Supporting Augmented Reality based Children's Play With Pro-cam Robot: Three User Perspectives

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Abstract

This paper shares the experiences from the application of AR using the pro-cam robot assistant to managing children's play from three user perspectives, namely, the operator (teacher), the actors (children), and the audience (mainly children).

First a preliminary expert survey was conducted to assess the expected benefits and any particular provisions needed both educationally and technically. Based on the expert survey, the original implementation was slightly modified, particularly for the robot control interface design for the teachers (e.g. to support easier multi-tasking). Finally, a formative evaluation and analysis was conducted to assess the educational effects to the children (both actors and audiences) and their attitudes when a pro-cam robot was used to run an AR based play, as compared to when a conventional approach was used.

The study has found that robot-assisted AR based play showed improved learning effects, compared to the conventional play, in language and creativity and this is attributed to the operational flexibility, novelty, robotic mediation and capturing the attention of the children. The result was also made possible in part by designing an effective interface for the teachers to control the robots and manage the simultaneously occurring tasks.

CR Categories: H.5.1[Information Interfaces and Presentation]: Multimedia Information Systems - Artificial, augmented, and virtual realities; D.2.2[Software Engineering]: Design Tools and Techniques - User Interfaces; K.3.1[Computing Milieux]: Computers and Education - Computer Uses in Education

Keywords: Human Robot Interaction, Interface Design, Augmented Reality, Projector Robot, Education, Children's Dramatic Play

1. Introduction

Dramatic play is one of the most effective activities and integral curriculum for enhancing young children's speaking and listening abilities in early childhood education settings [Jalongo 2005]. However, it is not practiced as frequently as expected, other than on special occasions because it is not very easy to successfully run and manage a play for young children. Scripts are difficult for the children to memorize and their attention span is quite short. Running the play also requires backdrops, a variety of costumes and props, and thus takes a considerable amount of time for a teacher to prepare for it. Thus, it would be desirable, for example, to devise a technical solution to assist the teachers and help the kids concentrate during the dramatic activity and facilitate its practice.

With recent advances in new media technologies, the educational sector is making new attempts to put these technologies into use in a creative way [Resnick 2009]. In particular, augmented reality (AR), a medium through which virtual objects appear "registered" in the right place in the real world, seems particularly opportunistic and suitable for supporting children's play, e.g. with its novelty effect [Rogers 2002] to draw attention, replacement of physical masks and costumes with digital augmentation, and using props as means for all-purpose interaction. More specifically, AR can be used in its most natural form, i.e. producing augmented video imagery in which children (both actors and audience) can see story specific characters and objects mixed and behaving in the real world. The children actors would have to wear and manipulate, during the dramatic activities, marked objects or props for the AR system to recognize and mix in the graphic augmentation.

While possibly effective in its own right, such a scheme still has several restrictions. Dramatic activity often requires a backdrop, and AR alone cannot help much in the tedious and time consuming stage preparation. The AR camera capturing the children's acts is usually fixed in its location with a limited field of view, constraining the children to act in a relative small area. This is often problematic for young children who would not understand these technical requirements.

Therefore, we have developed a semi-autonomous remote-controlled projector-camera (pro-cam) robot as an assistant to the teachers in running the play (using a mobile interface). Under teacher's control, the pro-cam robot helps by timely projecting pictorial backdrops (created using simple tools like PowerPoint) on various spots on the stage wall, eliminating the need to produce, replace and stage background objects. In addition, the pro-cam can assume the role of the "camera man" focusing on a particular object or actor depending on the play context and flow. Actors would not have to worry about having to stand/pose on the sweet spot so that their markers or props can be recognized by the AR system. Such a scheme also provides a "stable" AR imagery. The on-robot monitor shows the live AR imagery to the acting children and even guides the children through narration and teleprompts. The robot not only assists the teachers but also implicitly interacts with the audience in promoting their immersion ito the play as well (see Figure 1).

We have recently deployed the robot assistant for a play ("Three Little Pigs") at an actual kindergarten, and investigated for the effectiveness of the overall proposed approach. This paper shares the experiences from the application of AR using the pro-cam

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robot assistant to managing children's play from three user perspectives, namely, the operator (teacher), the actors (children), and the audience (mainly children). First a preliminary expert survey was conducted to assess the expected benefits and any particular provisions needed both educationally and technically. Based on the expert survey, the original implementation was slightly modified, particularly for the robot control interface design for the teachers (e.g. to support easier multi-tasking). Finally, a formative evaluation and analysis was conducted to assess the educational effects to the children (both actors and audiences) and their attitudes when a pro-cam robot was used to run an AR based play, as compared to when a conventional approach was used. Teachers were also interviewed and surveyed regarding the difficulties and requirements for the overall system.

This paper is organized as follows. First we review related research, for example, previous work in the application of AR and robots to education, particularly for dramatic plays. We also briefly review literatures in human-robot interaction in relation to our robot interface design for the teachers. Next, we give an overview and the detailed features of the in-situ operated robotic pro-cam assistant introduced earlier. Then, follows the detailed presentations of the Delphi based expert survey, mobile control interface design, and the formative evaluation. We conclude our paper with a discussion and concluding remarks including continued plans for future research.

Figure 1. *Running the children's play with the help of the proposed projector-cam robot (detailed view of the robot in the right).*

2. Related work

AR is starting to be applied to children's education and studied for its true educational effect. The general findings point to positive responses and enhanced educational effects through promotion of active and intentional learning [Shelton 2002][Kaufmann 2003][Shim 2007]. Examples include the Magic Book, AR based shadow games, AR pictograms and role playing using augmented masks [Chera et al. 2003][McKenzie et al. 2004][Dunser et al. 2007][Pictostudio]. As for AR applied to provide mixed reality based story-telling, Cheok et al. have introduced an interactive theatre based on an embodied augmented/mixed reality space and wearable computers. The augmented space provided an immersive stage within which the user could interact with virtual objects and experience a story [Cheok et al. 2002]. Gandy et al. also developed a similar AR based environment for the story of Wizard of Oz [Gandy et al. 2005]. However, the educational effects and provision for technical support have not been investigated in depth.

On the other hand, robots are also another emerging medium touted for its potential in children's education [Hyun et al. 2009] [Hyun et al. 2012]. Robots can promote learning through various aspects such as its anthropomorphism, autonomous initiation, ability to perform physical activities and display non-verbal messages, convenient and substitute communication for teachers, and encouraging of creativity and immersion [Han 2010]. Ito et al. introduced a robotic system called GENTORO which used (similarly to our approach) used environment augmentation (with a hand-held projector) and a robot tell stories and interact with school children [Sugimoto et al. 2009]. Chang et al. presented a similar learning environment called the RoboStage that uses environment projection and moving robots. The robots were designed to play live interactions among characters and promote learning the English language. A study with 36 junior high students showed significant improvements in both the sense of authenticity and motivation [Changa et al. 2010]. However, in these studies, the robots were not the central figures in driving the learning system, but rather used as a small toys to promote physicality and concreteness.

Thus, in the context of robot assisted learning in which robots take up the central role in the teaching process, human robot interaction has become an important subject of research. Several guidelines and evaluation metrics have emerged for HRI from the HCI and robotics communities over the years [Breazeal 2002][Drury et al. 2003][Goodrich et al. 2003]. Most guidelines are quite abstract and general, and also seem to be oriented toward "direct and close" interaction [Bartneck et al. 2008][Cramer et al. 2009] or tele-operation control [Drury et al. 2004][Fong et al. 2003]. In our setting, however, we are particularly interested in two aspects due to the requirements of the way our robot is designed to assist the teacher in managing the play: (1) a mobile interface proper for in-situ control (i.e. teacher is present and moving in the classroom with the robot, and the robot is not intelligent to be completely autonomous), and (2) supporting multi-tasking (e.g. the teacher has many control tasks, moving the robot, initiating narration, controlling the camera, etc.) and (3) environment projection based group communication (the robot is interacting with the operator/teacher, actors and audiences thus direct and personal communication is not proper).

Relatively little research has been focused on remote control interface design for on-site robots. Especially with regards to the three aspects mentioned above. Thus, there is not a clear guideline as how to properly design the robot control interface for the best performance and highest usability especially with regards to the three aspects mentioned above. The most typical form of an in-situ control interface for a robot would be through the use of a simple remote control. Therefore, the ordinary remote control tends to be small/compact, one way, function-oriented and difficult to use (e.g. button/code/mode based) [Hruschak 2010]. Interface design becomes even more important for efficient control of or interaction with multi-robots or robots with multi-tasks (e.g. navigation, manipulation, interaction, etc.) [Zhu et al. 2011][Chen et al. 2004]. In this context, traditional interface devices such as joysticks, joy-pads, wheels, switches and buttons are being replaced with a new breed that offers rich visual feedback and mobility (e.g. smart phones, tablet PC), gestural input, and tangibility to compensate for the operator's limited working memory and induce more natural and easier interaction.

Finally, one alternative, in the context of HRI, is to mount a display device like a touch screen or a projector on the robot [Kawata et al. 2006][Kwon et al. 2010][Machino et al. 2006][Matsumaru et al. 2009][Yamashita et al. 2001] and offer a separate visual channel and space for communication and interaction. Touch screen on a robot is a common and popular solution because the interface is stable and familiar to the desktop computer users. However, it requires the users' inconvenience to interact very closely and having to adjust to the robot's size. Matsumara et al. proposed the use of a projector for HRI. However, in relation to our work, they only looked at very specific and narrow issues like effectively displaying robot motion information and using the foot for interacting through the projected floor display. Machino et al. were also one of the early teams to use projectors. However, their vision or concern was more for using it as a mean for telepresence or augmenting information in the environment (using markers).

3. System Design: Robot Pro-Cam System

The proposed robotic pro-cam system is designed and implemented with the following requirements to support the management and running a child play (see Table 1).

Requirements / Support Features		System Elements
Actors	Augmented masks and costumes	Use of markers and detection using a pan-tile camera
	Actor Interaction	Use of special hand-held objects and props (e.g. marker attached, colored)
Robot	Flexible digital backdrop	Environment projection with robot mounted projector
	Stable camera work	Camera mounted on a (stable) robot platform
	(Synthesized) Narration	Speaker on the robot
	Tele-prompt and self-viewing	LCD monitor mounted on the robot showing AR imagery and guidance scripts
	Anthropomorphic look	Decoration for humanoid look
Operator (interface)	Multitasking support and robot control	Scenario based mobile interface
Audience	Audience viewing	Augmented imagery shown to the audience using a separate large display

First, markers are attached to the actors (children) head and body and detected to provide the necessary augmentation in the final synthesized imagery. Actors also may hold and use specially marked or colored "all purpose" props which are also tracked and recognized to augment them with virtual story objects, enact simple interactive motion gestures (e.g. casting a spell with a magic stick) and interact with the projected display surface (interact with an object in the backdrop) (see Figure 2).

Figure 2. *A preliminary test for user interacting with the wall projector robot using a colored ball*

On the other hand, a wheeled mobile robot (Adept Pioneer 3-DX) was used to assist managing of the play. It was mounted with a computer, pan-tilt camera, speaker, ultrasonic sensors, and a panning projector (Figure 1). The projector was mainly used to project a backdrop into the background of the stage. It was positioned and angled in such a way (by default) to minimize the glare for the children actors. At the time of the deployment, the distortion due to off-axis projection was not handled as the robot/projector was, in most cases, facing the stage in a near right angle all the time. The pan and tilt camera was used to stably capture the video imagery and at the same time to intermittently zoom into certain actors or part of the scene. Depending on the situation, the robot moved instead of using the pan-title camera for flexible camera work (all these under teacher's control). The computer processed the video imagery and used the AR Toolkit [ARToolkit] to recognize and track the marker objects and produce the synthesized augmented imagery. The augmented imagery was seen both by the actors by the on-robot monitor directed toward the stage, and a separate audience on a large monitor. Note that the audience (rest of the children) was watching both the augmented imagery on the monitor and the actual stage at the same time. The speaker on the robot was used to provide narration sound (as if coming from the robot). The on-robot monitor also provided "prompts" as a guide to the children actors. Finally, the robot was decorated in such a way (e.g. semi-humanoid form) to attract attention and affinity from the children and elicit interests and curiosity. Since management of a play mostly follows a fixed play script, we designed a scenario based interface which made it easier for the operator to timely invoke the necessary functions by minimizing the attentional shifts (for more details, see Section 5) [Ahn et al. 2013].

4. Preliminary Delphi based Expert Survey

In order to assess the projected effectiveness of the proposed approach and help further refine the system design, we first conducted a the preliminary expert review employing the "Delphi" research method [Adler et al. 1996][Delbeq et al. 1986]. The Delphi method is a structured communication technique, originally developed as a systematic, interactive forecasting method which relies on a panel of experts. It is very useful in deriving a collective opinion regarding a new emerging issues or untested approaches. It involves a staged and repeated surveys and analyses and through such a process promotes the experts to review other expert's views and possibly correct their opinions to finally converge to a coherent conclusion [Linstone et al. 1979]. The rule of thumb for the proper number of expert panelists seems to be around 30. In our case, we formed a 33 member expert panel, 11 each in three distinct areas, namely, (1) children education experts, (2) children field educators (teachers and principals) and (3) technology (content developers, AR and robots developers).

4.1 Detailed Procedure

Our Delphi study went through three stages over about 4 month period. The first Delphi survey consisted of elements that refer particularly to the possible requirements and the impact of the AR or robot based educational contents and their unique characteristics in relation to children's education. To help the experts understand our vision of the robot assisted AR based dramatic activity, a short movie (snap shot shown in Figure 3) captured during a dry run was given as well. The survey materials and responses were sent and received via email. While we do not include the actual survey questions in the paper due to lack of space, the following three topics were of the main interest:

- The impact of the use of AR and the robot to children's development and learning, and to the role of the teachers
- Considerations to be made when using such technologies in the children's dramatic activity (either technologically or educationally)
- Criteria for the selection of the story when using AR and robot assistance

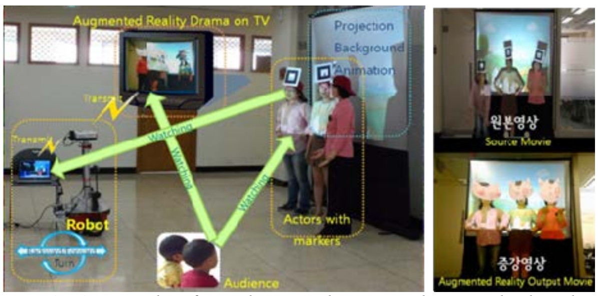


Figure 3. *A snap shot from the introductory video supplied to the experts for the Delphi study.*

As for the second survey, further corrections and improvements were made and redundancy eliminated from the first survey, resulting in 36 final questions. The experts were asked to indicate the appropriateness (to the theme of the study) of each question in 5 Likert scale (for the later in-depth analysis). And in the final third survey, the experts reviewed others' opinions and the overall statistical results to reevaluate their own responses. When one's opinion was deemed significantly different or deviated from the average, one was asked to explain through introspection.

4.2 Data Analysis and Results

The data collected from the first Delphi survey were analyzed for classification and intra-class consistency through the calculation of the Cronbach's alpha values. The second Delphi survey results were statistically analyzed with respect to the five categories identified from the first survey and prioritized. To assess the consistency between the second and third survey, the Coefficient of Variation was computed. Finally, to assess any differences among the three expert groups, ANOVA was applied with a post-hoc Scheffé analysis for identifying the specific source of any differences.

Table 2: *Effects to Children's Development and Learning.*

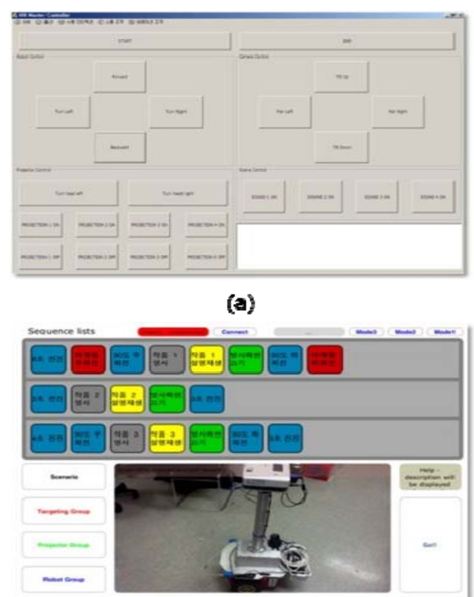
Question	Statistical results after 3rd Survey		
	Mean	SD	Skewness
Child's immersion and interests	4.09	.77	-1.05
Multimodal experience	3.88	.55	-.100
Imagination and creativity	3.61	.66	-.07
Improved ability in story understanding	3.55	.83	-.37
Improvement in expression and communication ability	3.15	.91	-.05
Self-evaluation and reflection ability	2.79	.78	-.40
Total	3.51	.48	-.39

Due to lack of space, we only give a sample of the raw result data and summarize the findings. Among the positive opinions about the proposed approach, the potential for increased immersion and sparking of creativity through the multimodal experience were most appreciated. Table 2 shows survey responses to the category of questions regarding the effects to children's learning and development and the mean score were about 3.51 above the mid-level score of 3 and the average skew-ness of only -0.39, indicating the general positive attitude and consensus toward the use of robot assisted AR dramatic activity. This stems from the novelty of the mixed reality imagery and the self-reflecting nature of the media harnessing the sensorial experience [Harper et al. 2000].

While most opinions were positive, there was also some concern as well. The experts emphasized that despite the projected benefits and operational convenience it was adamant that the children not be restricted or driven by the technology framework in terms of taking assertive attitudes and actions, communicating with each other, and extending their imagination. There was a definite concern for the additional "internal" efforts or burden put on the teachers in the field to integrate and reflect the benefits of this new approach (e.g. dealing and managing the technical operation). For more detailed report of on the results, refer to [Hyun et al. 2011].

5. Operator Interface Design

While the Delphi study showed mostly positive expected effects of the use of proposed system toward children's learning and development through assisting the child's play, post-hoc briefing and behavioral observation during the preliminary pilot deployment revealed quite a serious problem with the usability of the operation control (by teachers). It was reported and found through observation that the interface was not only difficult to use but also the task itself was difficult due to the simultaneous tasks that had to be managed (see Table 1).



(a)

(b)

Figure 4. *The naively designed original "bare" interface with simple control buttons (top) and the scenario based interface (bottom). The sequence of tasks appeared as buttons for the operator to simply activate (under normal circumstances). The tasks are logically grouped. The Camera/Sensor view is in the lower middle.*

Since there were relatively many tasks/subtasks to be managed and accomplished as quickly as possible and in order to aid the user quickly regain one's operating context between the occasional view switches, we developed a "scenario" and flow based interface. Figure 4(b) shows its snapshot in comparison to a naively designed simplistic "bare" interface (Figure 4(a)). It lays out, in the "Task Sequence View" (top part of Figure 4(b)), pre-configured buttons corresponding to a sequence of tasks to be accomplished for the operator to simply activate. For example, in Figure 4(b), the eight buttons in the top horizontal line prescribe "Move (robot) forward 1m," "Rotate (robot) 90 degrees to the right," "Turn on projector," "Play narration," and so on. The layout is configured by interpreting an XML based task specification file (see Figure 5). The buttons were color-coded or highlighted to e.g. indicate their status (currently pending, already finished) and types (navigation, camera control, projector control, etc.). In the case of assisting the play management, a complete and typical operational scenario (e.g. according to the given play) could be prescribed and reflected into the interface automatically.

```xml
<?xml version="1.0" encodig="utf-8"?>
<IHRI>
  <sequence line="1">
    <item event="background">BGCTRL_A0</item>
    <item event="foreground">FGCTRL_A0</item>
    <item event="narration">NRCTRL_A0_S01</item>
    <item event="interaction">ITRC_A0</item>
  </sequence>
  <sequence line="2">
    <item event="background">BGCTRL_B1</item>
    <item event="foreground">FGCTRL_B1</item>
    <item event="narration">NRCTRL_B1_S01</item>
  </sequence>
  <sequence line="3">
    <item event="background">BGCTRL_B2</item>
    <item event="foreground">FGCTRL_B2</item>
    <item event="narration">NRCTRL_B2_S01</item>
    <item event="robot" time="0.5">CTRL_L_DOWN</item>
    <item event="robot" time="1.0">CTRL_F_DOWN</item>
    <item event="projector" repeat="2">CTRL_PR_DOWN</item>
    <item event="interaction">ITRC_B2</item>
    <item event="interaction">ITRC_B2</item>
    <item event="interaction">ITRC_B2</item>
    <item event="robot" time="1.0">CTRL_B_DOWN</item>
    <item event="projector" repeat="2">CTRL_PL_DOWN</item>
    <item event="robot" time="0.5">CTRL_R_DOWN</item>
  </sequence>
</IHRI>
```

Figure 5. *The XML based task specification file.*

Normally, the user would simply use these pre-configured scenario-based buttons to accomplish the given task. In addition the task sequence view interface was used as a way to remind the user what to do without having to memorize the order and specifics of the tasks occurring in the play. However, note that it was not possible to automatically infer whether a certain task, despite being activated by the operator, really was carried out successfully or satisfactorily. For example, even if a "Move forward 1m" command was issued and executed, the robot may fail to accomplish it due mechanical slippage. In fact, there may be situations that deviate from the normal scenario flow (e.g. new obstacle to avoid). In such a case, the user would need a way to go around the scenario based interface and directly access the various task control interfaces (located in the lower left parts of the display in Figure 4(b)).

The Camera/Sensor view (lower middle part of the display in Figure 4(b)) simply showed the video imagery captured by the "user" camera located in the back of the interface (i.e. i-pad) facing toward the operating environment (not to be confused with the AR camera on the robot). The interface was implemented on an Apple iPad [Apple iPad] which communicated the user commands (with screen touch to various control buttons) to the on-board computer which in turn controlled the robot (movement), projector (on/off, panning), camera (pan and tilt), and voice output. In informal trials, the scenario based interface vastly improved the performance and user satisfaction over the naively designed "bare" interface. No formal experiment was further conducted as this result was quite expected and obvious.

6. In-Field Testing of the Effectiveness of Robotic Assistant for AR based Children's Play

Encouraged by the positive opinions formed by the experts from the Delphi Study and with the interface improvement, we proceeded to deploy the system in an actual kindergarten and conducted an in-depth study for the educational effects of the proposed pro-cam system. Our study focused on the effects to (1) language development, (2) creativity and (3) attitude toward scientific thinking. These were aspects deemed and expected to be important by the experts in the Delphi study.

6.1 Experimental Setting and Groups

Normally, a play is run according to a script acted by the participating children. The actors do more than just following the script and will naturally empathize with the character and use one's creativity to express the assigned character and situation the best they can, and even improvise to express one's own feeling. While the children will memorize the script and practice acting ahead of time, due to their relatively low age, the teacher will often guide them from the side for smooth running. The teacher also assumes the responsibility of the narrator and managing the start and end of each act. In the normal case, the children will wear costumes, masks and props according to the assigned character on a pre-decorated stage. The backdrop may be changed manually between different acts.

With the application of the augmented reality assisted by the robot, children will wear markers instead which is augmented in the final imagery synthesized by the computer and shown to the actors themselves (through the small monitor on the robot facing the stage) and to the rest of the children (audience) through a large monitor. The children actors may also hold special objects as augmented props to enact certain interaction (e.g. a gesture to cast a spell with an augmented magic stick). The robot projects the backdrop onto the background of the stage and makes narration according to the control by the teacher. The robot may time to time move about or move its camera to focus on a particular actor again by the teacher's control. To the children, it may seem like the robot is running the play, even though it is really controlled by the teacher. Children actors and the audience alike are excited to see themselves (or their friends) augmented as story characters and expected to be much more immersed (note that children at this age is easily distracted. The computer graphic augmentation is much more flexible than the usual physical costumes of masks, e.g. by the use of prompts, animation, scaling and special effects, and used effectively to guide and lead the children to focus on certain element of the story. Furthermore, all of these elements are expected to spark imagination and creativity on the part of the children, the most important goal of all.

The story selected for the play was selected by two experts in children's education and a teacher who has had prior experiences in running children's play: (1) Mommy! Where are you? [Genechten 2006], (2) The Gruffalo [Julia 1999], and (3) Animal's wishes [Sung et al. 2011]. Mainly considered factors were the difficulty level and the leveraging of the merits of augmented reality as much as possible.

6.2 Measurement of Dependent Variables

As mentioned, the three main dependent variables were effects to (1) language development, (2) creativity and (3) attitude toward scientific thinking. In this study, we used the Preschool Receptive- Expressive Language Scale (PRES) which is a simple Korean standard test for measuring language ability, both for understanding and expression, for kindergarten children [Kim et al. 2003]. As for the creativity assessment, the Korean version of a creativity test called the Torrance Test of Creative Thinking (TTCT) was used [Kim 1999]. The A and B type tests on geometric figures were administered to see the before and after effects. Finally, for the scientific thinking attitude assessment, we used the test developed by [Ahn 2003] similar to the one used in the US such as that by [Martin 1997]. Among others, it assesses the proactiveness (assertiveness), candidness, objectivity, openness, critical and cooperative behavior in a 4 level scale.

6.3 Experimental Procedure

Subject groups of 48 children from two kindergartens (24 each) participated in the study. The mean age of the children was 5. For one group (A), the proposed pro-cam system was deployed to help run the play, and for the other (B), the nominal traditional method was used instead.

A preliminary dry run was carried out first to adjust certain system parameters such as the proper size of the markers, methods of attaching them to children, size of the stage, ideal location of the robot, lighting condition, etc. Contents of the play were also modified to make it as easy as possible for the children. With marker based AR, it was necessary to make children understand that the markers they wore had to be visible by the camera (which they could confirm by looking at the on-robot monitor). The teachers also had to be trained with the operation control of the robot.

The children's plays were run nine times over six weeks using the three stories. Each session ran for about 40 minutes in the actual classroom. Before running the play, the children took the three aptitude tests to record the "before" state with regards to the three areas of learning. Likewise, the same tests were administered again for each group after experiencing the plays (both actors and audience[1]).

6.4 Analysis and Results

ANOVA was applied to seek any statistical difference between the before and after states of the children regards to those three aspects of learning, namely, language ability, creativity level and scientific thinking. One cannot expect drastic change in these aspects after merely experiencing few plays either in the conventional way or using the robot and AR technology, however, we had hoped to catch a glimpse of certain differential trends between the two groups, if any. Table 3 shows the language aptitude scores before and after the runs for the children in the respective group (A: AR play with robot, B: conventional play).

Table 3: *Language ability before and after the plays for groups A (AR play with robot) and B (conventional play).*

	Group	Before(N=24)		After(N=24)	
		M	SD	M	SD
understanding	A	52.12	4.98	55.33	4.51
	B	45.04	8.17	45.95	8.06
Expression	A	51.50	5.14	54.50	4.42
	B	47.00	8.40	48.50	7.46
Both	A	51.81	5.02	54.91	4.44
	B	46.02	8.26	47.22	7.80

[1] Most children got to try AR based acting in the three rounds of deployment.

ANOVA revealed that there were statistically significant difference between the two, in all categories, for language understanding ($F=10.91$, $p<.05$), expression ($F=5.85$, $p<.01$), and combined ($F=15.66$, $p<.001$) indicating a positive effect of the use of AR robot for language development.

Table 4 shows the differential results with the creativity aptitudes. ANOVA also revealed statistically significant differences collectively over all categories ($F=3.26$, $p<.05$), and more specifically, on the categories of fluency ($F=15.95$, $p<.001$), originality ($F=19.59$, $p<.001$), and unwillingness to quit ($F=5.21$, $p<.05$).

Table 4: *Comparative results with the creativity aptitudes between groups A (AR play with robot) and B (conventional play).*

	Groups	Before (N= 24)		After (N= 24)	
		M	SD	M	SD
Fluency	A	107.58	13.57	138.83	17.03
	B	108.04	16.19	117.67	21.11
Originality	A	95.79	13.34	133.21	19.05
	B	110.83	17.52	106.88	21.97
Abstract thinking	A	100.41	32.16	95.33	32.45
	B	83.17	28.13	83.88	32.38
Attention to details	A	122.96	21.32	124.88	23.88
	B	127.20	19.97	135.17	18.54
Unwillingness to quit	A	103.45	10.67	99.20	23.63
	B	104.91	9.52	109.91	6.78
All	A	106.04	11.91	118.29	16.31
	B	106.83	10.65	109.63	14.46

Finally, Table 5 shows the results for the aspect of the scientific thinking. Again statistically significant difference was found between the two groups collectively over all categories, ($F=6.35$, $p<.05$) particularly on objectivity ($F=9.62$, $p<.05$), openness ($F=28.85$, $p<.001$), cooperation ($F=14.64$, $p<.001$), and persistence ($F=4.16$, $p<.05$).

Table 5: *Before and after scores to the scientific thinking aptitude between groups A (AR play with robot) and B (conventional play).*

	Groups	**Before (N= 24)**		**After (N= 24)**	
		M	SD	M	SD
Curiosity	A	4.58	.97	6.29	1.33
	B	5.88	1.65	5.41	1.79
Proactiveness	A	4.96	.91	6.41	0.97
	B	4.59	0.92	5.63	1.58
Candidness	A	5.63	1.21	6.75	1.78
	B	5.13	2.07	5.58	1.89
Objectivity	A	5.71	1.20	7.08	0.92
	B	5.67	1.24	6.13	1.19
Openness	A	5.79	.98	6.96	1.40
	B	5.08	1.77	5.17	1.34
Critical mind	A	5.33	1.17	5.50	1.82
	B	4.71	1.99	5.54	1.91
Cooperation	A	5.58	1.25	7.25	.85
	B	5.79	1.22	6.04	1.30
Persistence	A	4.75	2.15	5.75	0.89
	B	4.21	1.44	5.08	1.17
All	A	42.33	7.05	50.70	8.51
	B	42.25	7.04	46.00	7.42

6.5 Discussion

As mentioned, the in-field study showed that Robot-AR based dramatic activity positively affected children's language ability more so than when using the conventional method. From the children's perspective, their listening ability seem to have been strengthened and focused by the robotic narration (it sounded as if coming from the robot), special sound effects synchronized with the actor's actions. In terms of language expression, seeing themselves in the screen augmented as different story characters encouraged the children to actively participate, imagine their roles, and verbalize such feelings (even as an audience). In addition, by watching both the synthesized AR imagery on the monitor and the actual play (where actors wearing markers are seen), the children seem to grossly grasp the concept of AR and such an interplay seem to have helped children's verbal thinking process. In this process, the actors learned how to leverage on augmentation to express themselves (e.g. moving toward the robot/camera, positioning carefully so that the markers are not missed, coordinating with other actors).

As projected by the Delphi expert survey, the robotic AR also had a positive effect on creativity development, especially on the aspects of fluency, originality, and unwillingness to quit. Children showed a high degree of improvisation in their carrying out the roles, which was also encouraged. They felt more natural and fluent in doing so than strictly following the script. Even so, by the nature of the play, where the overall story and theme is fixed, there seem to be little room for any ways of significantly promoting abstract or detail thinking.

Finally, scientific thinking was also positively affected (more so than using the conventional play setting) when a robotic AR technology was used. Again this is almost obvious to expect. As already mentioned, children became to understand "grossly" how AR operated, albeit in a simple manner (marker seen by the camera, then something comes up in the screen). Such a simple cause and effect concept was used to improvise certain scene or make a particular expression. As one can imagine, augmented reality time to time fails due to the changing lighting conditions, occlusions of the marker, changing distances/angles between the camera, etc. Children, after somewhat understanding the operation, showed strong interest and persistence to "work" with the system. It required some scientific thinking, patience and collaboration with their friends. And the children were thinking that they were interacting with the robot (as far as running the play is concerned), rather than a human teacher. Again, we emphasize that our results were obtained only after nine instances of running the play over six weeks. Longer and more systematic practice is expected to bring about more positive learning effects.

7. Conclusions

This paper has applied AR to children's dramatic activity using a robotic assistant. We have investigated the effects of our approach from the perspectives of the three main users: (1) actors, (2) audience and (3) teachers (operators). The study was composed of a preliminary expert survey, followed by a system refinement according to the survey results, and finally an in-field learning effects assessment study. For the actors and audience, both children, we found improved learning effects in various aspects of language development, creative and scientific thinking, as was projected by the preliminary survey. We have observed that the successful operation really hinged upon managing the simultaneously occurring tasks by efficiently controlling the robotic assistant. It required the right amount of autonomy and external control with intuitive interface for the teachers to run the play smoothly without technical interruptions. In summary, in managing AR based children's dramatic activity, the robot not only relieves the burden of coordinating the play and running the AR system, but also by itself serves as another attention drawing entity, resulting in the synergistically enhanced educational effects

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