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DEVELOPMENT ARTICLE

Examining young children's perception toward augmented reality-infused dramatic play

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Abstract Amid the increasing interest in applying augmented reality (AR) in educational settings, this study explores the design and enactment of an AR-infused robot system to enhance children's satisfaction and sensory engagement with dramatic play activities. In particular, we conducted an exploratory study to empirically examine children's perceptions toward the computer- and robot-mediated AR systems designed to make dramatic play activities interactive and participatory. A multi-disciplinary expert group consisting of early childhood education experts, preschool teachers, AR specialists, and robot engineers collaborated to develop a learning scenario and technological systems for dramatic play. The experiment was conducted in a kindergarten setting in Korea, with 81 children (aged 5–6 years old). The participants were placed either in the computer-mediated AR condition ($n = 40$) or the robot-mediated AR condition ($n = 41$). We administered an instrument to measure children's perceived levels of the following variables: (a) satisfaction (i.e., interest in dramatic play & user-friendliness), (b) sensory immersion (i.e., self-engagement, environment-engagement & interaction-engagement), and (c) media recognition (i.e., collaboration with media, media function & empathy with media). Data analysis indicates that

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children in the robot-mediated condition showed significantly higher perceptions than those in the computer-mediated condition regarding the following aspects: interest in dramatic play (satisfaction), interactive engagement (sensory immersion), and empathy with media (media recognition). Furthermore, it was found that the younger-aged children and girls, in particular, perceived AR-infused dramatic play more positively than the older-aged children and boys, respectively. The contribution of this study is to provide empirical evidence about the affordances of robots and AR-based learning systems for young children. This remains a relatively unexplored area of research in the field of learning technologies. Implications of the current study and future research directions are also discussed.

Keywords Augmented reality · Dramatic play · Educational robot

Introduction

Children naturally emulate what they observe in daily life, such as the use of objects, tools, roles, and behaviors in various situations around them. *Dramatic play* is a type of learning activity that allows children to increase their understanding of the world by learning to express themselves in creative ways. In a kindergarten classroom, drama often takes the form of play through storytelling activities, reading aloud of storybooks, and engaging in role-play. The importance of dramatic play in all domains of young children's development is well-documented (Mendoza and Katz 2008). Many studies have shown how dramatic play can enhance the overall development of children in the following ways: increasing verbal ability, allowing children to experience a contingency perspectives of self and others, increasing logical thinking, acquiring social skills through mimicking adult behaviors, and creating a platform for imagination, which improves literacy and creative thinking (e.g., Bodrova and Leong 1998; Boyle and Charles 2010; Drenten et al. 2008; Kozulin and Presseisen 1995; Peisach and Hardman 1984; Roskos and Christie 2000, Schirrmacher and Fox 2009; Smilansky 1990).

Chambers (1996) suggests that employing drama and dramatic play activities in a classroom helps children engage in reading, and experience different roles such as dramatists, directors, actors, audience, and even critics. Through such various engagements in dramatic play, children can increase their understanding of literature and role-playing characters (Mitchell 2003). Drenten et al. (2008) have found that even very young children (3–6 years old) were able to successfully utilize shopping scripts during their dramatic play in a grocery store context simulated in a classroom.

Despite the positive aspects mentioned above, dramatic play has not yet become a routine activity in most kindergarten settings. The underlying reason behind this phenomenon could be attributed to the fact that preparation for dramatic play, such as writing dialogue scripts and making costumes and props, represents a major expenditure of time and effort for teachers (Olsen and Sumsion 2000). Another challenge lies in the difficulty of making the enactment of dramatic play realistic, interactive, and participatory for children. How children interact with stories and roles played through their physical and sensory involvement is a critical socio-cognitive aspect of dramatic play. Yet, how to increase children's immersion into dramatic play activities with limited resources available in kindergarten settings remains a challenge for many teachers (Sheridan et al. 2009).

Recognizing the prevalent difficulties and challenges underlying dramatic play, this study explores the potential of infusing augmented reality (AR) technology in the design and enactment of dramatic play. In particular, we sought to enhance the preparation process of designing dramatic play activities, as well as to provide more engaging and interactive experiences for children through the integration of AR technology. To enable AR-infused dramatic play, we considered the following two alternative approaches: *computers with webcams* and *robots with built-in cameras*. While computers remain the most dominant form of learning technology on the educational scene, robots have, in recent years, received increasing attention for learning purposes. In Korea, more than 1500 intelligent robots have been disseminated as teaching assistants in kindergartens (Center for R-Learning Development Promotion & Support 2011). We conducted a review of previous research on AR technology in education and found that experimental research comparing computer- and robot-based systems for young children is, thus far, non-existent. This phenomenon may be due to technical challenges in integrating AR and robotics, coupled with practical difficulties in conducting experimental studies in kindergarten settings with young children. Given this situation, we believe that it is imperative to conduct a study that empirically examines the affordances of computers and robots for enabling and enhancing AR-infused dramatic play, and to draw relevant implications for the practical application of such technology-mediated solutions for young children's learning.

In the investigation of children's experiences with AR-infused dramatic play, we mainly measured three aspects of children's perception toward media as dependent variables: satisfaction (i.e., interest in dramatic play & user-friendliness), sensory immersion (i.e., self-engagement, environment-engagement & interaction-engagement), and media recognition (i.e., collaboration with media, media function & empathy with media). Furthermore, based on the findings from previous research on dramatic play and media use, we also considered how children's age and gender could affect their perceptions (Hyun & Yoon 2009; Wright et al. 1994). That is, we pay close attention to whether age and gender differences are significantly related to children's perceptions and experiences with AR-infused dramatic play. The following research questions guided the present study:

- How satisfied are the children with AR-infused dramatic play activities mediated by different media (computer vs. robot)?
- How sensory immersed are the children during AR-infused dramatic play activities mediated by different media (computer vs. robot)?
- How do the children recognize the affordances of different media (computer and robot) mediating AR-infused dramatic play activities?
- Are children's age and gender significantly related to differences in children's overall perceptions about AR-infused dramatic play?

Theoretical background

Computers and robots for children's learning

The role of computers for children's learning has received mixed views regarding educational efficacy. Some scholars have pointed out that computers have limited affordances, as they are too abstract for pre-school children who are at the pre-operational stage of development and may not have the necessary motor skills to manipulate concrete objects and models (e.g., Bredekamp 1987; Burns et al. 1990; Davidson 1989). Furthermore, as

Cordes and Miller (2000) point out, computers may pose serious health risks, and the reduction of human interaction can impact children's social, emotional, and moral development as well as their intellectual development including language skills, concentration and creativity. On the other hand, some scholars have argued for the positive impact of integrating computers for children's learning. It has been argued that activities involving learning with computers *do* provide children with opportunities to learn with cognitive tools in social environments where children can develop logical thinking, problem solving skills, and collaborative learning disposition (e.g., Crook 1998; Fessakis et al. 2013; Kafai and Resnick 1996; Papert 1980; Roschelle et al. 2000).

In recent years, with the advancement and dissemination of educational robots, the application of robots for learning has likewise received increasing attention. Robot-Assisted Learning (RAL) has several features distinctive from the general approach of computer-assisted learning. RAL's unique features include the anthropomorphism of media for learning, the presentation of physical activities with verbal/nonverbal interaction, the reciprocal and interactive nature of communication, and the greater integration of virtual and physical spaces for immersive experiences (Han 2010). Related to the anthropomorphism of robots, it is useful to examine the *Media Equation theory* by Reeves and Nass (1996), which claims that people tend to equate media with real people or places in the physical world and feel strong social presence with media. When applying the Media Equation theory to children's use of media, Chiasson and Gutwin (2005) found that children and adults did not show significantly different patterns in their response to the social characteristics added to a computer system. It was speculated that children aged ten to twelve had grown up with computers and hence did not strongly respond to the social cues in the computer system. Our previous study suggests that the effect of the media equation phenomenon was strong when children are younger. We found that children aged below 10 perceived the great differences between computers and robots (Han 2010; Hyun and Yoon 2009).

Some previous research has explored the affordances of robot-assisted learning for young children and suggests that young children tend to perceive robots as sociable and interactive (Bhamjee et al. 2011; Francis and Mishra 2009; Kanda et al. 2004; Hyun and Yoon 2009; Han 2012). For instance, Tanaka et al. (2007) found that 18–24 month old toddlers treated a robot as a peer rather than a toy after interacting with a social robot for 5 months. This finding suggests that it is possible to establish and sustain social bonding between robots and even young children. Similarly, Ryokai and Cassel (2000) argue that children can use a robot that behaves in the physical space as a character of their story, allowing the child to express the story in a creative manner as if they are producing a movie. Movellan et al. (2009) found that a low-cost sociable robot could help toddlers (18–24 months of age) learn vocabulary skills. Our prior research also found that young children tend to perceive that they could learn something educational from the robot, and the robot could assume some aspects of the teacher's roles (Hyun and Yoon 2009).

One of the defining attributes to explain such positives impact of robots on children's learning process is the robot's technical power for *embodiment* and *immersion*. For instance, Adalgeirsson and Breazeal (2010) examined how people perceived a robot-mediated operator differently when they used a static tele-robot versus a physically-embodied and expressive tele-robot. The results showed that people felt more psychologically involved and engaged in the interaction with their remote partners when a robot was embodied in a socially expressive way. The participants also reported much higher levels of cooperation and enjoyment when interacting with a socially-embodied tele-robot rather than a static robot.

Educational application of augmented reality

Augmented reality is a mixed reality technology that renders real-world environments with virtual objects triggered by markers or gestures, which enables seamless switching between physical and virtual spaces. While AR research in educational contexts is relatively in an early stage, the Horizon report 2012 (Johnson et al. 2012) predicted that AR technology would be widespread in K-12 education settings within 4–5 years. There have been a number of research studies that demonstrate cognitive and affective effects of AR applications on student learning process and outcome (Wu et al. 2013). In this section, we particularly articulate three unique affordances of AR technology as educational applications.

First, AR technology allows learners to experience immersive learning environments by manipulating virtual content and objects through a tangible interface (Billinghurst et al. 2005; Kesim and Ozarslan 2012; Lee et al. 2004). Klopfer and Squire (2008) suggest that the rapid development of hardware and software aspects of AR technologies have reached a maturity that AR applications coupled with handheld mobile computers can provide students with customizable, location-specific learning experiences. Rogers et al. (2002) propose a framework of "transform types" that divides "the conceptual space into four kinds of transformation by coupling different combinations of actions and effects, along with physical and digital dimensions" (p. 679). From children's perspectives, a physical action to a physical effect and a digital action to a digital effect are familiar types of transformation. Comparatively, children tend to be unfamiliar with cross-dimensional transformation such as a physical action to a digital effect and a digital action to a physical effect. Employing this conceptualization of transforming learning spaces, we can consider AR technology as a way to enable children to experience novel and unfamiliar effects by traversing physical and digital planes, which can affect children's motivation to learn and to immerse themselves into learning spaces.

Second, AR technology can enhance learners' understanding of complex objects or situations by presenting a variety of views through three-dimensional stereoscopic images and virtual simulation infused with the real environment (Kauffmann 2009; Yoon et al. 2012). AR not only allows real-life simulation but also enables the impossible to be experienced. Overall, prior research indicates that student participation in an AR-integrated learning environment could lead to enhance students' spatial abilities and motivational factors. For instance, research studies by Billinghurst et al. (2005) and Seichter (2007) have demonstrated that AR applications visualizing complex concepts and principles can promote experiential learning, and enhance the learners' spatial abilities. The heightened sense of the existence of virtual objects and content can enable learners to understand certain objects and phenomena that are difficult to experience in real-life situations. Regarding motivational factors of AR applications, Di Serio et al. (2013) show that the students' levels of attention and confidence in an AR-integrated learning environment for a visual art course were significantly higher than those in a slides-based learning environment. The authors attributed the positive motivation effects to the immersive nature of AR technology that promotes students to sustain high levels of confidence and interest in learning materials.

Finally, AR technology enables a smooth transition from the mere presentation of information to the active exploration and knowledge construction (New Media Consortium 2012; Pemberton and Winter 2009). AR provides a medium with which learners can directly manipulate three-dimensional visual materials. While experiencing feedback through such direct manipulation of virtual objects, learners can deepen their understanding, grasp causal relationships and organize knowledge (Kaufmann and Schmalstieg 2003). Moreover, AR reinforces the users' context awareness, which can help to better understand context-specific concepts, skills, and knowledge. Squire and Klopfer (2007) investigated the application of location-based AR simulation games on handheld computers. They argue for the critical role of "space or locale" in the learning process where the AR application allows students to construct context-specific knowledge and practices. The students solved complex environmental problems by drawing relevant information and prior knowledge both in the physical and virtual spaces. Similarly, Kamarainen et al. (2013) research on the EcoMOBILE shows positive impacts of AR applications in students' cognitive understanding. In the EcoMOBILE project that integrated AR and probeware to support students' outdoor field trips in environmental education, students' level of understanding about the principles of water quality measurement had significantly improved compared to the level of their prior knowledge, after participate in the AR-integrated learning activities. This research demonstrates that AR applications linking learning experiences in and outside of classroom contexts could help students to draw connections between abstract scientific knowledge and situated knowledge applied in real contexts.

Previous research on AR-infused robot-assisted learning

While not many studies exist, some researchers have explored the potential of infusing AR and robot technology to enhance learning experiences. GENTORO is an example of an AR-integrated robot system for children's storytelling activities (Sugimoto et al. 2009). GENTORO uses a robot and a handheld projector to enable children to create a story collaboratively, which can be expressed interactively in a physical space. It was reported that GENTORO's features can enhance children's embodied participation in and their level of engagement with storytelling activities, and can support children in designing and expressing creative stories. RoboStage is another example of AR-augmented robot systems that users can take on either physical or virtual characters with authentic scenes by integrating mixed-reality technology and robot technology (Chang et al. 2010). A study with junior high school students using RoboStage indicated that the AR-integrated robot system significantly improved the students' sense of authenticity of the task and also positively affected their motivation for learning.

Method

Research problem and objectives

The main objective of this research study is to examine the affordances of AR-infused robot systems for enhancing children's dramatic play. Over the past few years, we have pursued this line of research by developing and implementing AR-infused robot systems in various learning contexts. Jo et al. (2011) developed an AR-based dramatic play projector robot with the capability of facial expression, text-to-speech (TTS), and action service. In another study, we developed a semi-autonomous remote-controlled projector robot with the capabilities of background projection and control. This system generates a synthesized augmented view, camera/movement control, story narration, and various special effects.

Overall, in the previous research, we observed that integrating robots and AR application indeed exhibited high potential for drawing children's attention to learning and enhancing learning outcomes. We also found that an intuitive interface was necessary for teachers to manage the right amount of external control in order to run dramatic play smoothly without technical interruptions.

In the research reported in this paper, we aim to advance our understanding of the affordances of AR-infused robot systems through a media comparison study. As mentioned earlier, while computers are the most dominating type of learning technology in educational contexts, in Korea, robots have received increasing attention due to their potential for enhancing learning process and outcomes. Examining situations where educational robots have been widely disseminated in Korean kindergarten settings, we aim to explore the affordances of computers and robots for mediating AR experiences for children's learning. Our current inquiry examines how different types of technological mediation (computer vs. robot) would affect children's perception toward AR-infused dramatic play. The main independent variable controlled in this experimental condition is the *degree of reality* through *embodiment* and *immersion*. As a mode of technological mediation, a computer-based platform mainly relies on the static representation of AR scenes with sound effects whereas a robot-based platform enhances the reality of dramatic play through the robot's physical embodiment such as changes of facial expressions, physical actions, and storytelling via text-to-speech. This research assumed that such an enhanced degree of reality in robot-mediated dramatic play would lead to a higher level of sensory immersion into the story characters, thus affecting children's satisfaction with learning activities.

Research context and participants

The present study (n = 81) was conducted as part of an after-school program at a kindergarten located in a middle-sized city in Korea. Informed consent in human subjects research was obtained from the participating children and their parents. Female teachers assisted in conducting this study. Table 1 presents the number of participants in each group. The participants were placed in either the computer-mediated AR condition (n = 40) or the robot-mediated AR condition (n = 41). There were 42 5-year old children and 39 6-year old children. Regarding gender, there were more boys than girls, with 48 and 33, respectively. It should be noted that in natural research settings, it was difficult to control the equal distribution of children in each experimental condition with regard to their gender and age. This difficulty is mainly due to the fact that we did not want to change the natural grouping already established in the kindergarten. Social bonding had already occurred in the participating kindergarten classes, and disrupting the bonding

Table 1 Characteristics of participating children

Media	5-year old			6-year old		
	Boys	Girls	Total	Boys	Girls	Total
Computer group (n = 40)	11	9	20	14	6	20
Robot group (n = 41)	10	12	22	13	6	19
Total (n = 81)	21	21	42	27	12	39

might impact the children's group dynamics and interaction patterns. Instead, we tried our best to keep the sample size as similar as possible in each condition.

In designing experimental research conditions, we intend to address the problems of previous media comparison studies, as suggested by Clark and Sugrue (1995) and Krendle et al. (1999), in the following two ways. Firstly, in some comparative studies, the researchers failed to convincingly attribute their results to the difference in media because they did not control for teaching methods or content variability. To prevent committing the same error, we organized two experimental conditions exactly identical in teaching methods and learning content, the only exception being the media type mediating AR experiences. Secondly, some of comparative studies have been criticized because they failed to control for the novelty effect where new media were introduced. In this study, the participating students had some initial exposure and experiences with both types of media (i.e., computers and robots) before the research commenced. The classroom was equipped with a computer, which was often used by the teacher to conduct lessons and to show multi-media resources to the children. The robot platform (explained in detail in the following section) was also available in the classroom for the children to freely play with it.

Robot platform

As a main robot platform of this study, we employed iROBIQ, which is the most widespread type of educational robot in Korean kindergartens. iROBIQ has the following system architecture: two degrees of freedom for the head, one degree of freedom for the arms, six touch sensors (two each for the head, arms, and wheels), a bumper sensor, infrared sensors, a 10-inch touch screen, a top speed of 45 cm/s, and English/Korean text-to-speech (TTS). The weight is approximately 7 kgs. Marker-based AR technology, the robot's facial expression, actions, and TTS were employed to support interaction between the children and the robot. iROBIQ has facial expressions ranging from basic emotions (e.g., anger, disgust, fear, happiness, sadness, and surprise) to more complex contextual ones. In addition, the robot has a built-in speech recognition engine capable of simultaneously identifying English and Korean words (80 % recognition rate for approximately 200 words), and an image recognition engine for face-recognition and face-detection. For this study, however, the voice and image recognition feature were deactivated due to the poor noise and lighting condition in the experimental site.

When loaded with the AR Flash robot script, the AR-based dramatic play service is activated using the iROBIQ robot software platform, which consists of a Robot Service Executor (RSE) and a Robot Content Player (RCP). The robot script is executed by RCP. iROBIQ simultaneously executes the robot software platform and the AR library, such as Papervision 3D. The minimum CPU resource required would be at least 1.6 GHz and 1.75 GB of RAM.

System design and development

The study took approximately 9 months to complete. The first step of this study was to develop a learning scenario for dramatic play activities. The research team was multidisciplinary in nature, consisting of early childhood education experts, preschool teachers, AR specialists, and robot engineers. The team worked collaboratively to develop a learning scenario and an AR-infused robot system for dramatic play. In this study, the familiar children's story of "Three Little Pigs" was selected for designing and developing

Fig. 1 Children with cubic marker hats

AR-infused dramatic play. To design a learning scenario, we conducted natural observations to identify how the teacher led the dramatic play process in a typical classroom setting. Based on the learning scenario plan, a computer-mediated AR system was developed and pilot-tested with children. After this pilot test, a storyboard was created to show how iROBIQ would lead similar forms of dramatic play by utilizing iROBIQ's facial expression, actions, and dialogue text-to-speech.

To mediate children-robot interaction through AR, we utilized a marker in the form of a three-sided cubic hat to process three-dimensional coordinate information. A marker means "a sign or image that a computer system can detect from a video image using image processing, pattern recognition and computer vision techniques" (Siltanen 2012, p. 39). A marker-based approach is widely used in AR to align virtual objects in the environment. As shown in Fig. 1, the cubic hats that the children are wearing support easy AR-mapping with multiple angles of characters (i.e., front and side views). We used the marker created to enable an easy switch to the next scene aligning with the flow and sequence of the children's play.

Table 2 shows the flow of the storyboard and the various output embodied by the robot in each story scene. The AR technology and robot system were integrated to increase the degree of reality of dramatic play through physical embodiment and multi-modal immersion. In Table 2, noteworthy are the changes of the robot's facial expressions, sound effects, and physical actions in each scene in accordance with the respective input received through the children's markers. For instance, when the children are acting out the scene "And started sawing" as indicated in the second row of Table 2, the robot changes its facial expression, produces the sound effect of sawing, and holds up an arm to show the action of sawing. Also, the monitor screen embedded in iROBIQ (where the children are acting the scene) simultaneously shows their physical actions represented in a virtual dramatic play with the real story characters (i.e., three pigs) and backgrounds. This increases the children's sensory immersion into the role-playing characters.

Experimental conditions

Before the experiment, all children had some free time to experience the AR application using the markers. The participants were assigned in either the computer-mediated AR

Table 2 Robot storyboard

Input (actors' activities based on their markers)	Output (robot's embodiment)			
	Facial expression	Text to speech	Action	Monitor (augmented reality scene)
		"The three little pigs set off along the road." (Cheerful background sound)		
		"And started sawing." (Hold up the right arm and sound effects of sawing)		
		(Sound effects of wind blowing and clattering)		

condition (n = 40) or the robot-mediated AR condition (n = 41). Each experimental condition was split into the actor group (four children) and the audience group (remaining children) to participate in the dramatic play activities. The selection to the actor group and the audience group was randomly made by the teacher. The experiment began with the introduction about the dramatic play and lasted for approximately 1 hour. During the dramatic play, the two groups used either a computer-mediated AR or robot-mediated AR to immerse in the story. The teacher provided necessary guidance to smoothly run the dramatic play, but their direct involvement was minimized throughout the play. After the dramatic play was over, the children in the audience group had the opportunity to experience the AR by manipulating the system.

We employed external systems such as video camera and TV to enable AR experiences for both the actor group and the audience group. The technical and physical set-up in each condition is shown in Fig. 2. First, in the computer-mediated AR condition (see Fig. 2a), a webcam receives images of actors with markers, and the computer monitor shows the AR-modified images with the characters mapped over the original images. The actors/actresses are able to dramatize while looking at the AR scenes on the computer monitor. The AR scenes presented on the computer screen are also broadcasted onto the widescreen TV. This broadcast allows children in the audience group, who are not directly participating in the dramatic play, to watch how the actors/actresses perform their roles in the drama with the mediation of the AR screen.

Figure 2b presents a technical set-up in the robot-mediated AR condition, where a robot leads the dramatic play with text-to-speech and actions. With iROBIQ, it is possible to use a projector to project images or pictures directly on the wall. However, the lighting

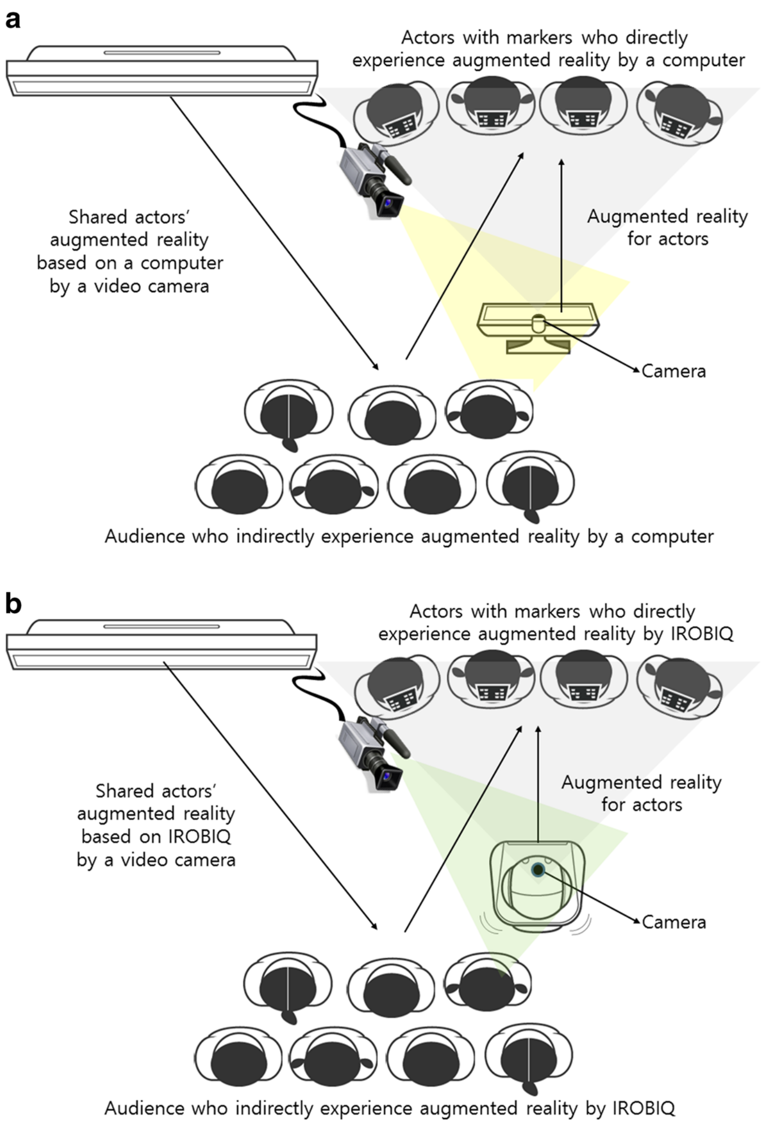

Fig. 2 Computer-mediated AR experience environment (**a**) and robot-mediated AR experience environment (**b**)

condition of the classroom was too bright to use the projection function embedded in the robot. Instead, we employed a TV, which is widely available in most kindergartens. Similar to the technical set-up in the computer-mediated condition, when the actor group with maker cubic hats is acting out the story activities, the AR-mediated story scenes are shown on the monitor embedded in the robot, as well as on the widescreen TV for children in the audience group.

Data collection and analysis

In this study, the independent variable was the different types of AR mediation: computer versus robot. To measure the children's perception toward each type of AR-mediated dramatic play, we used three dependent variables: (1) satisfaction, (2) sensory immersion, and (3) media recognition. In this study, *satisfaction* is defined as children's interest in dramatic play and the user-friendliness of the AR-infused dramatic play system. *Sensory immersion* refers to how children perceive the degree of reality in a virtual environment through various sensory engagements, including self-engagement, environment-engagement, and interaction-engagement. *Media recognition* encompasses children's perception toward three specific aspects of media, namely empathy, collaboration, and media function, which were adapted from the human-robot interaction study by Kidd and Breazeal (2007).

We developed a questionnaire to measure the children's perception of the AR-infused dramatic play. Establishing the external validity of the questionnaire items was achieved by means of a literature review of relevant articles and collaborative work with a group of early childhood education experts, preschool teachers, educational technology specialists, and robotics engineers. The questionnaire consists of a total of eight items: two items on satisfaction with dramatic play, three items on sensory immersion in dramatic play, and three items on media recognition during dramatic play. Table 3 presents major constructs and question items. All items use a four-point scale to measure responses (1—strongly disagree, 2—disagree, 3—agree, 4—strongly agree). While we did not validate the instrument with another group of children prior to this study, we asked the kindergarten teachers to check the content validity of the survey, including the difficulty and appropriateness of the language used.

Methodologically, it is challenging to measure the perceptions of children at this young age as they generally have limited vocabulary to express their feelings or opinions and to accurately interpret the meaning of written question items. Thus, we employed two approaches to address this methodological challenge. First, instead of asking children to write

Table 3 Questionnaire items and constructs

Construct		Question item
Satisfaction	Interest in dramatic play	I enjoyed this 3-D AR dramatic play more than the dramatic play we did with the teacher before
	User-friendliness	It is easier to do this 3-D AR dramatic play compared to the dramatic play we did with the teacher before
Sensory immersion	Self-engagement	I felt like I was actually transformed into the pig and the wolf
	Environment-engagement	It felt like the pigs were actually building the houses
	Interaction-engagement	When the wolf "huffed and puffed," it felt like the house was really being destroyed
Media recognition	Collaboration with media	The robot (computer) helped our 3-D AR dramatic play
	Media function	The robot (computer) made the 3-D AR dramatic play fast and accurate
	Empathy with media	The robot (computer) must be tired after helping us do the 3-D AR dramatic play

responses directly to the printed questionnaire, we conducted a one-to-one, face-to-face interview with each child to help them understand the meaning of the questionnaire items and allow the children to ask questions if they did not understand certain concepts or terms. Four researchers independently conducted interviews immediately after the research intervention, and the interviews lasted for about 10 min with each participant. To control for response interpretations among the four researchers, the interviewers were trained not to force the children to make any particular choices and remained neutral throughout the interview process. The researchers assisted the children only when they asked for help. Second, on the four-point scale in the questionnaire, each point is represented with a smiley face, a numeric value, and textual information to increase children's accuracy in indicating their feeling or opinion for each item asked.

For data analysis, both descriptive and inferential statistics were used to analyze the collected data. We performed independent sample t-tests with the alpha value of .05 to examine whether there were any significant differences in the participants' perceptions with each AR-infused dramatic play condition (computer vs. robot). We also conducted a *t* test to examine whether there were any significant differences in children's perceptions toward AR-infused dramatic play in terms of their gender (boys vs. girls) and age (5-year-olds vs. 6-year-olds). Due to the small sample size, we decided not to further break down the participants for comparing gender and age differences in computer versus robot conditions. Instead, we examined the children's overall perception of AR-mediated dramatic play (regardless of mediation mode) according to gender and age factors.

Results

Children's perception of AR-infused dramatic play: mediation via robot vs. computer

Table 4 presents the analysis results according to the media type (computer vs. robot). First, "satisfaction with the dramatic play" includes two items about children's *interest in dramatic play* and the *user-friendliness* of the technological mediation system. Overall, the mean scores were higher in the robot-mediated group than those in the computer-mediated group. T-test analysis revealed that the robot-mediated group showed significantly higher interest in dramatic play than the computer-mediated group. However, no significant difference was found in the aspect of user-friendliness.

Second, children's "sensory immersion with dramatic play" includes three items measuring *self-engagement*, *environment-engagement*, and *interaction-engagement*. The robot-mediated group showed higher mean scores for all the three aspects of sensory immersion measured than the computer-mediated group. However, t-test analysis revealed that only interaction-engagement is significantly different between the robot-mediated and the computer-mediated groups. This means that children who participated in the AR-infused dramatic play mediated by a robot perceived a level of interactive engagement higher than those children in the computer-mediated condition. Children's perception of the self-engagement and the environment-engagement, however, were not significantly different between the two conditions compared.

The last construct, "media recognition during dramatic play" includes three items measuring *collaboration with media*, *media function*, and *empathy with media*. Overall, the mean scores in the robot-mediated group were higher than those in the computer-mediated

Table 4 AR-infused dramatic play: Mediation via robot vs. computer

Construct		Condition	M	SD	*t*	*df*	*p*
Satisfaction	Interest in dramatic play	Robot	3.88	.40	2.284	79	.025*
		Computer	3.58	.75			
	User-friendliness	Robot	3.39	.70	.998	79	.036
		Computer	3.23	.80			
Sensory Immersion	Self-engagement	Robot	3.24	.92	.794	79	.429
		Computer	3.08	1.00			
	Environment-engagement	Robot	3.49	.90	.319	79	.751
		Computer	3.43	.87			
	Interaction-engagement	Robot	3.46	.90	2.488	79	.015*
		Computer	2.95	.96			
Media recognition	Collaboration with media	Robot	3.78	.48	1.314	79	.193
		Computer	3.63	.59			
	Media function	Robot	3.42	.74	1.631	79	.107
		Computer	3.10	.98			
	Empathy with media	Robot	3.29	.87	3.398	79	.001**
		Computer	2.55	1.08			

* $p < .05$, ** $p < .01$

group. *T* test analysis showed that among the three aspects of media recognition measured, only empathy with media is significantly different between the two conditions compared. That is, children tend to show a higher level of empathy with media when they are interacting with a robot than a computer. No statistically significant differences were observed for the aspect of collaboration with media and media function.

Children's perception of AR-infused dramatic play: age and gender differences

One of our research questions was to examine whether children's age and gender are significantly related to differences in children's overall perceptions with AR-infused dramatic play. As mentioned earlier, a comparative analysis of children's overall perceptions was carried out regardless of the media type (i.e., robot and computer) due to the small sample size in each experimental condition. First, it was observed that 5-year-old children's perceptions with AR-infused dramatic play were higher than those of 6-year-old children for all the variables compared, except for the aspect of environment-engagement under sensory immersion. As presented in Table 5, *t* test analysis showed that there were statistically significant differences between the 5-year- and the 6-year-old groups with respect to (a) interest in dramatic play, (b) user-friendliness, and (c) interaction engagement. This implies that younger children tend to have higher satisfaction with AR-infused dramatic play and to perceive higher levels of sensory immersion in the aspect of interaction–engagement in AR-infused dramatic play than older children.

Second, the overall trend of descriptive statistics also indicates that girls tend to show higher mean scores than boys when a comparison of all the variables was carried out. However, t-test analysis indicated that gender differences were statistically significant only in the aspect of empathy with media. No significant differences between boys and girls were found in other variables.

Table 5 AR-infused dramatic play: age and gender differences

Construct		Factor	Group	M	SD	*t*	*df*	*p*
Satisfaction	Interest in dramatic play	Age	5-year old	3.88	.33	2.394	79	.019*
			6-year old	3.56	.49			
		Gender	Boy	3.67	.66	−.998	79	.321
			Girl	3.81	.54			
	User-friendliness	Age	5-year old	3.57	.63	3.482	79	.001**
			6-year old	3.03	.78			
		Gender	Boy	3.18	.81	−1.879	79	.064
			Girl	3.50	.62			
Sensory Immersion	Self-engagement	Age	5-year old	3.36	.88	1.958	79	.054
			6-year old	2.95	1.00			
		Gender	Boy	3.06	.97	−1.161	79	.249
			Girl	3.31	.93			
	Environment-engagement	Age	5-year old	3.43	.89	−.297	79	.767
			6-year old	3.49	.88			
		Gender	Boy	3.43	.89	−.355	79	.724
			Girl	3.50	.88			
	Interaction-engagement	Age	5-year old	3.60	.70	4.114	79	.000***
			6-year old	2.80	1.03			
		Gender	Boy	3.16	1.05	−.539	79	.591
			Girl	3.28	.81			
Media recognition	Collaboration with media	Age	5-year old	3.81	.45	1.877	79	.064
			6-year old	3.59	.59			
		Gender	Boy	3.63	.60	−1.491	79	.140
			Girl	3.81	.40			
	Media function	Age	5-year old	3.43	.83	1.829	79	.071
			6-year old	3.08	.90			
		Gender	Boy	3.16	.94	−1.223	79	.225
			Girl	3.41	.76			
	Empathy with media	Age	5-year old	3.07	1.07	1.305	79	.196
			6-year old	2.77	1.01			
		Gender	Boy	2.74	1.06	−2.078	79	.041*
			Girl	3.22	.98			

* $p < .05$, ** $p < .01$, *** $p < .001$

Discussion and conclusion

Amid the increasing interest in applying AR in educational settings, this study explored the design and the enactment of an AR-infused robot system to enhance children's satisfaction and sensory engagement with dramatic play activities. Specifically, we conducted a media comparison study to empirically examine children's perceptions toward the computer- and robot-mediated AR systems designed to make dramatic play activities realistic, interactive and participatory. We applied AR-infused dramatic play activities in the context of early childhood education and compared the young children's responses to different types of media (computer vs. robot) on three aspects: satisfaction with dramatic play, sensory immersion in dramatic play, and media recognition during dramatic play.

Overall, our results suggest that children in the robot-mediated condition showed significantly more positive perceptions than their counterpart in the computer-mediated condition in the following aspects: *interest in dramatic play*, *interactive engagement*, and *empathy with media*. That is, when children participated in AR-infused dramatic play mediated by a robot, they tend to enjoy this more than the traditional approach of dramatic play (i.e., no technological mediation). Children tend to perceive a higher level of interactive engagement and feel more empathy with the type of media that they are interacting with when compared to computer-mediated dramatic play. These results partially support our initial assumption about the criticality of the degree of reality through embodiment and immersion for enacting AR-infused dramatic play activities. The unique affordance of robots lies in their technical power for enabling physical embodiment and immersion (Adalgeirsson and Breazeal 2010). The robot-mediation system designed and employed in this study embodies changes of facial expressions and enactment of physical actions, and this, in turn, makes children become emotionally more attached to the media they are interacting with. Furthermore, we suggest that, with such an enhanced sense of multi-modality, the children were able to seamlessly connect the real scenes played by their peers and the virtual scenes displayed via a robot, thereby affecting their overall interest in dramatic play. The degree of multi-modal engagement was relatively low in the computer-mediated condition since the representation of virtual scenes tends to be static and less interactive, hence less effective in enabling sensory immersion.

While the overall mean scores in the robot-mediated condition were higher than those in the computer-mediated condition, we did not observe significant differences in other variables compared, such as user-friendliness, self-engagement, and collaboration with media. This may indicate that the children tend to perceive both types of technological systems as equally user-friendly. Based on this finding, we suggest that additional work is necessary to enhance the level of sensory immersion in designing future robot-mediated AR systems.

We also examined the impact of gender and age based on the previous research about dramatic play and media use (e.g., Jo et al. 2011; Wright et al. 1994). Our results indicate that the younger-aged children and girls perceived AR-infused dramatic play more positively than the older-aged children and boys, respectively. In particular, younger children tend to have more positive perceptions with respect to (a) interest in dramatic play, (b) user-friendliness, and (c) interaction-engagement. Regarding gender differences, we found that girls tend to perceive a higher level of empathy with media than boys. We speculate that younger children and especially girls tend to have somewhat lower expectations about the quality of interaction with robots than older children and especially boys who possess a wider range of prior experiences with technological tools. Hence, younger children or girls would find the level of human-robot interaction more acceptable and interesting than older children or boys. Furthermore, the level and type of interaction that the current robot technologies can offer is rather limited, so children may have difficulties sustaining their interaction with the robot for a longer period. This speculation is consistent with the previous studies reporting that children's interaction with a robot could not be sustained for longer engagement despite the use of humanoid robots (Kanda et al. 2004; Park et al. 2011). Among the previous research that similarly examined the effect of humanoid robots on children's learning, Kanda et al. (2004) found that younger children spent more time interacting with a robot than older children, but the overall engagement level decreased after the second week.

While we believe that this study investigated the effect of robot-mediated systems for designing and enacting dramatic play for young children, we also need to emphasize the exploratory nature of the present study and acknowledge some limitations, which we plan to address in future research. First, the results include the responses from both groups of children who directly interacted with the robot (direct-experience group), as well as, those who assumed the audience role (indirect-experience group). We did not perform separate statistical analyses between the direct-experience group and the indirect-experience group due to the small sample size in the direct-experience group. However, it is possible that the perceived level of engagement and satisfaction would differ between children who enacted the dramatic play and those who were in the audience group. Hence, we plan to further examine this aspect of differentiated embodied experiences in a future study with more participants in a direct-experience group involved. A second limitation is the duration of the experiment, which was limited to one session. To demonstrate the sustainable usage and impact of such AR-infused dramatic play systems, there is a need to conduct an experimental study for a longer period. Third, since the questionnaire is self-reported in nature, additional objective measures such as observation data about children's learning behaviors for triangulation would make the research findings more comprehensive. Lastly, we want to acknowledge that the robot-mediated system employed in the present study needs additional technical improvement to better support physical embodiment and the representation of virtual worlds in AR scenes. If the features of voice and gesture recognition were added to the system, dramatic play could better support children's multi-modal engagement. The possibility of integrating voice and gesture recognition technology will be pursued in our future research and development effort.

The contribution of this study is to provide empirical evidence about the affordances of robots and AR-based learning systems for young children, which has remained relatively unexplored in the field of learning technologies. As we mentioned earlier, while dramatic play holds much pedagogical potential for young children's learning, it has been challenging to design and to enact dramatic play activities owing to practical difficulties coupled with the lack of technological systems to support the design and enactment of such activities. We believe that our research has demonstrated the affordances of AR and robot-based systems to make the design and the enactment of dramatic play more interactive and participatory, thereby increasing children's interest and participation in learning activities. Considering that education robots are becoming more accessible and affordable than ever before, we contend that more rigorous research studies are necessary to show the potential of robot-assisted learning in various contexts.

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