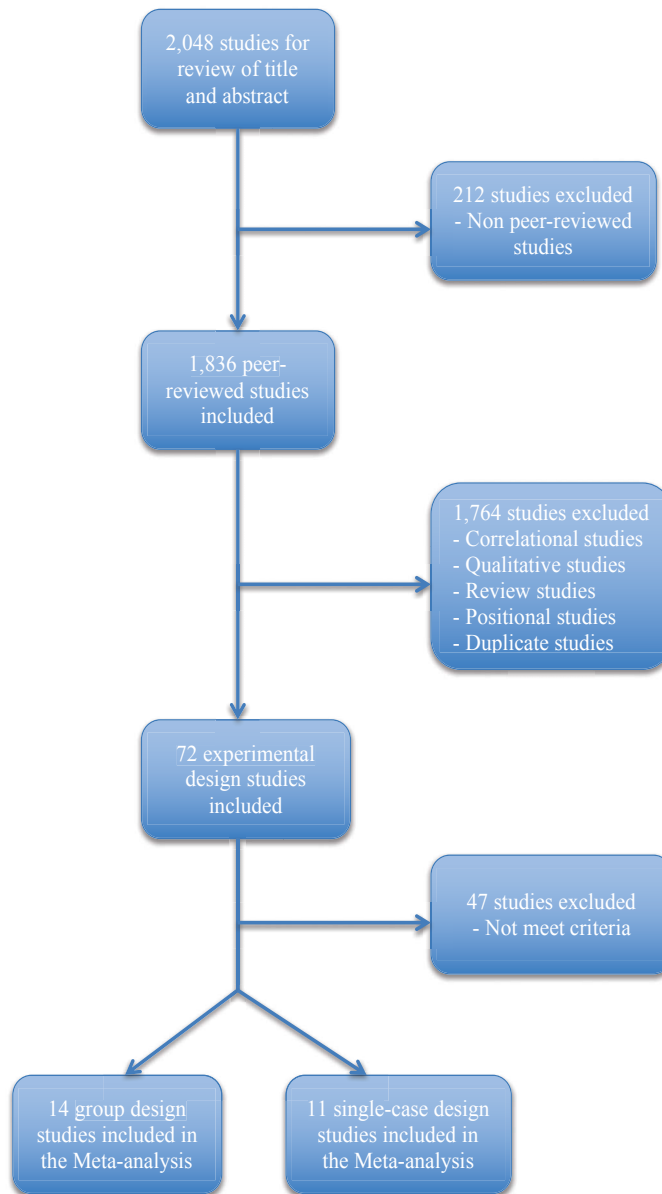


Figure 3.1. PRISMA Flowchart for Study Identification and Selection Process for This Study

Evaluation of the Quality of the Studies

In order to increase the validity of the results of this study by minimizing the bias that can underestimate or overestimate intervention effects, a quality assessment was conducted on the final 30 studies that met the selection criteria. For quality evaluation, Jitendra's (2011) coding criteria, proposed based on the quality indicators suggested by Gersten et al. (2005) for a group design (See Appendix A) and Horner et al. (2005) for single-case design (See Appendix B) was employed. The coding criteria consists of a 3-point rating scale (i.e., indicator met = 3, indicator partially met = 2, and indicator not met = 1) for both research design. The criteria for group design consisted of four essential quality indicators, and the criteria consists of seven essential quality indicators for a single-case design. Appendix A and B show essential quality indicators of a group design and a single-case design.

Data Coding and Target Variables

The coding framework proposed by Shin and Bryant (2015) was modified for the meta-analysis. A coding sheet was developed using Microsoft Excel, and target variables for coding were categorized into the eight variables (dependent variables and moderators); (a) grade; (b) gender; (c) intervention type; (d) instructional time; (e) session frequency; (f) intervention outcomes; (g) allocation; and (h) ASD types. Table 3.1 shows the coding data of moderators.

In one study, when grade levels were overlapped, they were classified into the grade level with the highest number of participants for coding. In the study by Parsons et al. (2004), for example, the total number of students with ASD participating in the study was 12 students (7 middle school students and 5 high school students). In this case, they were coded as middle school students.

Table 3.1. Coding Data for Moderators

Moderator	Type	Coding Detail
Grade (age)	Categorical	Preschool (under 6), Elementary school (6-11), Middle school (11-14), High school (14-18), N/S
Gender	Continuous	Male percent (%)
Intervention type	Categorical	VR, AR
Instructional time	Categorical	30 or less, 30-50, Above 50, N/A
Session	Categorical	15 or less, 15-30, Above 30, N/A
Outcome	Categorical	PS, SK, EF, EN, PA, LS, LO, CP
Allocation	Categorical	RCT, NRCT
ASD type	Categorical	HFA, LFA, HFA+LFA

Note. RCT = random control trial, NRCT = non-random control trial, HFA = high functioning autism, LFA = low functioning autism, PS = play skills, SK = social skills, EF = executive function, EN = engagement, PA = physical activities, LS = living skills, LO = learning outcomes, CP = contextual processing, N/S = not specified, N/A = not available, VR = virtual reality, AR = augmented reality

When the mean age of students was presented without information on ages or school years of individual students with ASD participating in the study, like in the study by Strickland et al. (2013), the grade level was coded based on the presented mean value. However, when the range of age was very broad (e.g., Didehbani et al., 2016), the grade level was coded as N/A, as more than two grade level were overlapped. The classification of the type of ASD was based on the reports by the authors.

In this study, two steps were taken to assess inter-rater reliability (IRR). First, the two researchers independently examined all the studies included in this study to assess whether the studies satisfy the inclusion/exclusion criteria. Second, the reliability of coding was measured. To this end, the researchers randomly selected approximately 30% of the studies and performed independent double coding. After that, the researchers discussed about inconsistent coding items until 100% consensus was reached for reliability.

Data Analysis Procedures

As the current study aimed to investigate the effectiveness of mixed reality-based intervention for students with ASD. Data were coded according to the reference analysis framework of coding by extracting information on the characteristics of selected studies, which are the characteristics of participants and those of intervention methods. This is not only to explain the properties of each study, but also to rationalize the analysis of the heterogeneity of effect sizes.

In the case of group design, the mean, standard deviation, *df*, *p*-value, and each statistical value (e.g., *t* value, *F* value, and χ^2) of pre- and post-test scores of the intervention group and the control group were used to calculate effect sizes. The effect size refers to the value obtained by calculating the mean difference between the intervention group and the control group, and then dividing the result by the pooled standard deviation. As a value converted into a common index to statistically analyze the results of individual studies, this value is appropriate for quantifying the degree of relationship between two variables or the difference between two groups (Borenstein et al., 2009). In this study, Cohen's *d* was calculated to test the effect of intervention as an effect size measure (Borenstein et al., 2009).

$$\text{Cohen's } d = \frac{\bar{X}_1 - \bar{X}_2}{S_{within}}$$

$\bar{X}_1, \bar{X}_2$ = sample means in the two groups, S_{within} = within-groups standard deviation, pooled across groups

$$S_{within} = \sqrt{\frac{(n_1 - 1)S_1^2 + (n_2 - 1)S_2^2}{n_1 + n_2 - 2}}$$

n_1, n_2 = sample sizes in the two groups, S_1, S_2 = standard deviation in the two groups

However, it is difficult for the Cohen's d to predict the exact standard deviation of the population because Cohen's d tends to be overestimated if the number of cases is small, as most of the experimental studies assume equal variance for the population and the group for comparison (Borenstein et al., 2009). In order to address this issue, the values of effect size were corrected to Hedges' g as presented:

$$\text{Hedges' } g = J \times d \text{ (} J = \text{correction factor)}$$

$$J = \left[1 - \frac{3}{4(n_1 + n_2) - 9} \right] \text{ or } \left(1 - \frac{3}{4df - 1} \right)$$

In addition, overall effect for group design studies was calculated by applying the random-effects model considering that the research method, sample, and intervention method of

each study varied (Borenstein et al., 2009; Hedges & Vevea, 1998; Littell, Corcoran, & Pillai, 2008).

For single-case design, Tau-*U* values were employed to calculate the effect sizes of intervention. Tau-*U* not only represents the effect sizes through the percentage of non-overlapping data between the baseline and intervention phases, but also controls the unstable trend of the baseline (Parker, Vannest, Davis, & Sauber, 2011). Like Mann-Whitney *U* test and Kendall's rank correlation, Tau-*U* also provides numeric values to interpret the significance of probability and confidence intervals (CIs) through a non-paramedic test (Bowman-Perrott et al., 2013; Parker et al., 2011). Tau-*U* scores range from -1.00 to 1.00 and can be interpreted in terms of size of effect (i.e., small effect: 0-0.62, moderate to high effect: 0.63-0.92, and large or strong effect: above 0.93; Parker, Vannes, & Davis, 2011; Parker et al., 2011).

In this study, the resulting graphs were analyzed using the GetData Graph Digitizer 2.26 program (<http://www.getdata-graph-digitizer.com>). Furthermore, a web-based calculator (<http://www.singlecaseresearch.org/calculators/tau-u>) was used to calculate Tau-*U* and the upper and lower limits of CIs 95%.

A fixed-effects model was used to perform the meta-analysis for single-case design studies. A fixed-effects model is more appropriate to use than a random-effects model when reviewing studies that have already been done on a specific subject (Hedges & Vevea, 1998) or when the number of cases is small (Borenstein et al., 2009).

Q-statistics (a measure of weighted squared deviations) were performed to test whether the effect sizes extracted from each study have homogeneity (Borenstein et al., 2009; Hedges & Olkin, 1985). T^2 (the between-studies variance) and I^2 (the ratio of true heterogeneity to total observed variation) were calculated to measure excess variances that exceeded the homogeneity

of effect sizes because Q values only test the existence of a null hypothesis (Borenstein et al., 2009). The Calculation formulas for T^2 and I^2 are shown:

$$T^2 = \frac{Q - df}{C}$$

$$C = \sum W_i - \frac{\sum W_i^2}{\sum W_i}$$

$$W_i^* = \frac{1}{V_{Y_i}^*} = \frac{1}{V_{Y_i} + T^2}$$

$$I^2 = \frac{Q - df}{Q} \times 100\%$$

C = Scaling factor, df = degree of freedom, W = weight, V_Y^* = total variance for a study, Q = observed variance

If T^2 value is zero, there is no problem in choosing a random-effects model, because a random-effects model becomes a fixed-effects model. It is reasonable to say that there is a considerable degree of heterogeneity if p value is less than .10 and I^2 value is 50% or more (Borenstein et al., 2009).

Furthermore, the moderating effect analysis was conducted. A meta-Analysis of Variance (ANOVA) was used for categorical variables, while meta-regression was conducted for continuous variables. Publication bias was estimated to check the validity of each study. For this, the Egger's regression analysis was performed (Egger, Smith, Schneider, & Minder, 1997). All effect sizes were analyzed using Comprehensive Meta-Analysis ver. 3.0 (CMA 3.0) program.

Results

Summary of Selected Mixed Reality-Based Intervention Studies

General Characteristics of Group Design Studies. 343 (90%) out of 381 students with ASD were participants in the group designs. Male students were 63% ($n = 216$), female were 9% ($n = 32$), and unknown gender were 28% ($n = 95$). The range of instructional time (min.) varied from 3-60 (four studies were not reported instructional time), and the range of instructional session varied from 1-40 (one study was not reported instructional sessions). Five intervention studies (36%) conducted with students with high functioning autism (HFA), and four intervention studies (28%) conducted with students with low functioning autism (LFA). Five studies (36%) conducted on students with HFA and LFA. Most of the study participants were elementary school level ($n = 74$, 22%), middle school students ($n = 31$, 9%), high school students ($n = 41$, 12%). 57% ($n = 197$) of participants were unable to distinguish the grade level. There were a total of 14 group design studies; 13 were VR-based intervention studies and only one was an AR-based intervention study. In addition, 10 studies were employed non-randomized control trails (NRCT) and four studies were used randomized control trials (RCT). Table 3.2 shows the summary of the features of selected studies for group designs.

In order to increase the validity of the meta-analysis, Jitendra's (2011) coding criteria was employed for the quality assessment. As results, overall quality assessment score was 2.18 out of 3 points. The average score of description of participation was 2.28, intervention/comparison condition score was 2.22, and the average score of outcome measure was 2.31. The average score of data analysis, which is 1.92, was scored relatively low compared to other quality indicators. Table 3.3 shows the quality assessment results for group designs.

General Characteristics of Single-Case Design Studies. 38 (10%) out of 381 students with ASD participated in the single-case design studies. Male students with ASD were 80% ($n = 30$) among the students who participated in the studies, female students were 10% ($n = 4$), and unknown gender were 10% ($n = 4$). The range of instructional time (min.) varied from 5~60 (one study was not reported instructional time), and the range of instructional session varied from 6-68. 10 intervention studies conducted on students with LFA ($n = 9$), two studies conducted on HFA ($n = 1$), PDD – NOS ($n = 1$). Most of the study participants were elementary school level ($n = 26$, 68%), and middle school students with ASD were 32% ($n = 12$). There were no studies on preschool and high school students. 72% ($n = 8$) studies were employed a VR-based intervention and 27% ($n = 3$) were AR intervention studies. Table 3.4 shows the summary of the features of selected studies for single-case designs.

In order to increase the validity of meta-analysis, the quality assessment using Jitendra's (2011) coding criteria was also conducted. As results, overall quality assessment score was 2.47 out of 3 points. Among the quality indicators, average score of baseline (2.77) was the highest. Participants and setting score was 2.51, dependent variable was 2.65, independent variable was 2.36, experimental control/internal validity was 2.57, and social validity was 2.36. The average score of external validity was relatively low compared to other quality indicators. Table 3.5 shows the quality assessment results for single-case designs

Table 3.2. Summary of the Features of Selected Studies for Group Designs

Study	Participants	Outcome	Study Design	Length (min)	Session	Intervention Description
Bai et al. (2015)	<i>N</i> = 12 10M/2F Age: 4 to 7 HFA+LFA	Play skills	NRCT	5	1	The researchers developed an interactive system using AR technology to visually conceptualize pretense in an open-ended play environment. The participants were given random objects to engage in pretend play and after a period, an AR scenario (i.e., bridge, track, runway) was added to the play time through a marker-based tracking system.
Bernardini et al. (2014)	<i>N</i> = 29 28M/1F Age: 4 to 14 LFA	Social skills	RCT	15	3	ECHOES, a virtual game (a total of 12 learning activities), was used to increase social communication skills. Participants interact with an intelligent Avatar in the context of social situations through a large LCD display with eye-gaze tracking.

Table 3.2. Continued

Study	Participants	Outcome	Study Design	Length (min)	Session	Intervention Description
Didehbani et al. (2016)	<i>N</i> = 30 26M/4F Age: 7 to 16 HFA	Social skills	NRCT	60	10	The participants accessed multiple VE representing school, home and community social settings using a standard keyboard and mouse. The VE contained Avatars representing the students and other social participants that were controlled by the training clinician. The Avatars engaged the participants into social interactions and allowed them to practice social skills with immediate feedback.
Fornasari et al. (2013)	<i>N</i> = 16 N/A Age: 7 to 14 HFA+LFA	Physical activities	NRCT	45	2	VE was created to analyze navigation and exploration of an urban setting. Two separate sessions were presented with the first session instructing the students to freely navigate an unfamiliar environment and the second session presented the same environment, but was paired with a goal of finding specific targeted objects.

Table 3.2. Continued

Study	Participants	Outcome	Study Design	Length (min)	Session	Intervention Description
Gal et al. (2009)	<i>N</i> = 6 6M Age: 8 to 11 HFA	Social skills	NRCT	20	8	Story Table, a co-located cooperation enforcing interface, was used to facilitate collaborate and positive social interaction. The students received instruction on different aspects of collaboration and cooperative skills in the areas of “sharing activities”, “providing help and encouragement”, and “learning to persuade and negotiate”.
Hopkins et al. (2011)	<i>N</i> = 49 44M/5F Age: 6 to 10 HFA+LFA	Social skills	RCT	18/20	12/8	FaceSay, a computer-based social skills training program, was used to provide social skills learning through interaction with an Avatar. The intervention consisted of three interactive games with the Avatar focusing on attention to eye gaze, discrimination of facial expression and recognizing faces and emotions.

Table 3.2. Continued

Study	Participants	Outcome	Study Design	Length (min)	Session	Intervention Description
Jarrold et al. (2013)	<i>N</i> = 37 N/A Age: 8 to 16 HFA	Social skills	NRCT	10~20	N/A	This study looked at a public speaking paradigm in the area of social attention, its moderators and associations with classroom learning. The participants were assessed on their ability to interact with nine virtual students in a virtual classroom while simultaneously answering self-referenced questions.
Lorenzo et al. (2016)	<i>N</i> = 40 29M/11F Age: 7 to 12 LFA	Social skills	RCT	35	40	This study looked at improving and training emotional skills for students in different social situations using an immersive VR environment. The participants interacted with Avatars in a virtual party and classroom scene choosing different emotional recognition tasks and responses.

Table 3.2. Continued

Study	Participants	Outcome	Study Design	Length (min)	Session	Intervention Description
	<i>N</i> = 42					
Mineo et al. (2009)	N/A Age: 6 to 18	Social skills	NRCT	40	3	Each participant engaged in an animated video and were exposed to an additional screen based segment involving video of self, video of a familiar person engaged with and immersive VR game or immersion of self in the VR game.
	LFA					
	<i>N</i> = 7					
Mitchell et al. (2006)	4M/3F Age: 14 to 16	Social skills	NRCT	40	3	The participants performed tasks in a virtual café and bus scenario, facilitated by the researcher, engaging in a variety of social dialogue dependent on choices they made in response to the prompts, cues, and task at hand.
	HFA+LFA					
	<i>N</i> = 30					
Mora-Guiard et al. (2017)	26M/4F Age: 10 to 15	Social skills	RCT	N/A	3	The participants explored a magical virtual world through using body motion as an interaction mediator in a physical space. The researcher observed the participants' social initiations, requests, responses, shared behaviors, and gestures.
	HFA+LFA					

Table 3.2. Continued

Study	Participants	Outcome	Study Design	Length (min)	Session	Intervention Description
Parsons et al. (2004)	<i>N</i> = 12 10M/2F Age: 13 to 18 LFA	Executive function	NRCT	N/A	4	The researchers looked at time spent on completing task, errors made, basic understanding of representational quality of VE and the social appropriateness of performance for the participants in a virtual café setting. The participants were given a checklist in the VE of five tasks to complete
Stichter et al. (2014)	<i>N</i> = 11 11M Age: 11 to 14 LFA	Social skills	NRCT	7	31	This study looked at providing instruction in social competence using 3D virtual learning through iSocial, a distance education program. the participants accessed a 2D interface where they were provided instruction and interaction in facial expressions, sharing ideas with others, turn taking in conversations, recognizing feelings, problem solving, emotions of self and others.

Table 3.2. Continued

Study	Participants	Outcome	Study Design	Length (min)	Session	Intervention Description
Strickland et al. (2013)	N = 22 22M Age: 16 to 19 HFA	Social skills	RCT	30	1	This study examined the effectiveness of a web-based interviewing skills program (JobTIPS). The participants were assigned an Avatar and accessed a VR human resource office environment via the Venugen platform. The participants interacted with a job interviewer Avatar who provided feedback on answers, body language, facial expressions, greetings, and offered instructional opportunities to rehearse interviewing skills.

Note. RCT = randomized control trial, NRCT = non-randomized control trial, HFA = high functioning autism, LFA = low functioning autism, VR = virtual reality, VE = virtual environment, AR = augmented reality, M = male, F = female

Table 3.3. Quality Assessment for Group Designs

Study	Quality indicators			
	Description of participation	Intervention/comparison condition	Outcome measure	Data analysis
Bai et al. (2015)	2.33	3.00	2.00	2.00
Didehbani et al. (2016)	2.33	2.33	2.50	2.00
Fornasari et al. (2013)	2.33	2.00	2.00	1.50
Gal et al. (2009)	2.00	2.66	2.50	2.00
Hopkins et al. (2011)	2.66	3.00	3.00	2.50
Jarrold et al. (2013)	2.00	1.66	2.00	2.00
Lorenzo et al. (2016)	2.00	2.00	2.50	1.50
Mineo et al. (2009)	2.33	2.33	2.00	1.50
Mitchell et al. (2007)	2.33	2.00	3.00	2.50
Mora-Guiard et al. (2017)	2.00	1.33	2.00	2.00
Parsons et al. (2004)	2.33	2.00	2.00	1.50
Stichter et al. (2014)	2.33	2.66	2.50	2.00

Table 3.3. Continued

Study	Quality indicators			
	Description of participation	Intervention/comparison condition	Outcome measure	Data analysis
Strickland et al. (2013)	2.66	2.00	2.00	2.00

Table 3.4. Summary of the Features of Selected Studies for Single-Case Designs

Study	Participants	Outcome	Length (min)	Sessions	Intervention Description
Bouck et al. (2014)	<i>N</i> = 3 3M Age: 6 to 10 LFA	Learning outcomes	N/A	37	This study looked at concrete manipulatives in comparison to virtual 3D object manipulatives and effectiveness in teaching subtraction skills. The participants were presented with a writing instrument, five written word problems, and either virtual or concrete manipulatives to solve the problems. The concrete and virtual manipulatives were in the form of base 10 blocks with single cubes representing ones.
Chen et al. (2014)	<i>N</i> = 3 2M/1F Age: 10 to 13 LFA	Social skills	25-30	18	AR-based self-facial modeling was used to increase the ability to recognize facial expressions. The AR provided six facial expressions overlaid on participants faces to practice emotional judgement and social skills. The participants responded to questions based on scenario in the short stories by selecting the appropriate mask reflecting the emotional content of the scenario.

Table 3.4. Continued

Study	Participants	Outcome	Length (min)	Sessions	Intervention Description
Chen et al. (2016)	<i>N</i> = 6 5M/1F Age: 11 to 13 LFA	Social skills	35-40	20	AR-based video modeling storybook was used to improve social skills. Everyday life activities and social cue scenarios were presented to the participants in an AR storybook accompanied by video segments. The participants were asked to respond to questions based on the content by selecting an appropriate emotion for 6 basic facial expressions clips of the target emotion pictures and one of 6 adjectives to answer each question.
Cheng et al. (2010)	<i>N</i> = 3 3M Age: 8 to 10 LFA	Social skills	30-40	29	VE-based social interaction system was used to examine the understanding of empathy, perspective-taking and performance of understanding empathy. The VE was in a restaurant setting displaying different social scenarios. Each student had their own 3D expressive avatar and were ask to choose an expression based on questions and events taking place in the VE

Table 3.4. Continued

Study	Participants	Outcome	Length (min)	Sessions	Intervention Description
Cheng et al. (2015)	<i>N</i> = 3	Social skills	30-40	19	This study investigated the effectiveness of a VR social understanding system targeting non-verbal communication, social initiation, and social cognition skills. The participants engaged in a question answer format in a virtual environment with school based scenarios that were presented through a head-mounted display.
	3M				
	Age: 10 to 13				
Cheng & Huang (2012)	LFA	Social skills	30-40	20	This study designed the Joint Attention Skills Learning (JASL) system to examine joint behavior attention skills using a data glove in a VE. This study specifically looked pointing, showing sharing things and behavior interactions in a VE playroom.
	<i>N</i> = 3				
	3M				
	Age: 9 to 12				
	PDD – NOS				

Table 3.4. Continued

Study	Participants	Outcome	Length (min)	Sessions	Intervention Description
Cheng & Ye (2010)	<i>N</i> = 3 2M/1F Age: 7 to 8 LFA	Social skills	30-40	17	VE-based social interaction system was used to examine social competence and behavior performance in social and cognitive interactions. The VE was set in a classroom and an outdoor scene engaging the participant in an eight eliciting emotion-eliciting question format. Each student had their own 3D expressive avatar to use for interaction with in the VE.
Cihak et al. (2016)	<i>N</i> = 3 3M Age: 6 to 7 LFA	Living skills	5	68	This study examined the use of AR to teach a chain task. The researchers used a maker-based AR picture prompt to trigger a video modeling a student brushing their teeth.

Table 3.4. Continued

Study	Participants	Outcome	Length (min)	Sessions	Intervention Description
Ke & Im (2013)	<i>N</i> = 4	Social skills	60	6-9	This study examined Second-Life, a social interaction program set in VR. The program simulated a virtual school setting and house party where the students practiced with a virtual partner on recognizing a) body gestures and facial expressions, b) responding and maintaining interactions in a school cafeteria, and c) initiating and maintaining interactions at a birthday party.
	N/A				
	Age: 9 to 10				
Wang & Reid (2013)	HFA	Contextual processing	10	9-11	VR-cognitive rehabilitation intervention was used to improve contextual processing of objects. The intervention was set in a VE with three different dimensions testing perceptual, spatial, and functional relationships of discriminating moving objects and their relationships to a multiobject context.
	<i>N</i> = 4				
	3M/1F				
	Age: 6 to 8				
	LFA				

Table 3.4. Continued

Study	Participants	Outcome	Length (min)	Sessions	Intervention Description
Root et al. (2017)	<i>N</i> = 3 3M Age: 7 to 11 LFA	Learning outcomes	34	15-20	This study evaluated the effects of a modified schema-based instruction for solving mathematical word problems by comparing the effects of concrete and virtual manipulations. Participants were presented with a) problem solving mat b) laminated student self-instruction sheet, c) a graphic organizer presented concretely in paper form or virtually using an iPad 3, and d) written compare word problems.

Note. PDD – NOS = pervasive developmental disorder – not otherwise specified, HFA = high functioning autism, LFA = low functioning autism, VE = virtual environment, VR = virtual reality, AR = augmented reality, M = male, F = female

Table 3.5. Quality Assessment Results for Single-Case Designs

Study	Quality indicators						
	Participants and setting	DV	IV	Baseline	Experimental control/internal validity	External validity	Social validity
Bouck et al. (2014)	2.33	2.80	3.00	2.50	2.66	3.00	2.75
Chen et al. (2015)	2.66	2.40	2.00	3.00	2.33	2.00	2.25
Chen et al. (2016)	2.66	2.80	2.33	3.00	2.66	2.00	2.50
Cheng et al. (2010)	2.33	2.60	2.33	2.50	2.66	2.00	2.00
Cheng et al. (2015)	3.00	2.80	2.33	2.50	2.66	2.00	2.00
Cheng & Huang	2.00	2.80	2.00	3.00	2.66	2.00	2.25

Table 3.5. Continued

Study	Quality indicators						
	Participants and setting	DV	IV	Baseline	Experimental control/internal validity	External validity	Social validity
Cheng & Ye (2010)	2.33	2.60	2.33	2.50	2.66	2.00	2.25
Cihak et al. (2016)	3.00	3.00	3.00	3.00	3.00	2.00	3.00
Ke & Im (2013)	2.00	2.20	2.00	2.50	2.33	2.00	2.00
Wang & Reid (2013)	2.33	2.20	1.66	3.00	2.66	2.00	2.00
Root et al. (2017)	3.00	3.00	3.00	3.00	2.00	2.00	3.00

Note. DV = dependent variable, IV = independent variable

Meta-Analysis of Mixed Reality-Based Intervention: Group Design Studies

The Estimated Effect Sizes of Mixed Reality-Based Intervention. The results of Hedges' g for 14 selected studies were presented in the forest plot. A total of 16 effect sizes (Hedges' g) were extracted from the 14 individual studies and analyzed in the meta-analysis. When multiple mixed reality-based interventions were conducted in an individual study, the research results were individually calculated. Figure 3.2 shows the results of the overall effect size of the studies.

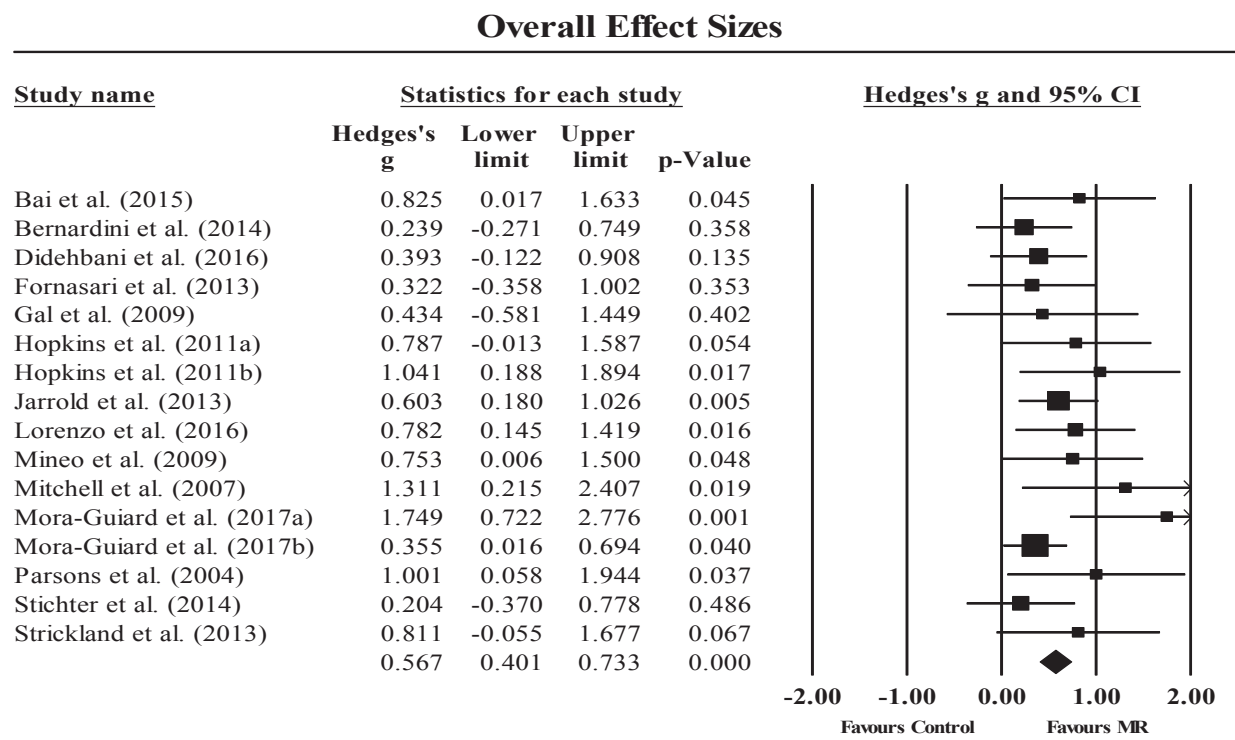


Figure 3.2. Results of the Overall Effect Size of Group Design Studies

The random-effects model produced the average effect size was .567, $CI_{95} [.041, .733]$, $p = .000$. If this result is expressed by $U3$ (Cohen, 1988), it can be interpreted that the average of group corresponds to approximately 72% of the comparative group when the average of control

group is 50%. And if this is expressed with Binomial Effect Size Display (BESD; Lipsey & Wilson, 2001; Randolph & Edmondson, 2005) that compares a success rate of the group and the control group, it can be interpreted that while a success rate of the control group is 36%, a success rate of the experimental group is 64%. The effect sizes calculated for each study ranged from .204 to 1.749, which was relatively inconstant across the studies.

The Q-value indicates the observed weighted sum of squares of each effect size in the meta-analysis. It signifies the total variance including both the sampling error or the random error and the true variance. I^2 is an index indicating heterogeneity and is represented in the ratio of true variance to the total observed variation. In other words, it shows the ratio of variation between the actual studies to the total variation. In general, heterogeneity of effect sizes is determined to be considerable when the ratio of true variance to the total variation (I^2) is greater than 50% and the p -value of heterogeneity test is less than .01. (Higgins & Green, 2013). In this study, heterogeneity test was not statistically significant ($I^2 = 7.168\%$, $Q = 16.158$, $p = .372$). Table 3.6 shows average effect size of the selected group design studies, where k is the number of the effect size.

Table 3.6. Average Effect Size of the Selected Group Design Studies

Model	k	Random Effects (Hedges' g)				CI _{95%}		Heterogeneity		
		<i>Mean</i>	<i>SE</i>	<i>Z</i>	<i>p</i>	LL	UL	I^2	Q	$p(Q)$
Random Effect	16	.567	.084	6.710	.000	.401	.733	7.168	16.158	.372

Note. k = number of effect size, LL = lower limit, UL = upper limit.

Outcome Variables. Table 3.7 shows the effect size of mixed reality-based intervention effects by outcomes. It shows that executive functions had the largest size of mixed reality-based intervention effect, Hedges' $g = 1.001$, and there was a significant improvement, $CI_{95} [.005, 1.977]$. Followed by social skills had Hedges' $g = .567$, $CI_{95} [.363, .770]$, $p = .000$. The intervention effect sizes were not statistically significant on play skills (Hedges $g = .825$, $CI_{95} [-.044, 1.694]$, $p = .063$), engagement (Hedges' $g = .753$, $CI_{95} [-.060, 1.566]$, $p = .069$), and physical activities (Hedges' $g = .322$, $CI_{95} [-.430, 1.074]$, $p = .402$). In addition, there was no significant differences in the effect sizes according outcome variables ($Q = 1.626$, $df = 4$, $p(Q) = .084$).

Table 3.7. Group Design Effect Sizes by Outcomes

Dependent Variables	k	Random Effects (Hedges' g)				$CI_{95\%}$		Heterogeneity		
		<i>Mean</i>	<i>SE</i>	<i>Z</i>	<i>p</i>	LL	UL	<i>Q</i>	<i>df</i>	<i>p(Q)</i>
Social Skills	12	.567	.104	5.451	.000	.363	.770			
Play Skills	1	.825	.443	1.860	.063	-.044	1.694			
Physical Activities	1	.322	.384	.839	.402	-.430	1.074	1.626	4	.084
Engagement	1	.753	.415	1.815	.069	-.060	1.566			
Executive Functions	1	1.001	.508	1.970	.049	.005	1.977			

Note. k = number of effect size, LL = lower limit, UL = upper limit.

The Moderator Effects. The variables that were commonly reported as being related to the effectiveness of mixed reality-based intervention for students with ASD were considered to see if those variables played a significant role as moderators. To determine the moderator effects, a moderator analysis according to the grade levels, gender, allocation, ASD types, instructional time and sessions were performed, and a random-effects model was employed to perform the analysis. Grade levels, allocation, ASD types, intervention type, instructional time and sessions were classified as categorical variables and analyzed using meta-ANOVA. Gender was classified as a continuous variable and analyzed using meta-regression.

The results showed that the effect size was the largest for high school students, Hedges' $g = 1.003$, $CI_{95} [.451, 1.554]$, $p = .000$, followed by elementary school students, Hedges' $g = .604$, $CI_{95} [.230, .979]$, $p = .002$. The effect size was the least for the middle school students, Hedges' $g = .316$, $CI_{95} [.024, .608]$, $p = .034$. However, the differences in the effect sizes by grade level were not significant ($Q = 5.361$, $df = 3$, $p(Q) = .147$). The effect sizes of the mixed reality-based intervention were analyzed according to the function of allocation, intervention and ASD types. The effect size for RCT was Hedges' $g = .615$, $CI_{95} [.374, .855]$, $p = .000$, and Hedges' $g = .536$, $CI_{95} [.284, .788]$, $p = .000$ for NRCT. For intervention type, the effect size for VR was Hedges' $g = .562$, $CI_{95} [.338, .736]$, $p = .000$, and AR was Hedges' $g = .825$, $CI_{95} [-.012, 1.662]$, $p = .053$. For ASD types, the effect size for students with LFA was Hedges' $g = .528$, $CI_{95} [.260, .796]$, $p = .000$, HFA was Hedges' $g = .609$, $CI_{95} [.335, .883]$, $p = .000$. The effect size for intervention on students with HFA and LFA together was Hedges' $g = .688$, $CI_{95} [.186, 1.190]$, $p = .007$. The differences in the effect sizes by allocation ($Q = .195$, $df = 1$, $p(Q) = .695$), intervention types ($Q = .364$, $df = 1$, $p(Q) = .546$) and ASD types ($Q = .365$, $df = 2$, $p(Q) = .833$) were not significant.

Table 3.8 shows the effect size of mixed reality-based intervention effects by allocation, intervention and ASD types.

Table 3.8. Group Design Effect Sizes by Moderators

Moderators	<i>k</i>	Random Effects (Hedges' <i>g</i>)				CI _{95%}		Heterogeneity		
		<i>Mean</i>	<i>SE</i>	<i>Z</i>	<i>p</i>	LL	UL	<i>Q</i>	<i>df</i>	<i>p(Q)</i>
Elementary	4	.604	.191	3.163	.002	.230	.979	5.361	3	.147
Middle school	2	.316	.149	2.121	.034	.024	.608			
High school	3	1.003	.281	3.564	.000	.451	1.554			
N/A	7	.606	.117	5.159	.000	.376	.836			
RCT	8	.615	.123	5.005	.000	.374	.855	.195	1	.659
NRCT	8	.536	.129	4.172	.000	.284	.788			
VR	15	.562	.089	6.333	.000	.388	.736	.364	1	.546
AR	1	.825	.427	1.932	.053	-.012	1.662			
LFA	6	.528	.137	3.867	.000	.260	.796			
HFA	7	.609	.140	4.351	.000	.335	.883	.365	2	.833
HFA+LFA	3	.688	.256	2.688	.007	.186	1.190			

Note. *k* = number of effect size, RCT = randomized control trial, NRCT = non-randomized control trial, VR = virtual reality, AR = augmented reality, LFA = low functioning autism, HFA = high functioning autism, LL = lower limit, UL = upper limit.

The effect sizes of the mixed reality-based intervention were also analyzed according to the function of instructional time and sessions. The results showed that the effect sizes were the

largest for 30-50 min. instructional time, Hedges' $g = .718$, $CI_{95} [.292, .1.143]$, $p = .001$, followed by less 30 min., Hedges' $g = .530$, $CI_{95} [.250, .809]$, $p = .000$. The effect size, however, was the least for above 50 min., Hedges' $g = .393$, $CI_{95} [-.229, .1.015]$, $p = .215$. For intervention sessions, the effect size of less 15 sessions was Hedges' $g = .608$, $CI_{95} [.395, .822]$, $p = .000$ and the effect size of above 30 sessions was Hedges' $g = .470$, $CI_{95} [-.014, .953]$, $p = .057$. In addition, there were not statistically differences according to both instructional time and sessions; instructional time: $Q = 1.117$, $df = 3$, $p(Q) = .773$; instructional sessions: $Q = .268$, $df = 2$, $p(Q) = .875$. Table 3.9 shows the effect size of mixed reality-based intervention effects by instructional time and sessions.

Table 3.9. Group Design Effect Sizes by Instructional Time and Sessions

Time & Session	Category	k	Random Effects (Hedges' g)				$CI_{95\%}$		Heterogeneity		
			<i>Mean</i>	<i>SE</i>	<i>Z</i>	<i>p</i>	LL	UL	<i>Q</i>	<i>df</i>	<i>p(Q)</i>
Time (min)	<30	7	.530	.142	3.719	.000	.250	.809	1.117	3	.773
	30-50	4	.718	.217	3.304	.001	.292	1.143			
	50>	1	.393	.317	1.239	.215	-.229	1.015			
	N/A	4	.674	.186	3.633	.000	.310	1.038			
Session	<15	13	.608	.109	5.538	.000	.395	.822	.268	2	.875
	30>	2	.470	.247	1.904	.057	-.014	.953			
	N/A	1	.603	.271	2.226	.026	.072	1.134			

Note. k = number of effect size, LL = lower limit, UL = upper limit.

meta-regression was conducted to examine if the effect sizes of mixed reality-based intervention for students with ASD were changed based on gender. A regression line is the predicted value of the effect size by covariate and shows the relationship between covariate and effect size. As shown in figure 3.3 and table 3.10, gender didn't impact the effect sizes, $Q = 14.68$, $df = 11$, $p(Q) = .197$. According to the regression equation, the effect size (y) estimated with the percent of male students (moderator) was formulated as $y = 1.395 - .009 (\text{male } \%)$. In this regression equation, the Z value (slope) is $-.850$ and the p -value is $.396$, indicating that the regression coefficient is not significant.

Table 3.10. Group Design Effect Sizes by Gender

Gender	β	Random Effects (Hedges' g)			CI _{95%}		Heterogeneity		
		SE	Z	p	LL	UL	Q	df	$p(Q)$
Male %	-.009	.011	-.850	.396	-.030	0.12	14.68	11	.197
Intercept	1.395	.933	1.500	.135	-.434	3.224			

Note. LL = lower limit, UL = upper limit.

As shown in the figure 3.3, the straight line is the regression line and the circles around the line means the number of male participants. The circles are weighted by the number of male participants: the large the circle, the greater the number of male participants.

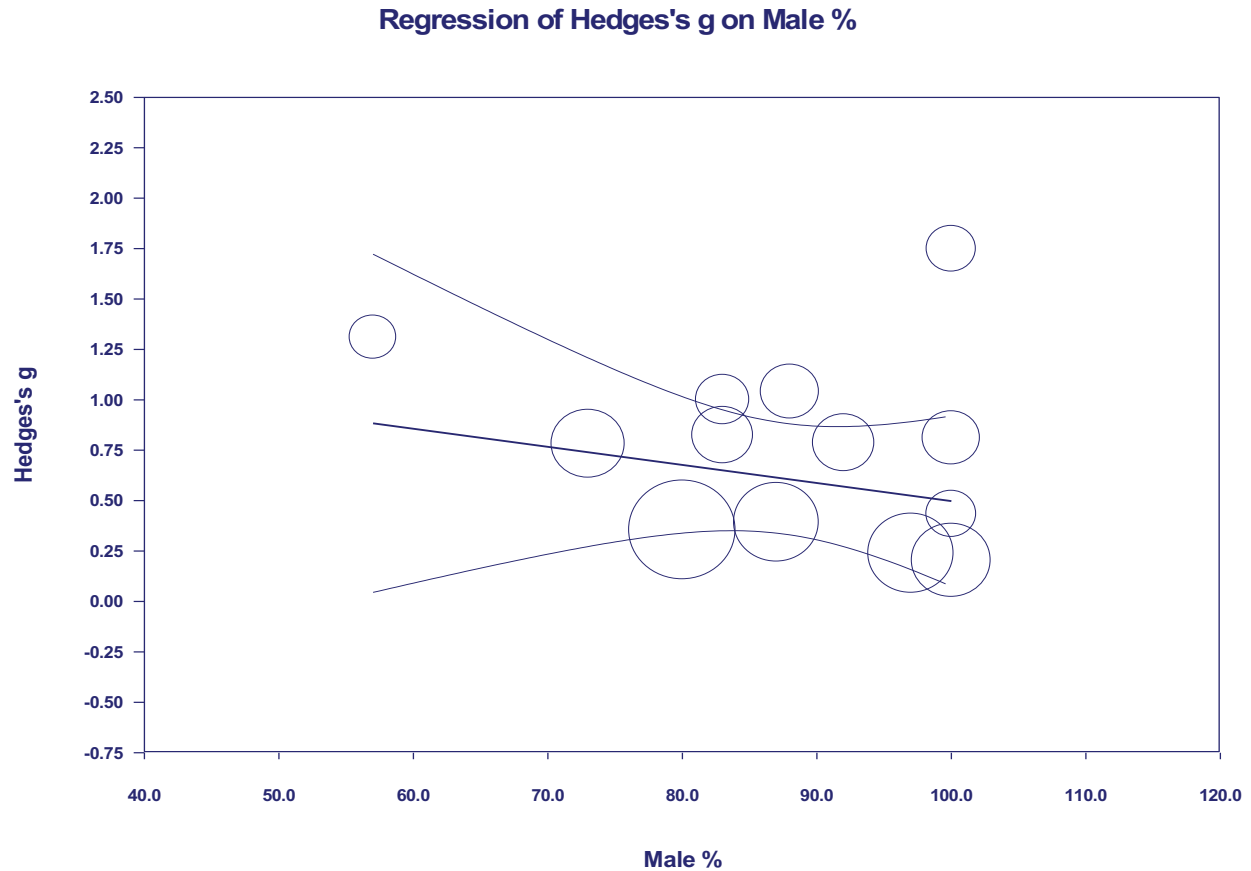


Figure 3.3. Regression on Hedges' g on Gender of Group Design Studies

Publication Bias Test. In the publication bias test, symmetry was checked using a funnel plot which is the generally recommended approach (Borenstein et al., 2009). Then, for a more objective verification, an Egger's regression was performed. According to the Egger's regression test results, the publication bias was found ($t = 3.686$, $df = 14$, $p = .002$). To further investigate the effect of publication bias on the results of the current meta-analysis, Duval and Tweedie's (2002) trim-and-fill method was performed (Borenstein et al., 2009). According to the results, 6 studies were trimmed and the overall effect size was decreased from .567 to .446. However, the results still showed a positive mixed reality-based intervention effect on students with ASD ($CI_{95} [.302, .590]$). Figure 3.4 shows the adjusted effect sizes after trim-and-fill. Table 3.11 also

shows adjusted effect sizes by Duval and Tweedie's Trim-and-fill. The white points on the funnel plot indicate the studies actually analyzed in this meta-analysis. From the center of the funnel plot, the left and right are asymmetrical, which signifies that there is a publication bias. The black points are data points that are virtually created to compensate for the bias using the Trim-and-Fill technique. Through these hypothetical points, underestimate and/or overestimate due to publication bias can be compensated.

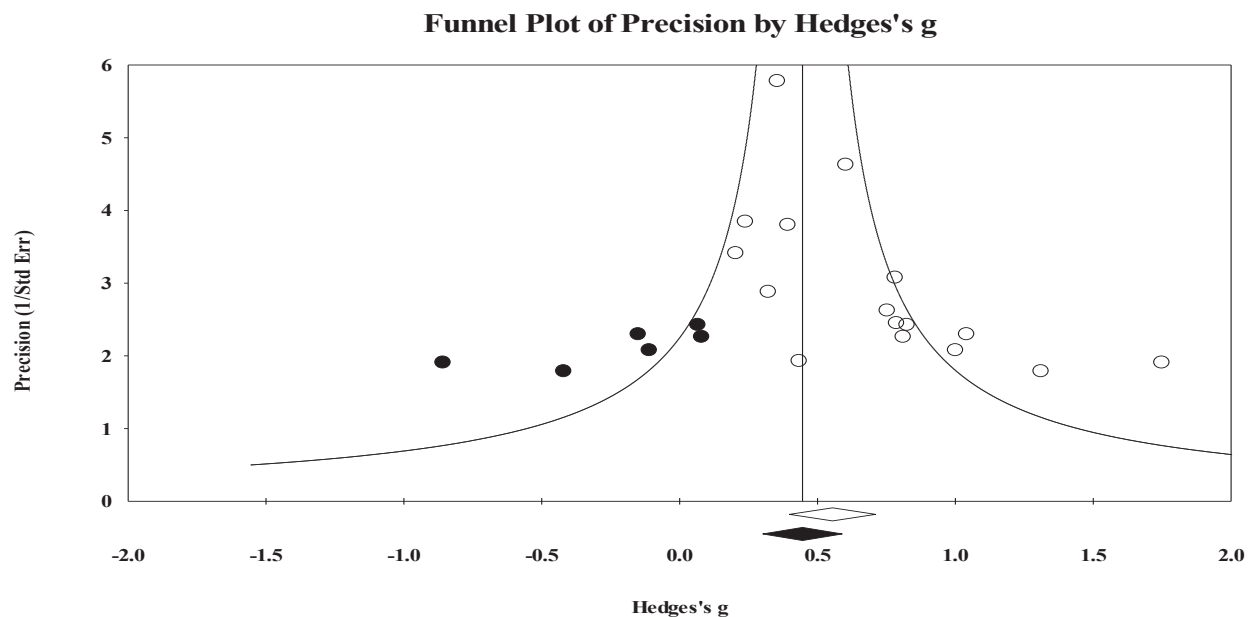


Figure 3.4. Funnel Plot of Precision by Hedges' g of Group Design Studies

Table 3.11. Adjusted Group Design Effect Sizes by Duval and Tweedie's Trim-and-Fill

	Studies Trimmed	Point Estimate	LL	UL	Q Value
Observed Values		.567	.401	.733	16.158
Adjusted Values	6	.446	.302	.590	31.351

Note. LL = lower limit, UL = upper limit.

Meta-analysis of Mixed Reality-Based Intervention: Single-case Design Studies

The Estimated Effect Sizes of Mixed Reality-Based Intervention. The overall effect size was calculated by contrasting the baseline and the intervention phase of the selected 11 studies. A total of 11 effect sizes (Tau- U) was extracted from the 11 individual studies and analyzed in the meta-analysis. When multiple mixed reality-based interventions were conducted in an individual study, the research results were individually calculated. Figure 3.5 and table 3.12 show the results of the overall effect size of the studies, where k is the number of the effect size.

The fixed-effects model produced the overall effect size of the 11 studies, which was Tau- $U = .797$, CI_{95%}[.735, .859], $p = .000$, indicating moderate effect (Parker et al., 2011). That is, mixed reality-based interventions used for students with ASD between the baseline and the intervention phase estimated as effective overall. The effect sizes calculated for each study ranged from .315 to .875, however, except Ke and Im's study (2013), it was relatively constant across the studies. The heterogeneity test of the effect sizes was $I^2 = 0\%$, also indicating no inconsistency across the studies (Higgins & Green, 2013).

Table 3.12. Average Effect Size of the Selected Single-Case Design Studies

Model	k	Fixed Effects (Tau- U)				CI _{95%}		Heterogeneity		
		<i>Mean</i>	<i>SE</i>	<i>Z</i>	<i>p</i>	LL	UL	I^2	Q	$p(Q)$
Fixed Effect	11	.797	.032	25.055	.000	.735	.859	.000	7.338	.693

Note. k = number of effect size, LL = lower limit, UL = upper limit.

Overall Effect Sizes

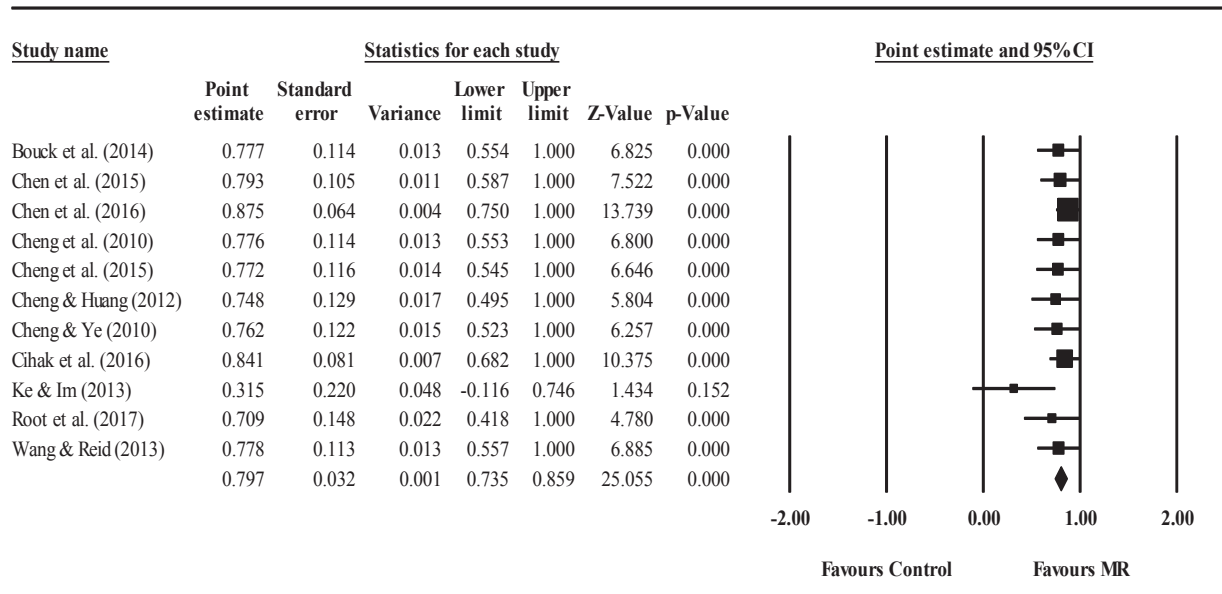


Figure 3.5. Results of the Overall Effect Size of Single-Case Design Studies

Outcome Variables. Table 3.13 shows the effect size of mixed reality-based intervention effects by outcomes. It shows that living skills had the largest size of mixed reality-based intervention effect, $\text{Tau-}U = .841$, and there was a significant improvement from the baseline to the intervention phase, $\text{CI}_{95} [.682, 1.000]$, $p = .000$, followed by social skills ($\text{Tau-}U = .797$, $\text{CI}_{95} [.720, .875]$, $p = .000$), contextual processing ($\text{Tau-}U = .778$, $\text{CI}_{95} [.557, 1.000]$, $p = .000$), and learning outcomes ($\text{Tau-}U = .752$, $\text{CI}_{95} [.575, .929]$, $p = .000$). In addition, there was no statistically significant differences in the effect sizes according to dependent variables, $Q = .572$, $df = 3$, $p(Q) = .903$, indicating that the mixed reality-based interventions showed moderate effect size on social skills, living skills, learning outcomes, and contextual processing for four outcomes were similar.

Table 3.13. Effect Sizes of Single-Case Design by Outcomes

Dependent Variable	<i>k</i>	Fixed Effects (Tau- <i>U</i>)				CI _{95%}		Heterogeneity		
		<i>Mean</i>	<i>SE</i>	<i>Z</i>	<i>p</i>	LL	UL	<i>Q</i>	<i>df</i>	<i>p(Q)</i>
Social Skills	7	.797	.040	20.100	.000	.720	.875			
Living Skills	1	.841	.081	10.375	.000	.682	1.000	.573	3	.903
Learning Outcomes	2	.752	.090	8.324	.000	.575	.929			
Contextual Processing	1	.778	.113	6.885	.000	.557	1.000			

Note. *k* = number of effect size, *LL* = lower limit, *UL* = upper limit.

The Moderator Effects. This study examined the variables that affect the effectiveness of mixed reality-based intervention for students with ASD. To do so, a moderator analysis according to the grade levels, gender, outcomes, ASD types, instructional time and sessions were performed, and a fixed-effects model was employed to perform the analysis. Grade levels, outcomes, ASD types, intervention type, instructional time and sessions were classified as categorical variables and analyzed using meta-ANOVA. Gender was classified as a continuous variable and analyzed using meta-regression.

Table 3.14 shows the effect size of mixed reality-based intervention effects by moderators. For grade levels, the results showed that the effect size for elementary school students was $\text{Tau-}U = .767$, $\text{CI}_{95} [.686, .849]$, $p = .000$, and middle school students, $\text{Tau-}U = .839$, $\text{CI}_{95} [.742, .935]$, $p = .000$. The effect size of mixed reality-based intervention was higher among the middle school students than elementary school students. However, the differences in the effect sizes by grade levels were not significant, $Q = 1.222$, $df = 1$, $p(Q) = .268$. For intervention type, the effect size of AR-based interventions ($\text{Tau-}U = .850$, $\text{CI}_{95} [.761, .938]$, $p = .000$) was

higher than VR-based intervention effect ($\text{Tau-}U = .745$, $\text{CI}_{95} [.658, .833]$, $p = .000$). The heterogeneity, however, was not found ($Q = 2.674$, $df = 1$, $p(Q) = .102$). The results for ASD types showed that the effect size was the largest for students with LFA ($\text{Tau-}U = .811$, $\text{CI}_{95} [.746, .876]$, $p = .000$), followed by students with PDD – NOS ($\text{Tau-}U = .748$, $\text{CI}_{95} [.495, 1.000]$, $p = .000$). The effect size, however, was the least for students with HFA ($\text{Tau-}U = .351$, $\text{CI}_{95} [-.116, .746]$, $p = .000$). Heterogeneity, however, was not found ($Q = 5.144$, $df = 2$, $p(Q) = .076$).

Table 3.14. Effect Sizes of Single-Case Design by ASD Types

Moderator	<i>k</i>	Fixed Effects (Tau-U)				CI _{95%}		Heterogeneity		
		<i>Mean</i>	<i>SE</i>	<i>Z</i>	<i>p</i>	LL	UL	<i>Q</i>	<i>df</i>	<i>p(Q)</i>
Elementary	8	.767	.042	18.448	.000	.686	.849	1.227	1	.268
Middle School	3	.839	.049	16.991	.000	.742	.935			
AR	3	.850	.045	18.776	.000	.761	.938	2.674	1	.102
VR	8	.745	.045	16.671	.000	.658	.833			
LFA	9	.811	.033	24.437	.000	.746	.876			
HFA	1	.315	.220	1.434	.152	-.116	.746	5.144	2	.076
PDD – NOS	1	.748	.129	5.804	.000	.495	1.000			

Note. *k* = number of effect size, *LL* = lower limit, *UL* = upper limit, *VR* = virtual reality, *AR* = augmented reality, *LFA* = low functioning autism, *HFA* = high functioning autism, *PDD – NOS* = pervasive developmental disorder – not otherwise specified

The effect sizes of the mixed reality-based intervention were analyzed according to the function of instructional time and sessions. Table 3.15 shows the effect size of mixed reality-based intervention effects by instructional time and sessions. For instructional time, the effect sizes were decreased as the amount of instructional time was increased; less 30 minutes: $\text{Tau-}U = .812$, $\text{CI}_{95} [.703, .922]$, $p = .000$; 30-50: $\text{Tau-}U = .808$, $\text{CI}_{95} [.726, .890]$, $p = .000$; above 50: $\text{Tau-}U = .351$, $\text{CI}_{95} [-.116, .746]$, $p = .152$. On the other hand, the effect sizes were increased as the total number of sessions were increased; less 15: $\text{Tau-}U = .681$, $\text{CI}_{95} [.484, .878]$, $p = .000$; 15-30: $\text{Tau-}U = .806$, $\text{CI}_{95} [.730, .883]$, $p = .000$; above 30: $\text{Tau-}U = .820$, $\text{CI}_{95} [.690, .949]$, $p = .000$. However, there were not differences according to both instructional time and sessions (instructional time: $Q = 4.996$, $df = 3$, $p(Q) = .172$; sessions: $Q = 1.498$, $df = 2$, $p(Q) = .473$).

Table 3.15. Effect Sizes of Single-Case Design by Instructional Time and Sessions

Time & Session	Category	k	Fixed Effects (Tau-U)				$\text{CI}_{95\%}$		Heterogeneity		
			<i>Mean</i>	<i>SE</i>	<i>Z</i>	<i>p</i>	LL	UL	<i>Q</i>	<i>df</i>	<i>p(Q)</i>
Time (min)	30 <	3	.812	.056	14.538	.000	.703	.922	4.996	3	.172
	30-50	6	.808	.042	19.307	.000	.726	.890			
	50 >	1	.315	.220	1.434	.152	-.116	.746			
	N/A	1	.777	.114	6.825	.000	.554	1.000			
Session	15 <	2	.681	.101	6.778	.000	.484	.878	1.498	2	.473
	15-30	7	.806	.039	20.720	.000	.730	.883			
	30 >	2	.820	.066	12.410	.000	.690	.949			

Note. k = number of effect size, LL = lower limit, UL = upper limit.

meta-regression was performed to examine if the effect sizes of mixed reality-based interventions were changed by gender. As shown in figure 3.6 and table 3.16, gender didn't impact the effect sizes, $Q = 6.850$, $df = 9$, $p(Q) = .652$. According to the regression equation, the effect size (y) estimated with the male percent was formulated as $y = .675 + .002 (\text{male } \%)$. The initial value of the regression equation is .657, which indicated that there was a significant improvement from the baseline to the intervention phase for female students ($CI_{95} [.259, 1.055]$, $p = .001$). In addition, with each 1% increase in the male student ratio, there was an increase of .002 in the size of intervention effect. This, however, was not a significant increase, $CI_{95} [-.003, .006]$, $p = .486$.

Table 3.16. Effect Sizes of Single-Case Design by Gender

Gender	β	Fixed Effect (Tau-U)			CI _{95%}		Heterogeneity		
		<i>SE</i>	<i>Z</i>	<i>p</i>	LL	UL	<i>Q</i>	<i>df</i>	<i>p(Q)</i>
Male %	.002	.002	.700	.486	-.003	.006	6.850	9	.652
Intercept	.657	.203	3.24	.001	.259	1.055			

Note. LL = lower limit, UL = upper limit.

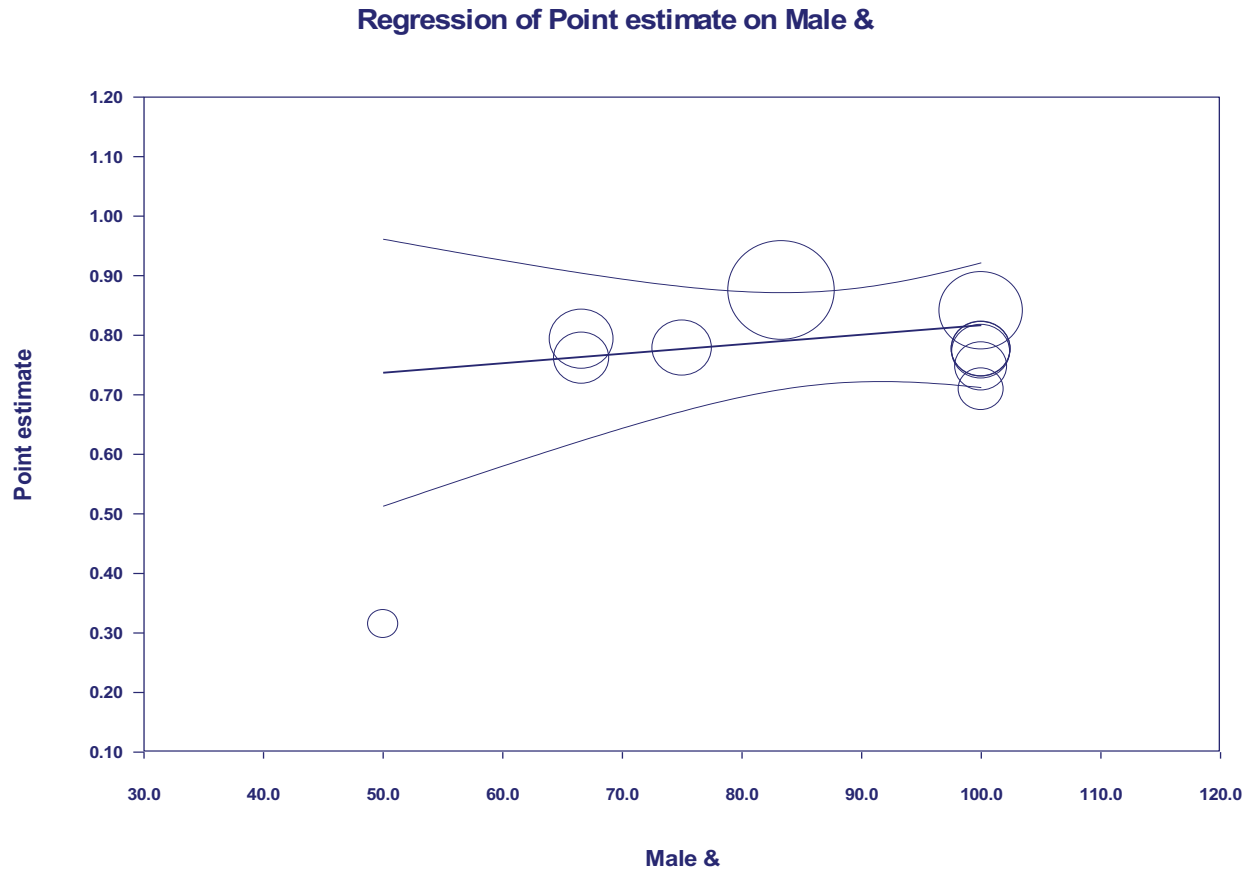


Figure 3.6. Regression on Point Estimate of Single-Case Design on Gender

Publication Bias Test. As a way to validate the results, the publication bias test was conducted. First, symmetry was checked using a funnel, a common approach to adjust extreme study results (Borenstein et al., 2009). Then, an Egger's regression was performed to check publication bias (Egger et al., 1997). According to the test, the publication bias was found ($t = 8.062$, $df = 9$, $p = .000$). To further investigate the effect of publication bias on the results of the current meta-analysis, Duval and Tweedie's (2002) trim-and-fill method was performed (Borenstein et al., 2009). According to the results, 5 studies were trimmed and the overall effect size was increased from .797 to .826. Figure 3.7 shows the adjusted effect sizes throughout trim-and-fill procedures. According to table 3.17, there was nearly no difference between the

observed and the adjusted effect sizes. It can be interpreted that the effect of missing studies is very small.

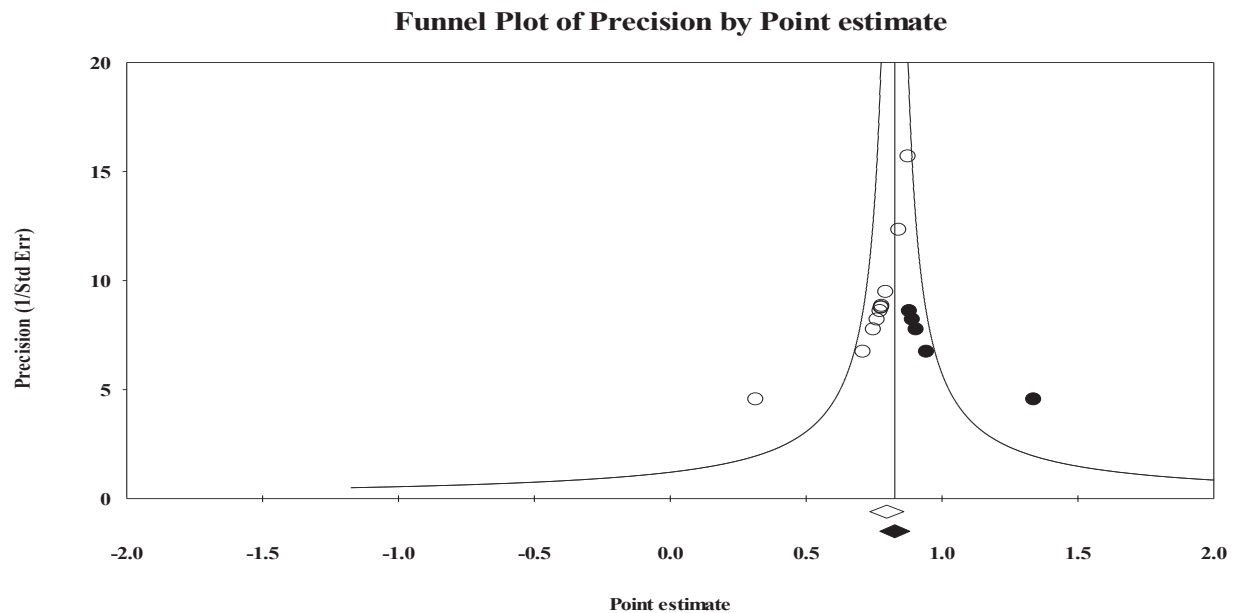


Figure 3.7. Funnel Plot of Precision by Point of Estimate

Table 3.17. Adjusted Single-Case Design Effect Sizes by Duval and Tweedie's Trim-and-Fill

	Studies Trimmed	Point Estimate	LL	UL	Q Value
Observed Values		.797	.735	.859	7.338
Adjusted Values	5	.826	.771	.882	15.100

Note. LL = lower limit, UL = upper limit.

Discussion

In this study, the effects of mixed reality-based intervention for students with ASD were analyzed quantitatively using a meta-analysis to evaluate the effectiveness of mixed reality-based

intervention and provide information which can be used to support the use of mixed reality as an evidence-based practice. Through the search procedures based on inclusion/exclusion criteria to locate appropriate studies, a total of 25 studies (14 studies using group designs, 11 studies using single-case designs) and 381 students with ASD (343 students in group designs, 38 students in single-case designs) were included for the meta-analysis. The effect sizes demonstrated that the mixed reality-based interventions for students with ASD used across the studies were effective to increase dependent variables. The results were stable across the selected mixed reality-based intervention studies (see F^2 values).

Overall effect size for group design studies (Hedges' g) for this study was .567 ($SE = .084$, $CI_{95} [.401, .733]$). This result was higher than the overall effect size reported in previous studies. Grynszpan et al. (2014) conducted a meta-analysis of innovative technology intervention (i.e., computer programs, virtual reality, and robotics) for students with ASD, and hedge's $g = .469$ was reported as the overall effect size. This result demonstrated that mixed reality-based interventions are more effective than other innovative technology-based intervention. Merchant et al. (2014) conducted a meta-analysis of VR-based instruction on learning outcomes for students without disabilities in K-12 and higher education, and they reported Hedges' $g = .510$ ($SE = .130$, $CI_{95} [.250, .770]$). This result demonstrated that mixed reality-based intervention is as effective for students with ASD as for students without disabilities. Rather, the effect size of VR-based intervention (Hedges' $g = .562$, $SE = .089$, $CI_{95} [.388, .736]$) was higher for students with ASD.

Overall effect size for single-case design studies (Tau- U) for this study was .797 ($SE = .032$, $CI_{95} [.735, .859]$). This result was lower than the overall effect size reported in previous study. Kim, Park, Cihak, and O'Reilly (in review) conducted a meta-analysis of single-case

studies on intervention using AR for student with disabilities, and they reported overall effect size $\text{Tau-}U = .851$ ($SE = .024$, $CI_{95} [.804, .897]$). However, the mean effect size for AR in the current meta-analysis was $\text{Tau-}U = .850$, whereas, the mean effect size for VR was $\text{Tau-}U = .745$. Although there was no statistical difference between VR and AR as intervention types found regarding the moderator effects, it is worth noting that AR-based intervention is more effective for students with ASD than VR-based intervention.

This study also examined if the effect sizes of mixed reality-based interventions can be changed based the effects of moderators (i.e., intervention types, gender, grade levels, ASD types, instructional time and session frequency). The meta-ANOVA and meta-Regression results showed that the effect sizes of mixed reality-based interventions were not changed by these moderators. Kim et al. (in review) reported that the effect sizes of AR-based interventions were not affected by gender, grade levels, instructional time and session frequency. Grynszpan et al. (2014) reported that the influence of age on innovative technology-based interventions for students with ASD was not statistically significant. Furthermore, there were no moderator effects according to the intervention types and ASD types in this study. These results demonstrated that mixed reality-based interventions are effective for students with ASD regardless of moderators.

Although, there was no significantly differences found regarding the moderator effects. In the case of group designs, mixed reality-based intervention studies were centered on social skills. Executive functions showed the highest effect size, while physical activities demonstrated the lowest effect. The intervention was found to be most effective for high school students and least effective for middle school students. In addition, it was found that the intervention was more effective for students with HFA than students with LFA. In terms of intervention time, most studies implemented the intervention for less than 30 minutes, but it was found that the

intervention is most effective when implemented for 30 to 50 minutes, while it is least effect when implemented for 50 minutes or longer. This may be related to the attention span of students with ASD. In addition, the intervention was found to be more effective when carried out for 15 or fewer sessions compared to 30 or more sessions of intervention.

In the case of single-case design studies, mixed reality-based intervention studies were also centered on social skills as in the case of group design. The highest intervention effect was found in living skills, followed by social skills, contextual processing, and learning outcomes. Also, unlike the group design, the intervention was found to be more effective for middle school than for elementary school students, and more effective for LFA students than for students with HFA. Intervention time of 30 minutes or less was found to be most effective, although more sessions demonstrated more intervention sessions showed higher effect. These findings correspond to the meta-analysis results by Kim et al. (in review).

Limitations

Although this study attempted to verify the effectiveness of mixed reality-based interventions and aggregate the results as a way to examine if the mixed reality-based interventions can be used as evidence-based practice, there were some limitations with the methodological approach.

First, in the case of group design, a total of 343 students with ASD from 14 studies were included in the current meta-analysis. Since this study involved a limited number of students with ASD, the intervention study results themselves may not be representative of the entire population of students with ASD. In addition, the studies included in this meta-analysis had asymmetrical effect size. For example, although results indicated that the mixed reality-based intervention effect was highest in executive functions and lowest in physical activities, most of

the studies were conducted around social skills and there was only one study that respectively examined other dependent variables. Therefore, caution must be exercised in interpreting the current study results. Also, while the current study demonstrated that AR-based intervention is more effective than VR-based intervention, this finding needs to be interpreted with care because there was only one AR-based intervention study.

Second, in the case of single-case design studies, the meta-analysis included 38 students with ASD from 11 studies. Findings from such a small number of participants may be limited for generalization. In addition, Tau-*U* is limited as effect size. The problem with Tau-*U* is that, when sudden improved scores are present among the baseline phase, the non-overlap rate seriously decreases due to these scores (Parker et al., 2011). Furthermore, the studies included in this meta-analysis implemented the intervention focusing on the improvement of social skills and of student with LFA. Such imbalance should be taken into account when interpreting the findings.

In the current meta-analysis, the trim-and-fill techniques were used to investigate the effects of publication bias. This method has the limitation that, when the data are heterogeneous, the effect of publication bias can be imputed to other studies rather than missing studies. In other words, individual study-related factors can distort the shape of the funnel plot (Duval, 2005; Richardson & Rothstein, 2008). Therefore, it is necessary to perform trim-and-fill analysis for each subgroup.

Future Studies

Based on the limitations, the following suggestions are made for future research. First, most the studies used in this meta-analysis of group design and single-case design studies were centered on social skills. It is suggested that more diverse areas are examined rigorously in future studies. In the case of group design studies, most research studies were conducted around VR-

based interventions. Future studies, therefore, should look in more closely at AR-based interventions. Second, in this meta-analysis, Tau- U was used to examine the effect size of single-case design studies. Given the limitations of Tau- U when conducting meta-analysis on single-case design studies, future studies should examine the average level, trends, and predictability between distributions through more visual analysis methods (Kratochwill et al., 2010). Finally, there is still no research on preschoolers. Considering that early intervention in autism is most important (Corsello, 2005; Harris & Handleman, 2000; Rogers, 1996), it is suggested that future intervention studies include preschool student with ASD as their participants.

CHAPTER 4

AUGMENTED REALITY AS AN INSTRUCTIONAL TOOL FOR TEACHING SCIENCE VOCABULARY AND LIFE-CYCLE TO PRESCHOOL CHILDREN WITH AUTISM SPECTRUM DISORDERS

The rapid advancements in information and communication technology are transforming education in the 21st century (Beetham & Sharpe, 2013; Collins & Halverson, 2009; Gillet, De Jong, Sotirou, & Salzmann, 2013). These changes are more than simply changes in educational learning materials. They include overall changes in education including the learning environments, learning systems, teaching and learning processes, and assessment structures (Brady, Holcomb, & Smith, 2010). With the changes in the educational environment from the development of wireless network technology, education using various media can be offered in diverse settings, and new teaching methods with new technologies are now actively introduced. Among new teaching methods, educational research on the 3D virtual world is rapidly increasing in its volume (Merchant et al., 2014; Wang, Kim, Love, & Kang, 2013).

Among mixed reality using 3D virtual images, the one drawing attention in the area of special education is AR. The biggest advantage of AR is that it can take advantage of ubiquitous technology as it can be combined with mobile devices (Dunleavy et al., 2009; Wu et al., 2013). The educational effect of using mobile devices has been demonstrated by a number of studies (e.g., Cihak et al., 2016; McMahon et al., 2016; Smith et al., 2017). Traxler (2007) explained the benefits of education using mobile devices as follows. First, learning can take place anywhere based on the need of learners. The effectiveness and efficiency of education can be maximized because learning can take place at the very moment without any limitations of time and place due to the characteristics of portable devices. Second, it allows learners to have self-directed

learning. Learners can select the contents appropriate for their learning abilities and control their speed and volume of learning. Lastly, learners can improve their learning abilities through feedback on their learning performance as they perform self-directed learning.

Furthermore, smart phones or tablet PCs, as an icon of the young generation, are attractive media that can help students with disabilities integrate themselves into society, thus, being a factor that can reduce the resistance of students without disabilities against students with disabilities (Lim & Park, 2012). Since AR usually is implemented with apps, it is of great value for educating students with disabilities because it can be easily combined with mobile devices and induce interest and attention, which is the feature of AR.

For students with disabilities, the importance of individualized education is significantly emphasized due to their differences in individual disabilities (Fuchs, Fuchs, & Stecker, 2010; Horner et al., 2005; Wehmeyer & Schalock, 2001). AR in combination with mobile devices can become an effective education format for individualized education, which emphasized the provision of appropriate education service by considering the characteristics of individual students. In addition, AR induces the interest and attention of learners by using visual information as the primary stimulus. For this reason, AR can be an effective educational tool and/or intervention method for children with ASD who have strengths in visual stimuli (Cohen & Sloan, 2007; Litras et al., 2010; Ozonoff & Cathcart, 1998). In this context, the studies suggesting the effect of AR for children with ASD are gradually increasing in number.

With the recent advancements in mobile-related technologies, AR can now be easily used with an app. Furthermore, the scope of intervention for students with ASD is also widening. Examples include word cards using AR (e.g., McMahon et al., 2016), or a vocabulary intervention using books (e.g., Hulusic & Pistoljevic, 2015), or visual guides using AR devices

(e.g., McMahon, Cihak, & Wright, 2015), and the use of AR to improve the attention spans among students with autism by constantly giving them visual clues (e.g., Chen, Lee, & Lin, 2016). Moreover, there is a lot of interest in using AR technologies in science education (e.g., McMahon et al., 2016).

Students with ASD have difficulty learning scientific terminology and understanding scientific concepts. They also find it difficult to understand textbook material in a structured way, or they find it difficult to grasp the causal relationships (Mastropieri, Scruggs, Boon, & Carter, 2011). To improve their science vocabulary knowledge, what is needed is not textual information processing but rather use of visual images or semantic memory through experiences (Reid, 1996). However, vocabulary education as given by traditional science education uses word cards based on 2D images (Lee & Lee, 2015), and thus they are inadequate to motivate students with ASD or increase their participation in class (Gonzalez et al., 2010; Smith, 2012).

Science is a content subject, and words that contain different concepts are used when explaining scientific concepts (Loughran, Mulhall, & Berry, 2004; Young, 2005). Therefore, for students to understand the scientific content, they have to understand the underlying concepts with which those words are associated with. Those concepts can be grouped in semantic units according to their content, with the semantic unit forming a single scientific concept (Beck, McMeown, & Kucan, 2002; Scruggs & Mastropieri, 2013). Students with ASD, however, experience difficulty acquiring different terms and understanding them, or in grasping the relationships between words or in understanding the conceptual associations (Knight, Smith, Spooner, & Browder, 2012; Knight et al., 2013; Smith, Spooner, & Wood, 2013). To overcome this, a method of intervention that can be used to understand both the scientific vocabulary and the conceptual relationships is needed.

Male (2002) argued that there is a need to use various teaching methods that utilize multimedia in education for students with disabilities. Hence, attempts are being made to increase the level of contextual awareness using AR technology to show the world of reality in 3D graphics, and to increase interest and motivation in students with the use of new media (Chiang, Yang, & Hwang, 2014; Nilsen, Linton, & Looser, 2004; Serio, Ibáñez, & Kloos, 2013). Teaching materials developed for science using AR technology help address problems that come from the lack of equipment and materials for experiments and labs while at the same time increasing the level of immersion and interest among the students, which gets them more motivated to learn.

Also, using AR-based study programs is expected to contribute to improving academic achievement factors such as the acquisition of complex concepts and the understanding of phenomena (through presence). Traditionally, preschool students especially are going through Piaget's concrete operational stage, one of the stages in cognitive development, and this is a period where it is difficult for them to form formal thoughts (Piaget, 1965). Therefore, when it comes to the areas of learning such as the acquisition of difficult to acquire abstract concepts or understand principles only through linguistic explanations. Hence, AR technologies that have increased presence and visually show phenomena are expected to help preschool students better acquire scientific concepts and better understand scientific principles (Lee et al., 2010).

There have been vocabulary intervention studies using technologies conducted on students with ASD (see, Ramdoss et al., 2011). However, there has been only one intervention study using AR technology, McMahon et al. (2016), was conducted on students with disabilities for teaching science vocabulary. McMahon and his colleagues (2016) used AR-based educational content to teach scientific vocabulary to postsecondary student with ASD and ID,

and found that all students who took part in the study improved in their understanding of new science vocabularies and related content. Along with the objectivity with science-related AR-based intervention effects, thus for evidence-based practices, intervention studies targeting even more diverse grade levels should take place. Furthermore, there has been no intervention study using AR for preschool students.

The purpose of this study is to examine the effects of an AR-based intervention to teach preschool students with ASD science-related vocabulary words. Specific research questions follow:

1. What are the effects of augmented reality-based intervention on the acquisition of science vocabulary words of preschool students with ASD?
2. Do preschool students with ASD find augmented reality-based vocabulary intervention to learn new science vocabulary words socially acceptable?
3. What are the teachers' opinion of using augmented reality-based vocabulary intervention?

Methods

Participants

Three preschool children with ASD participated in this study. All children were enrolled in an urban preschool in South Korea. The preschool consisted of 120 children without disabilities and 32 children with disabilities. All participants were selected based on the following criteria: (a) diagnosis of ASD, (b) IEP goal to improve reading skills, (c) no physical disability that impeded the performance to access the assistive technology device, (d) attending

school regularly, and (e) consent to participate in the study. Table 4.1 lists participants' characteristics.

Table 4.1. Characteristics of Participants

Participant	Gender	CA	SA	SQ	RLA	ELA	K-CARS
Adam	Male	5	4.50	90.00	36 mo	28 mo	30.5
Billy	Male	6	4.70	78.33	33 mo	21 mo	34.5
Chris	Male	5	4.10	82.00	33 mo	24 mo	32.0

Note. CA = Chronological Age, SA = Social Age, SQ = Social Quotient, RLA = Receptive Language Age, ELA = Expressive Language Age, K-CARS = Korean-Children Autism Rating Scale, Mo = Months

Social Age (SA) and Social Quotient (SQ) are scores calculated from the Social Maturity Scale (SMS). Standardized from Vineland Social Maturity Scale in accordance with the situation in South Korea, SMS is a representative scale that measures social maturity (Kim & Kim, 1985) and is most widely used scale in the field of special education in South Korea (Hyung, Kim, & Kim, 2011). SQ is the number of SA divided by Chronological Age (CA), then multiplied by 100. SQ score of 100 indicates that the subject's social development matches his and/or her CA. SQ score lower than 100 means that the child's social development is slower than children of the child's age. In addition, SQ score higher than 100 demonstrates that the child's social development is faster than the child's peer group (Hyung et al., 2011).

Receptive Language Age (RLA) and Expressive Language Age (ELA) scores calculated from the Preschool Receptive-Expressive Language Scale (PRES; Kim, Sung, & Lee, 2013). The

PRES is a tool developed to measure the receptive and expressive language abilities of children between the age 2 and 6 years depending on their language development. The items of the PRES cover all aspects of language such as semantics, syntax, and pragmatics. The contents consist of 90 items, 45 of which are in the receptive language ability and the remaining 45 in the expressive language ability. Both domains are composed of 15 language developmental stages; and they are divided into 3-month intervals for ages between 2 years 6 months and 4 years, and into 6-month intervals for ages between 4 years 1 month and 6 years (Kim et al., 2013).

Converted from Children Autism Rating Scale (CARS; Schopler, Reichler, & Renner, 1988) into a South Korean version through standardization study, the Korean-Children Autism Rating Scale (K-CARS) is a scale that helps diagnose autism in children 24-months-old or over (Shim & Kim, 1998). CARS was especially developed to differentiate children with ASD from those without ASD but with other developmental delays (Schopler et al., 1998). K-CARS rates children on a scale from one (within the normal range for the age) to four (within the abnormal and severely autistic range for the age) by half point increase, thus consisting a total of seven categories (Shim & Kim, 1998). Therefore, the lower the K-CARS score, the more a child is excluded from being diagnosed as having autism. The composite score from the rating scale classifies children into non-autism (19-29.5), mild autism (30.0-36.5), and severe autism (37.0-60.0) criteria (Shim & Kim, 1998).

At the time of current study, Adam was a 5-year-old male child diagnosed with mild autism. He had a SA of 4.50 and a SQ of 90.00 on the SMS. Also, he had a RLA of 36 months and an ERA of 28 months. Using the K-CARS, Adam had a 30.5 score. He received one hour of speech/language therapy and one hour of art therapy each week. When the study began, Billy was a 6-year-old male child diagnosed with mild autism. He was deferring entrance elementary

school at the request of his parents. Despite his age of going to elementary school, he was attending in preschool. Results from the SMS indicate compared to peers of his age, he had a SA of 4.70 and a SQ of 78.33. Using the PRES, he had a RLA of 33 months and an ELA of 21 months. Billy had a 34.5 score on the K-CARS. He also received one hour of speech/language therapy and one hour of art therapy each week in the preschool. At the time of the study, Chris was a 5-year-old male child. He is also diagnosed with mild autism. According to the SMS, Chris had a SA of 4.10 and a SQ of 82.00. also, he had a RLA of 33 months and an ELA of 24 months. Using the K-CARS, he had a 32.0 score.

All participants in the study were children with mild ASD carrying a certificate of disability issued by the South Korean government. Certificates of disability for ASD are divided into grades 1 to 3. Grade 1 indicates severe ASD and grade 3 indicates mild ASD. The certificates of all the participants indicated grade 3, mild ASD. Besides ASD, participants had no other disabilities.

Settings

All participants attended an urban preschool in the South Korea. They attended a special education classroom for part of their school day to address academic and behavioral IEP goals and objectives. Additionally, all phases of the study occurred in the separate therapy room at a table free from distractions and other children.

Materials

Assessment Materials. Vocabulary tests were developed to assess child knowledge of science-related word lists related to the life cycle of ladybug. Science-related word list consisted of five life-cycle vocabulary words (i.e., egg, larvae, pupa, young ladybug, and adult ladybug).

The vocabulary test was a 15-item assessment that included three question types for each vocabulary word (see appendix C for an example of the test). The first question type was designed to measure each child's ability to correctly match the vocabulary definition to the vocabulary word. Definitions were adapted to simplify language from their original dictionary definitions. This question was presented in a multiple-choice format in which the definition was provided and the child identified the correct vocabulary word from a field of four choices (one correct and three incorrect responses). The three distractor words were other words from the word list being assessed. The second question type required the student to label a picture of the life-cycle with the correct vocabulary term. A word bank of targeted vocabulary words was included on the labeling section of the assessment. Pictures used were royalty free images selected by the investigator and modified if necessary (i.e. arrows pointing to a specific structure). The third question type required the student to correctly sequence the life-cycle vocabulary terms. Students were provided pictures of the vocabulary words and had to indicate the order in which the picture occurred during the life-cycle. Three assessment versions of each skill were created that varied the order of questions, possible answers, and labeling activities. This assessment was intended to measure the students understanding of the vocabulary terms by measuring the ability to correctly define, label, and sequence the selected science vocabulary words.

Intervention Materials. The intervention examined in this study is an example of an AR tool according to the mixed reality continuum (Milgram & Kishino, 1994). The mobile app Aurasma was used (Aurasma, 2014). This app provides an AR content viewing experiences and allows the user to create customized AR content by matching trigger images and/or objects with user created digital content. This mobile app is available on a variety of mobile device (e.g.,

iPads, iPhone, Galaxy Note etc.) platforms. For this study, children used an iPad with the Aurasma app.

AR Triggers. The investigator created an AR trigger for each target word. Each trigger contained the target vocabulary word and a unique design comprising of different shapes in order to provide enough detail for the app to distinguish one trigger from another. The vocabulary word was written using 48-point font. The triggers were produced using Microsoft WORD and then printed as handouts. The handouts were then stapled to create a six-page AR vocabulary booklet.

AR Content. The AR content was a 10- to 20-second video of each target vocabulary word created by the investigator. The components of each video included: (1) title slide of the vocabulary term, (2) the definition of the word that was also narrated aloud, (3) an image of the vocabulary word, (4) a 3D simulation video showing vocabulary term during life-cycle sequence, during which the audio from the definition was repeated, and (5) repeat of the image of the vocabulary term as shown in the labeling and sequence part of the assessment with the audio of the definition being played a third time.

The AR content components were edited using the video editing program iMovie. The video was programmed within the Aurasma app to play when the corresponding AR vocabulary word (i.e., trigger) was detected. During the intervention phase, an iPad equipped with the Aurasma app and the AR vocabulary booklet were provided to each child. When the child moved the mobile device so the marker was visible, using the device's camera, the app detected the printed vocabulary card and displayed the corresponding AR vocabulary video content. This augmented reality experience provided the user a view of the vocabulary word card and overlaid

digital information in the form of audio, pictures, and video designed to teach the meaning of each vocabulary word.

Variables and Data Collection

The independent variable was the AR intervention to learn new science vocabulary words and the sequence of the life-cycle. The dependent variables were (1) the number of vocabulary words defined correctly, (2) the number of vocabulary words labeled correctly, and (3) the number of vocabulary words sequenced correctly. Permanent product (i.e., vocabulary test) data collection procedures were used to record the number of questions correct. The number of correct vocabulary words was divided by the total number of questions (i.e., 5 questions) to calculate a percentage of correct responses per question type (i.e., definition, label, and sequence).

At the start of each session, children completed the vocabulary test to assess the acquisition of science words and sequence of the life-cycle. Questions were ordered randomly to reduce practice effects. If the participant correctly answered the question, then it was recorded as a correct response. If the participant did not answer the question correctly or did not respond, then it was recorded as an incorrect.

Design

A multiple probe across participants design (Gast & Ledford, 2014) was used to examine the relation between the AR-based vocabulary intervention and each participant's performance to correctly define, label, and sequence the life-cycle science vocabulary words. The AR intervention was introduced systematically across students. All children started the baseline phase at the same time. However, AR was introduced to child 1 first, while child 2 and 3 continued to be assessed in baseline. After child 1 reached acquisition criteria (i.e., 50%

independence for three consecutive sessions), AR was introduced to child 2. When child 2 achieved acquisition criteria, AR was then introduced to child 3. By systematically introducing the AR intervention at three different points in time, a functional relation could be demonstrated. Children participated in the AR-based intervention until 80% or higher accuracy was achieved for three consecutive sessions.

Procedures

Baseline. During baseline, each student completed a minimum of three vocabulary tests of the 15-item science vocabulary test targeting the 5 vocabulary words. Although the test was read aloud, no additional feedback or prompts were provided. Children were instructed to answer the vocabulary questions on the assessment and were told they could skip questions they did not know. This process occurred for a minimum three sessions until the life-cycle of 5 unknown science terms were identified or until the data were considered stable. Stability was determined using the “80%-20%” criteria of stability envelope (Gast & Ledford, 2014). If 80% of the data points fell on or within 20% of the mean of baseline, the data would be considered stable.

AR Training. Prior to introducing the AR for learning science vocabulary words, children participated in a training phase. Children were trained how to use the Aurasma application to scan vocabulary words to trigger the AR content to display (picture, video narration of defined term). In a one-to-one instructional format, children were shown objects (i.e., various denominations of U.S. currency) that triggered AR content to appear. They were trained to use AR independently using the Model-Lead-Test procedures (Adams & Engelmann, 1996). The investigator modeled how to use the app and the mobile device to position the camera screen around the target object. Then, the investigator led the child as they practiced

using the app to scan the target object. If a child was observed incorrectly using the device to view the AR content, the investigator implemented the system of least prompts to provide the correct way to view the content. Lastly, the investigator tested each child until they could independently scan the target object to view the content for three consecutive sessions.

AR Vocabulary Intervention. At the beginning of each intervention session, children completed the vocabulary test to assess their knowledge from the previous session. The assessment was conducted in the same way as baseline phase. Afterwards, children were given the 6-page AR vocabulary booklet, mobile device, and instructed to “try to define and beat the video.” That is, children tried to define the target word within the 5-second lag-time it took for the AR content video to start playing. After the children practiced the first target word, they proceeded to the second vocabulary word and so forth until all five target vocabulary words were practiced. Children then practiced all 5 words and the life-cycle card two additional times for a total of 3 practice opportunities. The intervention time per child was approximately 25-30 minutes. Figure 4.1 shows AR-based intervention example.

Maintenance

Follow-up probes were conducted 1 week after the child met acquisition criterion. During the maintenance phase, procedures similar to baseline were implemented. Children were given the 15-item test in which they were required to define, label and sequence the target life-cycle science words. Follow-up probes were collected to determine if the initial instruction maintained the children’s performance over time.

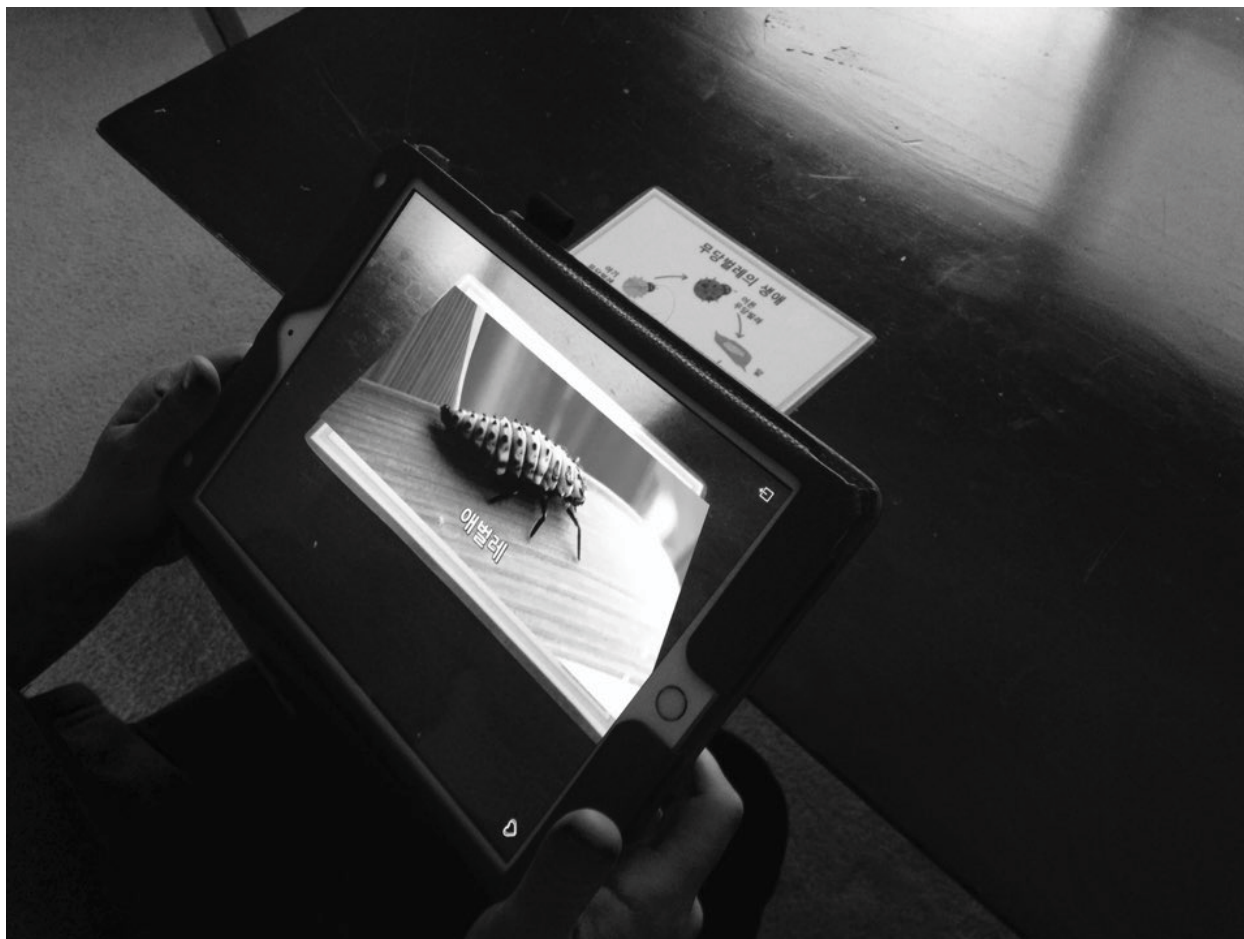


Figure 4.1. Example of AR-based Intervention. Photo by Byungkeon Kim.

Data Analysis Procedures

Visual analysis procedures were used to evaluate the results of the multiple probe across participants using AR to teach vocabulary. Six indicators were employed to examine intervention effects using data patterns: (a) level, (b) trend, (c) variability, (d) immediacy of the effect, (e) overlap, and (f) consistency of data patterns (Kratochwill et al., 2010). A functional relation, by definition, is established through prediction, verification, and replication. In terms of the current study, baseline data trends maintained at low rates (i.e., prediction). Upon beginning the intervention phase, the change in data trend can be attributed to the presentation of the

independent variable (i.e., verification), which was replicated across participants (Gast, 2012; Plavnick & Ferreri, 2013). Scruggs and Mastropieri (2001) suggested standards for evaluating magnitude intervention effects in single subject research. Large effect sizes are demonstrated with PND (percentage of non-overlapping data) greater than 90%, moderate to high effects are demonstrated with PND ranging from 70% to 100%, while less than 70% is questionable, and less than 50% is a poor or unreliable effect size.

Interobserver Agreement and Procedural Reliability

The investigator and a trained research assistant independently collected interobserver agreement (IOA) and procedural reliability data. IOA data were collected during a minimum of 40% of baseline and intervention sessions for each child. Interobserver agreement was calculated by dividing the number of agreements of participant responses by the number of agreements plus disagreements and multiplying by 100 (Gast & Ledford, 2014). IOA was defined as 90% or higher, if the agreement was lower than 90%, then the observers would have reviewed all test items and responses. The mean IOA for each child was Adam, 100%; Billy, 100%; Chris, 100%.

Procedural reliability data also were collected during a minimum of 40% baseline and intervention sessions for each child. The observer was provided a task analysis (See Appendix D) of the procedures to check whether the procedures were completed as intended. The procedural reliability was calculated by dividing the number of observed investigator's behaviors by the number of planned behaviors and multiplying by 100 (Gast & Ledford, 2014). Procedural reliability was defined as 90% or higher, if the agreement was lower than 90%, then the observers would have reviewed all intervention procedures. The mean treatment integrity for each child was Adam 100%; Billy, 100%; Chris, 100%.

Social Validity

Following the last session of the intervention phases, children and their teachers were asked to complete a Likert-type survey (See Appendix E and F) created by the investigator to assess their opinions and acceptability of using the AR intervention to teach new science vocabulary. The surveys were modified by the investigator using the social validity questionnaire created by McMahon (2014). The Likert-type survey ranged from 1 (Disagree) to 3 (Agree) for children with ASD and the survey was read aloud by researcher. On the other hand, the Likert-type survey ranged from 1 (Strongly Disagree) to 5 (Strongly Agree) for teachers. In addition, the social validity survey for teachers included two open-ended questions.

Results

Baseline scores on the assessments for the children indicated that participants had very low initial knowledge on the science words and the life-cycle system. Correct responses during baseline phase mostly appeared to be random chance because questions were not consistently answered and matched with a corresponding correct definition, labeling, and sequencing. Visual analysis for all children showed that the AR-based intervention was an effective strategy for teaching new science vocabulary words and life-cycle sequence. Generally, children's performance immediately increased when AR contents were introduced.

Adam. Adam learned the science vocabulary words and ladybugs life-cycle sequence using the AR-based instruction. Adam's baseline average percentage of correct responses for the definition were 0%, 6.67% for the labeling, and 0% for the sequencing. His results immediately improved the next session after using the AR-based intervention. During the intervention, on the definition, labeling, and sequencing, Adam reached criteria of 80% correct responses for three consecutive sessions after his fourth intervention session. In addition, his mean performance

immediate increased with 100% non-overlapping data for the definition, labeling, and sequencing. Visual analysis demonstrates that Adam's labeling and sequencing percentages increased at approximately the same rate. On the other hand, the definition percentage increased relatively less than two other scores.

Billy. Billy learned the science vocabulary words and the life-cycle sequence using the AR-based instruction. Billy's baseline average percentage of correct responses for the definition were 0%, 16% for the labeling, and 8% for the sequencing. During the AR-based intervention, his mean performance immediate improved with 100% non-overlapping data for the definition, 100% for the labeling, and 66.7% for the sequencing. Similar to the results of Adam, the Billy's labeling and sequencing percentages improved at approximately the same rate, and the definition percentage increased also relatively less than two other scores. Billy reached criteria of 80% correct responses for three consecutive session after sixth intervention session. However, his highest percentage for the definition was 80%.

Chris. Chris learned the science vocabulary words and the life-cycle sequence using the AR-based instruction like other children. His baseline average percentage of correct responses for the definition were 0%, 28% for the labeling, and 8% for the sequencing. During the AR-based intervention, his mean performance immediate increased with 100% non-overlapping data for the definition, 80% for the labeling, and 60% of sequencing. Similar to the results of other children with ASD, the Chris' labeling and sequencing percentages increased at approximately the same rate, and the definition percentage increased also relatively less than two other scores. Chris reached criteria of 80% correct responses for three consecutive session after seventh intervention session. As for Chris, the criteria were first met in labeling, and similar to other children with ASD, the criteria were reached the latest in definition.

A common data pattern was found in this study results: children with ASD were more likely to learn through AR-based intervention labeling and sequencing compared to definition. Between labeling and sequencing, it was found that children with ASD perform better in labeling. Children's results are presented in Figure 4.2.

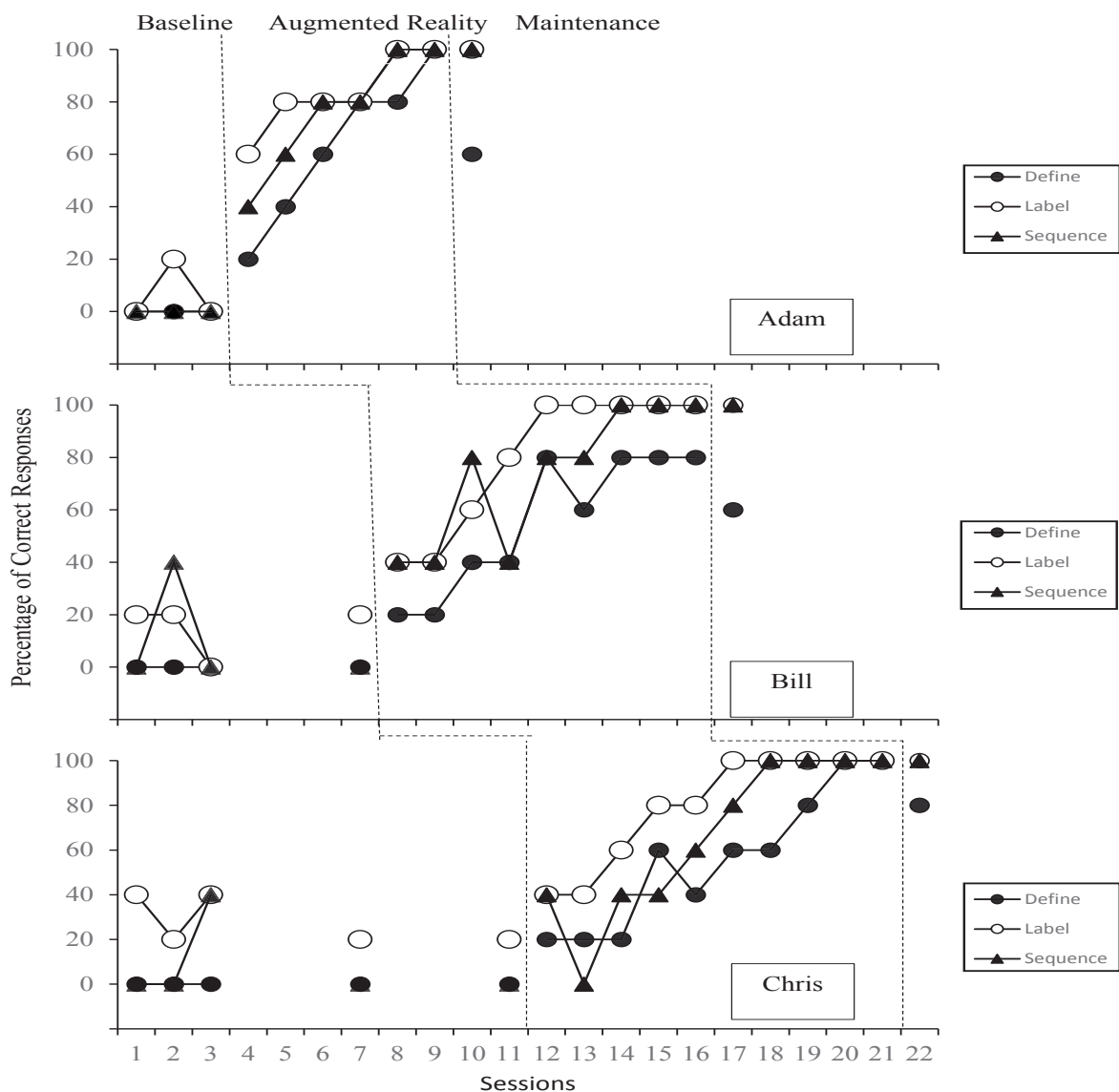


Figure 4.2. Participants' Percentage of Correct Responses.

Social Validity and Teacher's Opinion Results

After the conclusion of the study, children with ASD and their teachers completed a social validity questionnaire regarding the use of AR to teach new science vocabulary words and a life-cycle sequence. First, all children with ASD reported that the AR-based intervention for learning science vocabulary words and a life-cycle sequence was socially acceptable. Results also indicated that all children agree that they (a) liked using AR view the life-cycle cards, (b) liked seeing the vocabulary words and information about it at the same time through AR, (c) AR-based instruction was easy to use, and (d) would like to use AR more to learn new things.

Second, teachers reported that the AR-based intervention for teaching science vocabulary words and a life-cycle sequence was socially acceptable. Results also indicated that all teacher agree or strongly agree that they (a) thought that the children liked the AR-based intervention, (b) thought that the children learned science vocabulary effectively through AR-based intervention, (c) thought that the children learned a life-cycle sequence effectively through AR-based intervention, (d) thought that the AR instruction was easy to use for teaching science vocabulary words and a life-cycle sequence, (e) would recommend using AR to other teachers, (f) would use AR again to help children learn new science vocabulary words, (g) would use AR again to help children learn a life-cycle sequence. The social validity results showed that all participated children and teachers were satisfied with the AR-based intervention. The teachers' responses to the open-ended questions are shown in Table 4.2.

Table 4.2. Teachers' Responses to the Open-Ended Questions

Teacher	Questions	
	Question 1:	Question 2:
	What did you like best about using AR-based intervention?	What did you not like about using AR-based intervention?
Teacher 1	● Focus of the children was very high ● It seems to be able to easily transmit relatively complex contents through AR	● Making AR contents process seems to be complicated
	● It seems that children were able to learn about science in a fun way ● Using AR is likely to provide more diverse educational contents	● Because AR is unfamiliar concept, it seems that teacher education is needed to use it in the field of education

Discussion

The purpose of this study was to examine the effect of an AR-based intervention to teach new science vocabulary words and life-cycle sequence to children with ASD. All children demonstrated substantial increases in their ability to learn new science vocabulary and life-cycle sequence. These findings support previous studies that computer based assistive technology is an effective tool for teaching science vocabulary (McMahon et al., 2016; Smith et al., 2013). In

addition, this study supports previous studies that the use of mobile devices is an effective tool for teaching vocabulary (Dennis et al., 2016; McMahon et al., 2016).

This study extended the research in several ways. First, this study supports the theoretical framework that the use of visual supports is an effective and efficient approach for educating children with ASD. Among the previous studies using visual supports, AR studies have been centered on children with ASD. Researchers anticipated that AR-based intervention can be very effective in educating students with ASD (Escobedo et al., 2014; McMahon et al., 2016), because they tend to have a visual thinking, in which they recall an image when they think and understand a concept (Brian et al., 2003; Meadan et al., 2011).

Second, this study extended the literature that ‘fun’ is an important learning factor not only for children without disabilities (Malone & Lepper, 1987; Sim, MacFarlane, & Read, 2006), but also children with ASD. One of the reasons AR-based intervention is receiving attention as an effective teaching program is that it is ‘fun’ (Dunleavy et al., 2009; Nilsson & Johansson, 2007). Considering that joyful playing is an important element, especially in young children’s learning, AR was an appropriate intervention media for children with ASD because AR provided a play-like intervention to children with ASD.

Third, this study extended the language intervention literature for children with ASD. Although, Feich (2014) and McMahon et al. (2016) conducted a study using AR-based intervention in order to teach vocabulary for student with disabilities, no studies using AR have been conducted on language skills of preschool children with ASD.

Lastly, a common data pattern was found. Generally, the participants were more likely to learn through AR-based intervention science vocabulary labeling and life-cycle sequencing compared to science vocabulary definitions. The reason participants find definition difficult is

because the definition assessment was conducted only with verbal stimuli alone without visual stimuli. For example, throughout the AR-based intervention phase, Billy failed to reach 100% responding definition questions but achieved 100% in labeling. Definition and labeling assessments were composed of same questions. However, the difference is in the method of delivery, since children with ASD had to answer the question for definition based on verbal information alone, while the answer to the question for labeling was visualized. Therefore, it can be concluded that the presence of visual support affected the performance of the children with ASD. As pointed out by numerous scholars (Aresti-Bartolome & Garcia-Zapirain, 2015; Brian et al., 2003; Fornasari et al., 2013; Meadan et al., 2011; Yang et al., 2017), this implies that it is important to provide visual information when educating and/or teaching children with ASD.

Limitations

One of the limitations of current study is that all of the participating children were diagnosed with mild autism and there was an absence of female participants. Since the participant's characteristics, this study results may not be representative of entire population of children with ASD. The children with ASD who participated in this study learned science vocabulary and life-cycle sequence, this finding needs to be interpreted carefully because only life-cycle of ladybug set was employed to teach science vocabulary and life-cycle sequence to children with ASD.

Second, this study measured the participants' science vocabulary words acquisition and understanding of the ladybugs' life-cycle sequence in percentage of correct responses to examine their academic performance. The measurement tool was composed of 15 items. However, the percentage change from one question was great since in each part consists of five questions. In

addition, only one maintenance probe data was collected. Cihak et al. (2016) asserted that additional maintenance data would provide a stronger conclusion.

Future Research

Based on the limitations, the following suggestions are made for future research. First, this study was conducted only with children with mild ASD. Therefore, it is necessary for future studies to determine whether AR-based intervention is effective for children with severe ASD.

Second, examining the opinions of teachers, it was found that teachers commonly pointed out the need for teacher education to implement AR-based intervention in practical educational settings. For the application of AR-based intervention in practical settings beyond the scope of research, teachers in the field have to use AR-based intervention more frequently. To facilitate teachers in doing so, it is necessary to provide teachers with overall training for AR-based intervention including the development of AR intervention contents. In future researchers, it is necessary to investigate through in-depth interview how teachers' understanding of AR changes when teacher training for AR-based intervention is provided, and what their perceptions are about conducting classes with students using AR contents they have personally developed.

Third, the conceptual model frequently used in AR-based intervention research is the Keller's ARCS model (Bolliger et al., 2010; Chyung, 2001). Lee et al. (2010) developed an AR-based science learning program for the promotion of learning motivation of elementary students and applied the program in the classroom to investigate its effects on the participants' learning motivation and academic achievements. The study deduced AR-based science learning strategies from using the Keller's ARCS model as a design theory for the promotion of motivation. According to the study results, the experimental group scored significantly higher in all areas of ARCS. However, since this study was conducted with students without disabilities, it is

necessary for future researchers to investigate whether this model is meaningful for students with ASD.

Forth, Radu (2014) reported that AR-based interventions are effective for long-term memory of students from analyzing 26 studies in a meta-review and cross-media analysis of the educational use of AR. In addition, it has been reported that children with ASD have excellent visual memory among various sensory functions (Brian et al., 2003; Meadan et al., 2011). Hence, it is expected that AR-based intervention will have an effect on improving the long-term memory of children with ASD who have excellent visual memory by providing information through maximum visual stimuli. Accordingly, further research is needed to determine whether AR-based intervention influences the long-term memory of children with ASD as have been found to be effective with children without disabilities.

Lastly, variation of the assessment tool should be considered. The percentage variation was great since the small number of questions for each part. Therefore, it is recommended for future studies to consider constructing a large number of assessment questions to improve the determinant power of the research. In addition, further research is needed to verify the results of current study are consistent with participation of female children with ASD.

CHAPTER 5

IMPLICATIONS FOR THE FUTURE OF MIXED REALITY IN SPECIAL EDUCATION

The development of computer technologies is changing education in the 21st century (Gillet et al., 2013). The changes have occurred not just in teaching and learning materials but in all other areas including learning environments, learning systems, teaching and learning processes, communication structures and evaluation structures in the classroom (Brady et al., 2010; Johnson et al., 2013). These changes are occurring in special education (Edward, 2013; Giger & Markward, 2011; Ramdoss et al., 2011; Ramdoss et al., 2012; Sampath, Indurkya, & Sivaswamy, 2012) as well as in general education (Shuler, Levine, & Ree, 2012). In addition, with the development of hand-held devices, classroom activities that used to be carried out inside the classrooms are now being conducted outside the classroom (e.g., McMahon et al., 2015). The recent development of mixed reality technology has led these educational changes to expand their scope beyond education using the reality to include education using the virtual world (Ludlow, 2015).

The purpose of this dissertation was to investigate the overall effect size of MR-based intervention which are actively implemented in the field of special education nowadays, and to establish an empirical foundation of MR-based intervention for preschool children with ASD who have not yet been included MR-based studies so far. Specifically, the purpose of this dissertation was to examine the effectiveness of mixed reality-based intervention and confirm the validity of practical application by conducting a meta-analysis on mixed reality-based intervention studies performed on students with ASD. Furthermore, an empirical research study was conducted to evaluate the effectiveness of AR-based intervention to teach preschool children

with ASD science-related vocabulary words and a life-cycle sequence. The finding of this dissertation support and extend previous educational studies in variety of domains.

Motivation and Learning

Motivation is one of the most important factors in learning for every students, regardless of their disabilities (Linnenbrink & Pintrich, 2002; Siegel, 2003). Studies on underachievement in students with disabilities have suggested that their underachievement is associated with their limitations in managing learning due to poor use of learning strategies or deficiencies in metacognitive and executive functions, but concurrently emphasize that their academic achievement is related to motivation to a large extent (Hallahan et al., 2005; Lerner & Johns, 2012; Mercer, Mercer, & Pullen, 2011). Csikszentmihalyi (1990) observed that a high level of motivation has the power to immerse students in learning regardless of their learning outcomes because they experience pleasure in the learning activity itself. The Keller's ARCS model is mainly used to explain motivation, which is an important element of learning. Consistently proven to be effective in learning motivation, this model has been widely used in computer-based learning, online learning, etc. (Huett, 2006; Kim & Keller, 2008).

Keller's ARCS model can be useful in improving classroom instructions to reinforce the motivation of students with disabilities in the following aspects. First, because the model develops motivation design with a problem-solving and heuristic approach rather than a prescribed algorithmic approach (Keller, 2010), it is in line with implementing individualized education for students with disabilities and also provides them with customized motivation enhancement classes. Second, considering how existing intervention studies for students with disabilities focused mainly on self-confidence and their limitations of neglecting the issues of attention and satisfaction, the application of this model allows a balanced and systematic

consideration on various learning motivation problems in students with disabilities. Lastly, this model provides a conceptual model that can be used easily by teachers in the field who are planning motivation reinforcement classes for students with disabilities (Keller, 2010; Min & Park, 2016).

The Keller's ARCS model is widely used as evidence-based practices in general education, but related research with students with disabilities is lacking. Considering that this model is widely used in general education and is being applied to mixed reality-based intervention studies, it is necessary to examine whether the model is actually available in mixed reality-based intervention studies with students with disabilities.

Meta-analysis of Mixed Reality-based Intervention

With the development of computer technology, there have been more attempts to utilize computer technology in special education and many studies have been conducted to examine the effectiveness of computer technology in special education. At the same time, meta-analysis of technology-based interventions for students with disabilities has been conducted as well in order to establish evidence-based practice. However, previous studies have used in their meta-analysis a wide range of AT-based interventions under the name of technology-based interventions. This approach is limited in demonstrating the effectiveness of mixed reality-based intervention alone.

The current dissertation was important in that it successfully demonstrated the effectiveness of mixed reality-based intervention alone since the meta-analysis was carried out focusing only on mixed reality-based interventions. Based on this approach, it was also possible to compare the findings from the present study with overall effect size of technology-based interventions found in previous studies. This dissertation is also significant in that it confirmed a more objective intervention effect size by solving the problem of publication bias, which was

pointed out as a problem of existing meta-analyses. Lastly, it was possible to make concrete suggestions for future studies from identifying the areas in mixed reality-based intervention lacking in research.

Science Education for Children with disabilities

Recently, science educators are trying to provide science education to all students under the slogan, 'science for all' (Mastropieri, et al., 2006). It means that science education should not be limited to a certain group of people but should be provided to all and that students with disabilities should also not be excluded from proper science education. However, it is generally known that students with disabilities have difficulty with conceptual understanding scientific vocabulary (Scrugg, Mastropieri, Bakken, & Brigham, 1993). Students with disabilities also have difficulty in structuring and understanding the content presented in textbooks or grasping the causal relationship between them (Mastropieri et al., 2001).

Previous studies, however, have shown that AR-based interventions are effective in science education for students with disabilities. For instance, McMahon et al. (2016) conducted an intervention study using an AR technology for teaching science vocabulary to postsecondary students with disabilities. Their study, however, has a limitation in teaching only science vocabulary words even though they reported positive outcomes.

Nevertheless, research on intervention in science education are scarce and there are no relevant studies conducted with preschool students with ASD. Science education is important for preschool level because it provides preschool students with experiential foundation for developing the skills, knowledge and problem-solving skills required by society. This dissertation was meaningful in that it presented empirical data by verifying the effect of AR-based intervention in preschool students with ASD, who had not received much attention

compared to other age groups. Furthermore, most of the mixed reality-based interventions have been conducted around social skills as shown in the findings of current meta-analysis, whereas this dissertation extended the mixed reality-based intervention for students with ASD to academic outcomes.

Limitations

Several limitations of the meta-analyses warrant caution in interpreting results and findings. First, in the case of group designs meta-analysis, a total of 343 students with ASD from 14 studies were included. Since this study involved a limited number of students with ASD, the results may not be representative of the entire population. In addition, the studies included had asymmetrical moderators. Therefore, caution must be needed in interpreting the results. Second, in the case of single-case designs meta-analysis, a total of 38 students with ASD from 11 studies were included. Like the meta-analysis of group designs, the results may not be representative of the entire population and limited for generalization. In addition, Tau-U is limited as a measure of effect size. The non-overlap rate seriously decreases when sudden improve scores are present among the baseline phase (Parker et al., 2011). In this reason, effect size can be overestimated.

Several limitations of the current empirical study warrant caution in interpreting results and findings and emphasize the need for replication study. First, this empirical study is that all of the participating children were diagnosed with mild autism and there was an absence of female participants. In this reason, the results and findings may not be representative of entire population. Second, the participants learned science vocabulary words and a life-cycle sequence, the findings, however, need to be interpreted carefully because only life-cycle of ladybug set was used. Lastly, the current empirical study measured science vocabulary words acquisition and understanding of the life-cycle for ladybug as dependent variables in percentage of correct

responses to assess participants' academic performance. The assessment was composed of 15 items, but the percentage change from one question was great since in each part consisted of five questions.

Despite these limitations, the findings of these dissertation studies support the effectiveness of the use of mixed reality-based intervention for students with ASD. In addition, the AR-based intervention study also supported improving the academic performance of children with ASD. Future research can expand on these findings through further studies on mixed reality-based interventions for students with ASD.

Future Research

Since the mixed reality-based intervention usually uses visual stimuli, it is known to be an effective intervention for students with ASD who have visual strengths (Arresti-Bartolome & Garcia-Zapirain, 2015; Fornasari et al., 2013; Yang et al., 2017). According to the meta-analysis, the effectiveness of mixed reality-based intervention for students with ASD was verified. In addition, AR could be a powerful intervention tool for children to learn science vocabulary words and a life-cycle sequence. However, there were limitations of this dissertation. Based on the limitations, the following suggestions for future research are made.

First, when using mixed reality-based intervention for students with ASD, it is necessary to have them transfer the skills acquired through virtual reality to reality. Most of the studies in the current meta-analysis were aimed at promoting social skills. This is because it is difficult to repeatedly train the social skills trained in mixed reality-based intervention in actual situations, and there is a limit to experience and practice diverse situations in real life under a limited time frame. Therefore, it is important to have the students transfer the skills acquired through mixed reality-based intervention so that they can actually use them in their daily life. Each study used in

this meta-analysis was reports improvement of dependent variables centered on social skills. However, such improvements may not guarantee improved skills in students with ASD in their daily life situations. Therefore, in order to effectively apply the mixed reality-based intervention for students with ASD, plans for transferring the learning from intervention to later daily life situations should be considered with great importance.

Second, studies on the effects of mixed reality-based intervention should examine how and by what learning motivation and academic achievement are influenced. Learning motivation is known as a factor affecting academic achievement. In addition, Keller's ARCS model is often used as a conceptual framework for mixed reality-based intervention research. Therefore, it is necessary for mixed reality-based intervention studies to examine what kind of path relationships exist between mixed reality-based intervention, learning motivation, and academic achievement.

Third, more research should be conducted on diverse instructional design strategies for AR-based intervention. While AR-based intervention content may promote sensory engagement by multisensory stimulation, it is also understood that excessive and distracting stimuli may promote cognitive overload (Christakis, 2011). Therefore, it is necessary to study instructional design strategies aimed for the enhancement of cognitive efficiency as well as learning effect.

Lastly, this dissertation demonstrated that AR-based intervention for children with ASD are effective in teaching science concepts. However, given that participants in this study were limited to young children with mild ASD, it is necessary to investigate whether the AR intervention is effective in young children with severe ASD. It is also necessary to examine whether AR-based intervention is effective for young children with other disabilities.

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APPENDICES

Appendix A. Essential Quality Indicators of Group Design Studies (Jitendra et al., 2011)

Essential Quality Indicator	Indicator Not Met	Indicator Partially Met	Indicator Met
<i>Description of Participants</i>	1	2	3
Information on participants' disability or difficulties (e.g., age, race, gender, IQ, socioeconomic status, scores on academic assessments)	Cited school district / state criteria for disability status; did not document specific difficulties using assessments or diagnostic criteria	Provided criteria for disability or cited school district / state criteria, but did not conduct a screening assessment to determine specific difficulties AND provided information on three demographic variables as well as a reading measure	Provided criteria for disability / specific difficulties with results on an assessment measure to document that participants in the study met the criteria AND provided information on four demographic variables
Equivalence of groups across conditions	Did not randomly assign participants or classrooms to conditions AND did not document comparability of participant in conditions on a reading measure (did not provide the necessary scores for the reader to be able to assess equivalence	Randomly OR non-randomly assigned participants or classrooms to conditions AND documented comparability of participants in conditions on at least two demographic variables, as well as a reading measure	Randomly assigned participants or classrooms to conditions AND documented comparability of participants in conditions on at least three demographic variables, as well as a reading measure (or provided the necessary scores for the reader to be able to assess equivalence)

Essential Quality Indicator	Indicator Not Met	Indicator Partially Met	Indicator Met
<i>Description of Participants</i>	1	2	3
Information on intervention agents (e.g., years of experience, age, gender, race, teaching certificates, level of education, and familiarity with the intervention); equivalence of intervention agents across conditions	Specified intervention agents for each condition, but did not provide descriptive information OR did not specify intervention agents for each condition	Intervention agent was same for all conditions OR specified intervention agents for each condition and provided some descriptive information	Described intervention agents and randomly assigned or counterbalanced them across conditions OR documented comparability of intervention agents in conditions on at least three relevant characteristics
<i>Description and implementation of intervention and comparison conditions</i>	1	2	3
Description of intervention (e.g., conceptual underpinnings, duration of intervention, detailed instructional procedures, teacher actions and language, use of instructional materials, and student behavior	Provided specific information on two or fewer relevant dimensions of the intervention	Provided specific information on at least three relevant dimensions of the intervention, OR directed readers to another article for description of procedures	Provided specific information on at least four relevant dimensions of the intervention

Essential Quality Indicator	Indicator Not Met	Indicator Partially Met	Indicator Met
<i>Description and implementation of intervention and comparison conditions</i>	1	2	3
Description and measurement of procedural fidelity	Provided no description of treatment fidelity	Provided description of treatment fidelity (e.g., instruction provided by using scripted lessons)	Described treatment fidelity and assessed the extent to which specific components of the intervention were implemented (e.g., checklists of intervention components completed by an observer, self-monitoring checklists, or analysis of videotapes and field notes)
Description of instruction in comparison group	Did not describe nature of instruction in comparison conditions	Described instruction on at least two relevant dimensions (e.g., use of instructional materials, grouping, setting, and time for instruction)	Described nature of instruction, specifically teacher actions and expected student behaviors

Essential Quality Indicator	Indicator Not Met	Indicator Partially Met	Indicator Met
<i>Outcome measures</i>	1	2	3
Multiple measures or measures of generalized performance	Employed only outcome measures aligned with the intervention	Employed only measure of generalized performance	Employed outcome measures aligned with the intervention ASD measure of generalized performance
Appropriateness of time of data collection	Measured more than 1 month of intervention	Measured within 1 month of intervention	Measured within 2 weeks of intervention
<i>Data analysis</i>	1	2	3
Techniques linked to research question (s); appropriate for the unit of analysis	Did not align data analysis techniques with the research questions/hypotheses and did not use appropriate unit of analysis	Aligned data analysis techniques with the research questions/hypotheses, but did not use appropriate unit of analysis	Aligned data analysis techniques with the research questions/hypotheses and used appropriate unit of analysis
Effect size	Effect size not reported in text	Effect size reported in text but not interpreted	Effect size reported in text and interpreted

Appendix B. Essential Quality Indicators of Single-case Design Studies (Jitendra et al., 2011)

Quality Indicator	Indicator Not Met	Indicator Partially Met	Indicator Met
<i>Participant and setting</i>	1	2	3
Participant description (e.g., age, gender, IQ, disability, diagnosis)	Did not provide operational definition or criteria for disability; some or few details of participants included	Provided operational definition or criteria for disability; some details of participants included	Provided operational definition of disability; most details of participants included
Participant selection	Not described; included preassessment data OR described a criterion for selecting participants; did not including preassessment data	Described a criterion for selecting participants; included preassessment data	Described precise criteria (e.g., deficient performance) for selecting participants; included preassessment data
Setting description (e.g., type of classroom, room, arrangement, number of students to teachers)	Not described OR described a few critical features of setting	Described some critical features of setting	Precisely described critical features of setting to allow replication
<i>Dependent variable (DV)</i>	1	2	3
Description of DV	Described subjectivity or globally OR not described	Described adequately, but not in operational terms	Described with operational precision to allow direct observation and replication

Quality Indicator	Indicator Not Met	Indicator Partially Met	Indicator Met
<i>Dependent variable</i> (DV)	1	2	3
Measurement procedure	Measurement procedure did not generate a quantifiable index	Measurement procedure generated a quantifiable index for some but not all variables of interest	Measurement procedure generated a quantifiable index for all variables of interest
Measurement validity and description	Measurement not valid; minimal or no description of procedure	Measurement valid; limited description of the procedure	Measurement valid; precise description of procedure to allow replication
Measurement frequency	Measurement not repeated	Measurement repeated but infrequently	Measurement repeated frequently, with a minimum of 3 data points per condition, or reached criterion performance
Measurement reliability	Reliability data not provided for any of the DVs	Reliability data provided for some, but not all DVs; OR reliability data does not meet minimum standards	Reliability data provided for each DV; meets minimum standards (IOA = 80%)
<i>Independent variable</i> (IV)	1	2	3
Description of IV (e.g., instructional materials, procedures, length, and duration)	Description is imprecise, general, or not provided	Description is adequate, but lacks some details	Description is precise to allow accurate replication

Quality Indicator	Indicator Not Met	Indicator Partially Met	Indicator Met
<i>Independent variable</i>	1	2	3
<i>(IV)</i>			
Manipulation of IV	IV manipulated, but no documentation of experimental control	IV manipulated, but minimal documentation of experimental control	IV systematically manipulated, with precise documentation of experimental control
Fidelity of implementation	Did not report procedural fidelity	Reported procedural fidelity (use of teaching scripts), but not directly measured	Reported procedural fidelity by direct measurement of IV
<i>Baseline</i>	1	2	3
Measurement of DV	Measured DV infrequently (only one or two data points) in baseline	Measured DV frequently; baseline not stable before intervention implementation	Measured DV frequently; baseline stable before intervention implementation
Description of baseline condition (e.g., materials, procedures, setting)	Description of baseline condition is imprecise, general, or is not provided	Description of baseline condition is adequate, but lacks some details	Description of baseline condition is precise to allow replication
<i>Experimental control</i>	1	2	3
<i>internal validity</i>			
Experimental effect	No demonstration of experimental effect	1 or 2 demonstrations of experimental effect	3 or more demonstrations of experimental effect
Internal validity	Design controls for few threats to internal validity	Design controls for some threats to internal validity	Design controls for most threat to internal validity

Quality Indicator	Indicator Not Met	Indicator Partially Met	Indicator Met
<i>Experimental control</i>	1	2	3
<i>internal validity</i>			
Results (e.g., change in trend, or level)	Pattern of results does not demonstrated experimental control	Pattern of results demonstrated some experimental control	Pattern of results demonstrated experimental control
<i>External validity</i>	1	2	3
Replication of effects (e.g., across participants, behavior, or materials)	No replication	Few replication	3 or more replication
<i>Social validity</i>	1	2	3
Social importance of DV	Not important	Somewhat important	Important
Magnitude of change in DV	Not socially important	Somewhat socially important	Socially important
Implementation of IV is practical and cost-effective	Social validity data about intervention procedures not gathered from intervention agents or students	Social validity data provide documentation of 1 or 2 features (acceptability, feasibility, effectiveness, and continued use)	Social validity data provide documentation of at least 3 features
Nature of implementation of IV	Not reported or documented only 1 feature of IV implementation	Documented at least 2 features of IV implementation	IV implemented by (a) typical intervention agent, (b) in typical settings, (c) for an extended time period

Appendix C. Data Collection Instrument: Study 2 Language Intervention

Study 2: Augmented Reality Language Intervention

1. Data Collection Instrument

Quiz

1. _____ are to protect a baby ladybug from others as well as from the weather. This look like to yellow jellybeans.
 - a. larva
 - b. eggs
 - c. young ladybug
 - d. adult ladybug
 - e. pupa
2. Once the eggs hatch, the _____ will come out. They look sort of like tiny alligators.
 - a. larva
 - b. eggs
 - c. young ladybug
 - d. adult ladybug
 - e. pupa
3. The larva will start to change into _____. They look like a shrimp. It sticks itself to a safe place and it will seem to fall asleep.
 - a. larva
 - b. eggs
 - c. young ladybug
 - d. adult ladybug
 - e. pupa
4. Once the pupa hatch, the _____ will come out. They are yellow and spotless.
 - a. larva
 - b. eggs
 - c. young ladybug
 - d. adult ladybug
 - e. pupa
5. The young ladybug grows up and become an _____. They are red and have black spots on their shell.

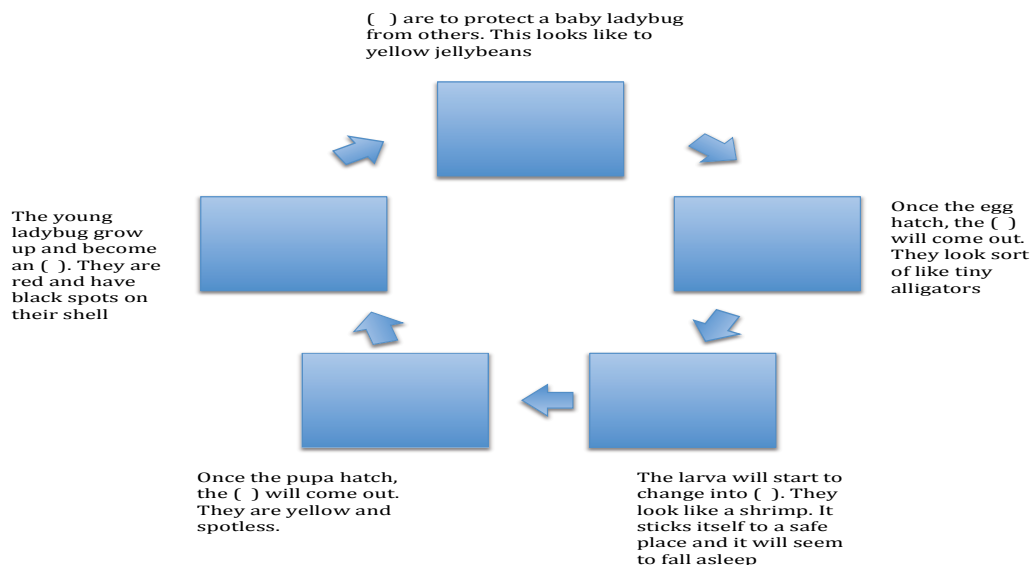
- a. larva
- b. eggs
- c. young ladybug
- d. adult ladybug
- e. pupa

2. Work sheets

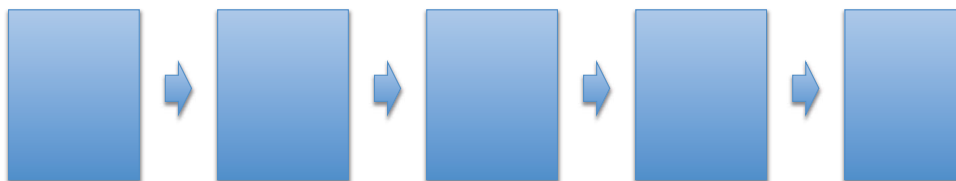
a) Science Vocabulary Cards



b) Labeling Work Sheet



c) Sequence Work sheet



Appendix D. Treatment Integrity Checklist: Study 2 Language Intervention

Study 2: Augmented Reality Language Intervention

Data Collector: _____ Date: _____
Coder Name: _____

	Observed
1. Tested words in the last session?	YES NO
2. Checked iPad battery charge prior to intervention session?	YES NO
3. Provided iPad to child to practice the vocabulary?	YES NO
4. Provided the word cards to the child?	YES NO
5. Instructed the child to view the AR contents for the word list?	YES NO
6. Observed the student wait for the AR app?	YES NO
7. Allowed 10 second wait time before providing next prompt throughout intervention session?	YES NO or N/A
8. Observed students practice all the vocabulary words?	YES NO or N/A
9. Collected iPad at the end of the intervention session?	YES NO
10. Collected the vocabulary cards at the end of the intervention session?	YES NO

Total: _____ / _____ = _____

Appendix E. Social Validity Questionnaire for Children: Study 2 Science Vocabulary Intervention

Study 2. Social Validity Questionnaire Augmented Reality Vocabulary Instruction

Child: _____ Date: _____

“I have some questions to ask you about the augmented reality vocabulary study. I am interested in your opinion, so there are no right or wrong answers. Do you have any questions before we begin?”

Questions		Responses	
1. I liked using AR view the vocabulary words.	Disagree	Neutral	Agree
2. I liked seeing the vocabulary word and information about it at the same time using AR.	Disagree	Neutral	Agree
3. The AR vocabulary instruction was easy to use on my own.	Disagree	Neutral	Agree
4. I would like to use augmented reality more to learn new things.	Disagree	Neutral	Agree

Appendix F. Social Validity Questionnaire for Teachers: Study 2 Science Vocabulary Intervention

Study 2. Social Validity Questionnaire Augmented Reality Vocabulary Intervention

Teacher: _____ Date: _____

“I have some questions to ask you about the augmented reality language intervention study. I am interested in your opinion, so there are no right or wrong answers. Do you have any questions before we begin?”

Questions			Responses			
1.	The children liked the AR-based intervention.	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
2.	I think that the children learned vocabulary effectively through AR intervention.	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
3.	I think that the children learned a life-cycle sequence effectively through AR intervention.	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
4.	The AR instruction was easy to use for teaching science vocabulary words and a life-cycle sequence.	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
5.	I would recommend using AR to other teacher.	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
6.	I would use AR again to help children learn new science vocabulary words.	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
7.	I would use AR again to help children learn a life-cycle sequence.	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
8.	What did you like best about using AR intervention?					

9. What did you not like about using AR intervention?

VITA

Byungkeon Kim earned a Ph.D in early childhood education from the Kyungpook National University in South Korea and a Ph.D in special education from the University of Tennessee in 2017 under the guidance of Dr. Cihak, F. David. Byungkeon have several years of teaching experience at college in South Korea; a special education teacher at preschool for four years; a graduate research assistant for CEEDAR (Collaboration for Education Development, Accountability, and Reform) project at University of Florida; a researcher for child-center in Klinikum Großhadern, Munich, Germany; a journal reviewer (*Journal of Children's Literature and Education*) since 2014.

During a doctoral program in South Korea, Byugneon gained various experience of research as a head researcher for Multicultural Education Research Group in Kyungpook National University. Byungkeon also had experience working and interacting with college students as a lecturer in Keimyung College and Yeungjin College. Besides academic training, Byungkeon also had field experience in DongKwang preschool in South Korea for four years as head of teachers in charge of teacher education and curriculum management.