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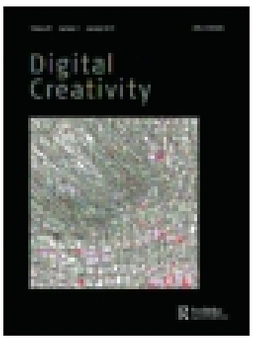
Published in:
Digital Creativity

DOI:
10.1080/14626268.2020.1868535

Published: 08/01/2021

Document Version
Publisher's PDF, also known as Version of record



Digital Creativity

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/ndcr20

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To cite this article: Teemu Leinonen , Jaana Brinck , Henriikka Vartiainen & Nitin Sawhney (2021): Augmented reality sandboxes: children's play and storytelling with mirror worlds, Digital Creativity, DOI: 10.1080/14626268.2020.1868535

To link to this article: https://doi.org/10.1080/14626268.2020.1868535

DIGITAL CREATIVITY
https://doi.org/10.1080/14626268.2020.1868535

Routledge
Taylor & Francis Group

Augmented reality sandboxes: children's play and storytelling with mirror worlds

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ABSTRACT

Augmented Reality (AR) technology has provided a new technological platform for 'mirror worlds', where layers of information, meaning, and functions are integrated with a digital twin of the real world. To explore mirror worlds, we designed and developed +Andscape, an interactive AR sandbox. In this conceptual and empirical case study, we observed children's (5–6-year-old, $N = 16$) collaborative play and storytelling with +Andscape. The qualitative content analysis from observational video-based data allows us to infer how children's play with the AR sandbox engaged their questioning and reflections of both the real world events and the computational mirror worlds. The use of the tool triggered children's imagination and opened for them a story world for exploration of current media events in a unique way. We conclude that when introducing mirror worlds, the focus should be on creative play, participation and storytelling through which the children can construct their own story worlds.

KEYWORDS

design; play; storytelling; children; augmented reality

1. Introduction

In the seventeenth and eighteenth centuries, landscape painters introduced a new aesthetic ideal: picturesque. Soft and hazy surfaces painted with mellow colours came into fashion. To help artists create these landscape paintings with misty edges, a new tool was developed. A black mirror, often called Claude glass. A small mirror with a dark surface and convex shape made it possible to make landscape picturesque and paint what was seen from the mirror. Additionally, aristocrats found the mirror entertaining. When the early tourists travelled to see romantic scenery, they turned their backs to the view and used a mirror to experience the picturesque landscape with oneself in the picture (Andrews 1989). An early form of an image filter and a selfie was invented. The picture created with the black mirror was a modified replica of the real world, one kind of augmented reality creating a new mirror world.

In a recent article in *Wired* magazine, Kevin Kelly (2019) claims that the next emerging digital platform is a mirror world, one where everything in the real world—every place, building, and lamppost—will have its digital twin. With references to recent Augmented Reality (AR) headsets and computer scientist David Gelernter (1993), Kelly points out that a mirror world

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is not only a replica of the real world but something that comes with layers of information, meanings, and functions that make it possible to interact with and manipulate. Kelly concludes dramatically that whoever dominates this emerging platform will become the most powerful people and companies in history. True or not, the possible scenario that mirror worlds as a platform of the future will be exclusively owned and controlled by someone should be critically studied.

In this partly theoretical and partly empirical study, we explore a small part of the emerging phenomena. We study what could be a children's collaborative play and storytelling in the possible forthcoming era of mirror worlds.[1] There are several reasons to study the topic with children. It is reasonable to claim that if mirror worlds constructed using AR will be the next technological platform with societal impact—like the impacts from the first big digital platform, the web, and the second platform, social media on mobile phones—we should have an idea of how and what we can learn with and from this platform. First, it is important that children have a deep understanding of the principles and functions of mirror worlds. Second, children should learn to be responsible when taking advantage of the platform in their own life endeavours.

Another reason to involve children in this study is more practical. In the history of computer software and hardware research, there are several examples of how something originally designed for children has later become a standard for all. Alan Kay and Adele Goldberg's work in the 1960s with graphical user interface (GUI) and Dynabook are probably the most well-known examples of this. Touchscreen devices, originally designed by Kay and Goldberger for children (Bergin and Gibson 1996), become the norm in human–computer interaction in the early 2000s with smartphones and tablets. Their idea of a computer for children, that is a dynamic medium for creative play, has had a lasting impact on human–computer interaction (HCI) design.

In this article, we present a prototype of an AR sandbox that is a step forward from dynamic, touch-screen media toward the direction of mirror worlds. We intentionally aimed to design an AR experience that is not limited to the use of mobile phone or head-worn devices, the most commonly used technologies for AR today (Liao 2018). The AR sandbox is designed to be a digitally enhanced space to build, shape, and squeeze. With digital augmentation, the environments built in the AR sandbox can be enhanced with programmable drawings, colours, and sounds. Therefore, the AR sandbox is primarily a mirror world for play and storytelling.

Previous research has shown that AR sandboxes may provide novel ways for children and students to explore geographic concepts (Savova 2016; Evans et al. 2019). However, little research has been published related to young children's play and creativity with AR sandboxes (George, Howitt, and Oakley 2020). Still, play and creation are essential ways to understand and learn about the world. In his seminal work, Dewey (1934; Goldblatt 2006) pointed out how art facilitated processes of inquiry. Later, the role of play in early childhood development was emphasized by a number of scholars, from the seminal works of Piaget (1962) and Vygotsky (1978) to more recent research such as Bornstein (2012) and Edmiston (2007).

In this article, we build on the importance of play for child development and acknowledge the role of embodiment and extension in cognition (Noe 2012; Shapiro 2010; Wilson 2002; Lakoff and Johnson 1999). Additionally, we are also interested in designing experimental computational environments and tools for play, art making and storytelling. We recognize and stress that these tools should be studied and designed from a pedagogical point of view.

In the article, we discuss Augmented Reality (AR), tangible interfaces for children (e.g. Ishii

et al. 1999; Druin and Hendler 2000; Wyeth and Purchase 2002; Zhou et al. 2004) and play and learning environments (e.g. Birchfield et al. 2008; Rogers et al. 2002) in the context of play and storytelling in one kind of mirror world. The reason for taking a closer look at mirror worlds and AR in this context is because these technologies are developing rapidly with very little human-centred research on them.

1.1. +Andscape: AR sandbox

To explore mirror worlds in the context of play and stories we designed and developed an AR sandbox. +Andscape is an extension of the original AR sandbox, developed at the University of California, Davis, which was designed to create topographic models by shaping sand. A top-down video projection onto sand provides images with colours representing elevation, topographic contour lines, and simulated virtual rain in real-time. When the sand is shaped by hand, the camera perceives changes in its shape, and the projected image changes accordingly (Woods et al. 2016).

+Andscape is an AR sandbox designed for young children, particularly to children attending pre-school or 1–2 grades in Finland. Similar to the original AR sandbox by Woods et al. (2016), children can shape the surface that is then coloured with a projected image. Instead of a cartographic representation of a landscape, the sand in +Andscape is coloured with rainbow colours (spectral colour) depending on the height of the landscape (Figure 1). The order of the colours follows that of a rainbow, from red in the deepest hole in the sand to violet on the highest pile of sand. With this projected mapping of rainbow colours on the contours of sand, the AR

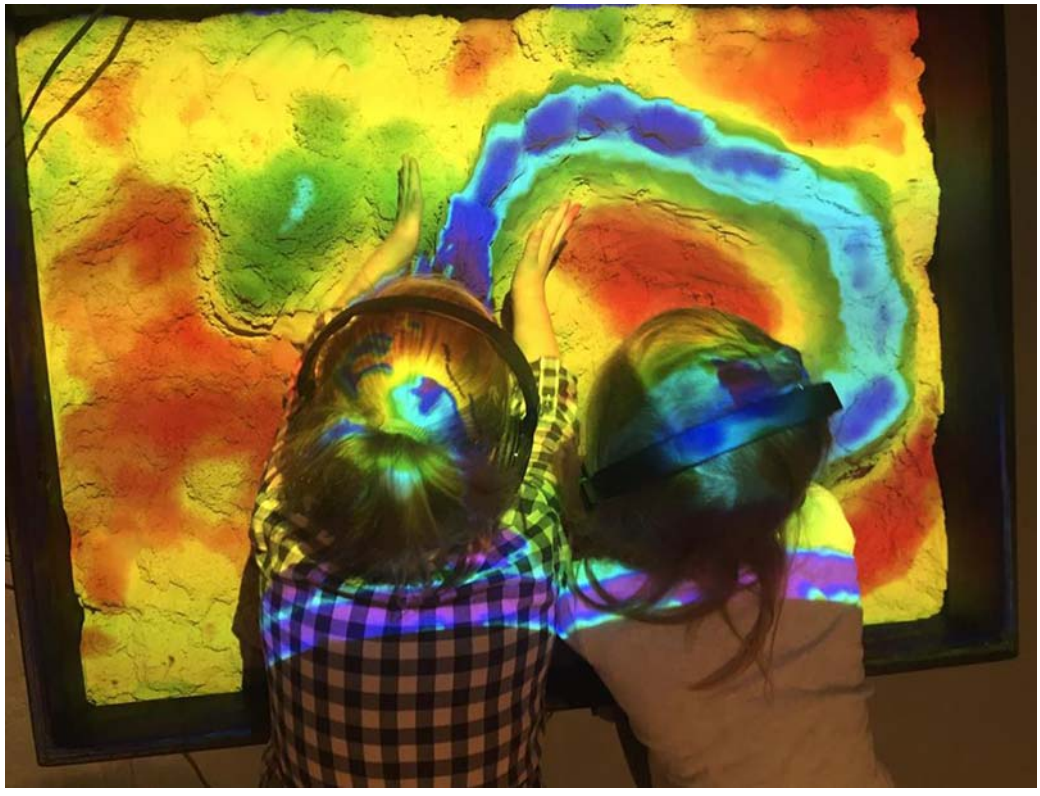

Figure 1. Children playing with +Andscape AR sandbox.

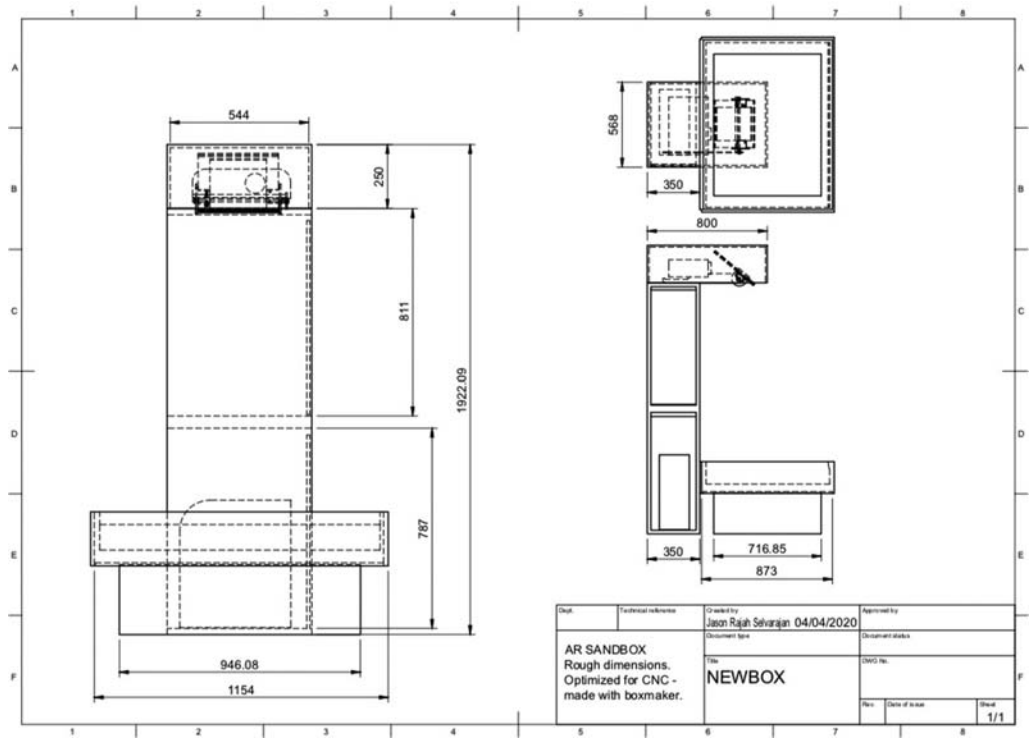

Figure 2. Structure of +Andscape.

sandbox is transformed into a canvas for paintings with shapes.

In addition to the projected colours, +Andscape comes with sound. A small, projected light dot circulates in the sandbox, controlled by a computer software written for the installation. The soundscape changes depending on the dot's location in the box. When the dot is deep in the sand, coloured red, there is quietness. When the dot moves uphill and downhill, the sound changes depending on the height of the shaped sand. By shaping the sand into different forms, children can create different kinds of soundscapes.

The +Andscape installation was assembled by integrating Kinect motion sensing devices, BenQ projector, two headphones, two arcade buttons with led-lights and Teensy microcontroller (Figure 2). The Kinect was used to sense the height of the sand and the projector to project the picture above to the sand via mirror. The headphones were providing the soundscape related to the light/sound dot and the arcade buttons were programmed to change the sandbox between +Andscape and the original AR sandbox. The default mode was set to be +Andscape. The installation was programmed and running on a GNU/Linux Mint computer.

1.2. Tangible interfaces and AR for children

With +Andscape, we aimed to explore new ways to bring mirror worlds into children's creative grasp. +Andscape makes it possible to touch, squeeze, mould, pile, and dig digitally augmented material. First and foremost, +Andscape provides a play environment where children can draw, build and make sounds together. In this way it differs from many other digital educational tools, which

are usually used individually on a 2D surface. Moreover, in +Andscape there are no rules for play. As proposed by De Valk, Bekker, and Eggen (2013), +Andscape is designed for open-ended play; to allow children to construct their own rules, goals and meaning.

Bower et al. (2014) review that AR in education has earlier been studied in skills training, such as driver training, practicing surgery or how to perform machine maintenance. From the pedagogical point of view, the most interesting digital learning tools are those that extend learning from digital platforms to experiences taking place in children's own sociocultural context. Computational tools with tangible interaction are creating mirror world(s) by escaping the frame of a computer screen. For example, a recent study by Hong, Ko, and Lee (2019) investigated technology-mediated play and found that digital augmentation with tangible objects served as a common cue that prompted children to gather together and share interpretations in their own creative way.

There have also been some earlier attempts to combine sandboxes and digital affordances. One of the earliest, according to our knowledge, is the Sandscapes project at the MIT Media Lab (Sawhney and Dodge 1998), a sand-based ambient display used as an experimental interface for peripheral communication of slowly emerging patterns of data. While this early prototype experimented with sand as a medium for data representation, we examined the value of such tactile approaches to designing playful learning experiences with children. Andrea Botero's (1999) interactive sandbox was a pioneering example in this direction. While this project did not use sand for interaction, children could draw on large floor surface; add digital and physical tags and media elements while interacting with physical tools—pens, brushes, and pointers (Figure 3).

In an educational context, AR Sandbox has been used to visualize topographic maps

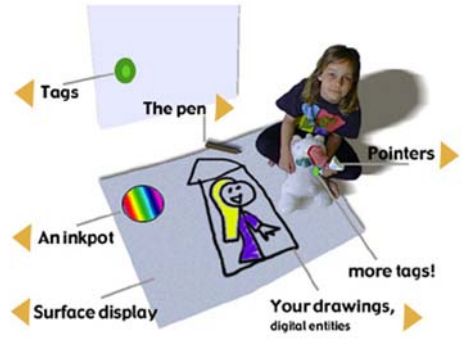

Figure 3. SANDBOX—an interaction toolkit for children (Botero 1999).

(Evans et al. 2019) and to represent conceptions of geology, hydrology, ecology for children and students (Savova 2016). George, Howitt, and Oakley (2020) explored how 4–5-year-old children used an AR Sandbox to enhance their spatial thinking. They found that children demonstrated exploration, model representation, imagination and collaboration, which all assisted in enhancing their spatial thinking. According to our knowledge, in addition to this study with only four participating children, free play AR Sandbox has not been studied as a small children's play environment.

1.3. The role of play in learning

Theoretically, the nature of open-ended and collaborative play with +Andscape draws from sociocultural theories of learning originating in the cultural–historical framework of Lev Vygotsky (1978) and his followers. Vygotsky's central idea was that our actions and thinking are mediated by cultural means (artifacts and tools) and by other people during specific social activities (Cole and Engestrom 1993). Accordingly, children's activities reside not only in individual interests or abilities; they are also distributed across the artefacts and tools at hand and the affordances provided by the environment and social settings (Wells and Claxton 2002).

Of particular relevance for early childhood development, Vygotsky considered play a crucial element of children's learning (Hedges and Cullen 2012). He viewed play as a way in which children increase their understanding of real-life situations and behaviours, often demonstrating this through the imaginary activities of characters and objects used in play. Sociocultural perspectives also suggest that when children engage in play, they use cultural tools and artefacts to interact with their peers in an interest-driven manner (Vygotsky 1978; Hedges and Cullen 2012). Play enhances children's opportunities to form goals and use these tools and resources in a way that is meaningful and thrilling to them (Samuelsson and Carlsson 2008).

In sum, we argue that play and inquiry with +Andscape AR sandbox is a socially, digitally, and materially embodied process in which children can explore ideas and questions that are of genuine interest to them. Our hypothesis is that with +Andscape, children are able to construct and influence their own learning environment, and thus are also offered the opportunity to develop understandings of mirror worlds. Dufva and Dufva (2018) call this approach to technology 'digi-grasping,' considered as active, embodied sense-making and existing in the interface between the digital and physical worlds. Consistent with a progressive inquiry model (Hakkarainen, Lonka, and Lipponen 1999; Muukkonen, Hakkarainen, and Lakkala 1999), we aimed in our design to reach meaningful use of mirror worlds and AR that encourages children to form their own observations, questions, and hypotheses and to generate explanations through play, experimentation and storytelling.

1.4. Research questions

To explore children's play and storytelling with mirror worlds, we conducted a case study to examine the possibilities of AR for playful exploration and storytelling. Specifically, we were interested in looking at elements of inquiry in the children's play and stories. Therefore, we defined the following research question for the study:

> **RQ**: What type of *inquiry* and *stories* emerges with AR play within mirror worlds (using the +Andscape AR sandbox)?

The main research question was then divided into two more specific questions:

> **RQ1**: What *observations*, *discoveries*, and *explanations* do children perform collaboratively while playing with a mirror world?

> **RQ2**: What type of *play* and *storytelling* do children create together within a mirror world?

In the following, we present the theoretical framework that has informed the design and the case study. We then present the research design of the study: the participants, the data collection, and the methods of analysis. After presenting the findings from the study, we conclude with a broader discussion on AR and mirror worlds.

2. Research design

In previous studies, the challenge to grasp the unpredictability and the complexity of children's play have been tackled through research designs that enable children's voice to be heard (George, Howitt, and Oakley 2020). Participant observation, video and audio recordings of children's activities and examining the materials that children create is a common research practice with young children. In earlier studies looking at children playing with augmented tools, observation (Hong, Ko, and Lee 2019) and a mosaic approach (Clark and Moss 2011; George, Howitt, and Oakley 2020) have been used to place children's perspectives into focus. Building on this tradition, in this study, we apply participatory design (Simonsen and Robertson 2012) in the first stage of the study and qualitative content

analysis (Schreier 2014) in the experimental stage.

2.1. Participatory design of +Andscape

With a constructive design research approach (Fallman 2008; Koskinen et al. 2011) we explored an AR sandbox as a platform for young children's play with mirror worlds. Therefore, we relied on the idea of a meta-design to set objectives and use processes to create environments that allow children to act as designers and active creators of their own worlds (Fischer et al. 2004).

This study applied research-based design methodology with contextual inquiry, participatory design, product design, and prototype as hypothesis phases (Leinonen, Toikkanen, and Silfvast 2008). The study was conducted in an ordinary public kindergarten in Helsinki with children coming mainly from middle-class families. The participating children were a regular kindergarten group, assigned by the kindergarten. The children took part in the workshops as part of their daily activities and thus were not especially selected for the study by the researchers. Also, the field trips to the Design Museum were part of their common activities.

The design process started as contextual inquiry in participatory design workshops with 5–6-year-old children ($N = 11$) in two groups with their teacher, a childcare assistant, and a researcher. In the workshops, children played with ordinary sand on a paper surface. The activity was documented with video recording. In addition, children themselves videotaped the play and discussed the activities.

After three days, a reflective discussion was followed by watching the video documentation of the first workshop with most of the children ($N = 8$) who participated in the first session. Children's interaction with the material and the stories that emerged, as well as how the play evolved in interaction with the sand, guided us in designing the features of +Andscape.

Another participatory design workshop was facilitated later on, involving educators to design +Andscape. The participants were a kindergarten teacher, three pedagogical specialists from the City of Helsinki, a librarian, and a pedagogical designer from the Design Museum ($N = 6$). The insights from the design workshop with the children were used as a starting point for the discussions and decision making. This way the design built on children's ideas. In the workshop with educators, we relied on the view that media technologies are not ideologically neutral in their design, in what type of interaction they allow or disallow users to engage in (Shaw 2017). The guiding design decision made in the second workshop was that instead of coding an environment with specific rules and conduct, it was more crucial to leave room for exploration, artistic expression, storytelling and free play.

2.2. Research ethics

The City of Helsinki officials approved the research plan and informed consent was addressed to the adult participants and the children's guardians. In addition, the nature of research was explained to children by the researchers with their teachers. The video recording was done mostly so that the children in it were not identifiable to protect their privacy. The videos were stored in a secure server accessible only for the researchers. The research followed ethical principles: participant constent, right to self-determination, prevention of harm and privacy and data protection. The study applied the guidelines and recommendations of the [nation] National Board on Research Integrity.

2.3. Participants and the data of the experiment (191)

For the study, we installed +Andscape in the Helsinki Design Museum for five

Table 1. The groups participating to the experiment and the video data collected.

Participants	Data
Group 1: Four (4) children girls (assumed) = 1; boys (assumed) = 3; born 2012, 5 y	Video: 00:25:47
Group 2: Four (4) children girls = 1; boys = 3; born 2012, 5 y	Video: 00:24:23
Group 3: Four (4) children girls = 2; boys = 2; born 2011, 6 y	Video: 00:24:39
Group 4: Four (4) children girls = 4; boys: = 0; born 2011, 6 y	Video: 00:24:11

months from November 2017 to March 2018. +Andscape was part of the museum's *California: Designing Freedom* exhibition and available to all museum visitors.

To collect data, we attended four sessions when kindergarten children were visiting the exhibition. Four play sessions, each with four children, were video recorded by one of the researchers (Table 1). The play was free-form with minimal intervention by the researcher.

2.4. Coding scheme

2.4.1. Analysis unit

The unit of the qualitative content analysis was defined to be the group's acts and incidents, which we named as episodes. With Atlas.ti software, we identified the episodes from each activity (Figure 4). An episode was seen as a meaningful unit of activity that was mediated through spoken words and/or gestures. An episode was defined starting when there was a shift of activity (e.g. Chi 1997).

2.4.2. Coding

The first coding scheme was defined based on a progressive inquiry model (Hakkarainen, Lonka, and Lipponen 1999; Muukkonen, Hakkarainen, and Lakkala 1999): *Question/Problem Statement*, *My Explanation/Hypothesis*, *Testing/Experimenting*, and *Discovery/Insight*. In the first coding phase, these codes were used in relation to individual children as well to group activity. The first coding phase was discussed among the researchers and found partly

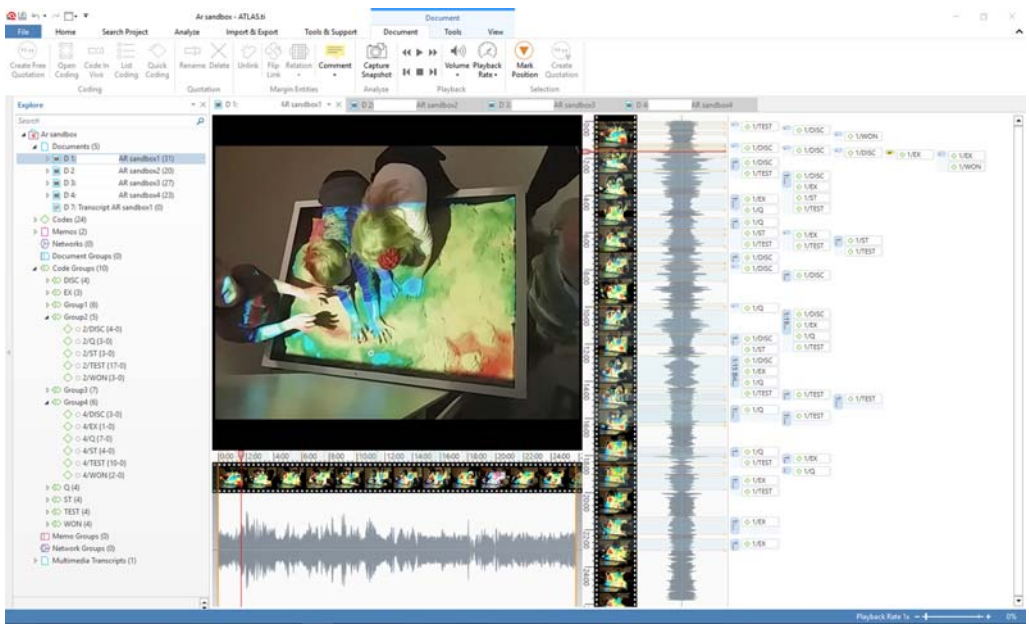

Figure 4. Screenshot from Atlas.ti analysis software to illustrate the coding process.

Table 2. The codes used in the data analysis.

Wondering WON	Question/problem statement Q	My explanation/ hypothesis EX	Testing/ experimenting TEST	Discovery/ insight DISC	Storytelling ST
Children are wondering about a function, feature, or some other issue related to the play with spoken words.	Children are asking or presenting questions or problem statements with spoken words or gestures.	Children are presenting their own explanations or hypotheses with spoken words or gestures.	Children are testing or performing experiments of something with gestures or spoken words.	Children are presenting some discovery with spoken words or gestures.	Children are using their imagination and telling stories while playing with the AR.
Example sentences used when conducting the coding					
WON Why is my hand blue?	Q What is that ball?	EX I think the ball is some kind of robot.	TEST Let's see what happens to the ball if we build a mountain in front of it.	DISC Did you notice that when you dig deeper different colours appear?	ST Then these would cook food for their children.

inconvenient. Coding by individual children was not found relevant, as the group activity and collaboration was entangled with all activity. Furthermore, from the first coding phase we were able to recognize two additional codes: *Wondering* and *Storytelling*.

The final coding was done with six codes, presented in Table 2. In our coding system, we used each group number plus the short name of the code for each episode (e.g. 1/Q, 3/EX, etc.).

The video data were analysed by three researchers (the authors) who at first independently watched the video recordings and wrote notes about their observations. From the note-taking exercise, it was evident that the analysis of messy play situations by episodes (acts and incidents) required a lot of interpretation. Therefore, in the next stage, initial detailed coding was conducted by one researcher with Atlas.ti software and then discussed, elaborated and modified with the two other researchers. Children's rapid and simultaneous interactions with +Andscape and overlapping discussions made the analysis challenging. Recognizing each episode (the start and end points) and categorizing them according to the codes required several data analysis sessions. The coding was confirmed by all three researchers.[2]

3. Findings

In this section, we present the findings from the case study with excerpts and descriptions of episodes. The children's acts and incidents during the play were analysed in terms of observations, discoveries, and exploration children were performing while playing with the AR and what kind of play and stories they invented with the AR. These acts and incidents in the situations were interpreted as signs of progressive inquiry learning (Hakkarainen, Lonka, and Lipponen 1999; Muukkonen, Hakkarainen, and Lakkala 1999).

Each group played for approximately 24 min with +Andscape. From the video data, we recognized 148 episodes of different acts and incidents, with an average of 37 episodes per group (Table 3).

The codes of Testing/Experimenting and Discovery/Insight dominated the data observed while the remaining four codes were relatively

Table 3. Distribution of codes.

	WON	Q	EX	TEST	DISC	ST	Total
Group 1	2	8	11	13	12	4	50
Group 2	3	3		17	4	3	30
Group 3	4	3	7	10	6	11	41
Group 4	2	7	1	10	3	4	27
Total	11	21	19	50	25	22	

equally distributed. Therefore, in our analysis, we were precisely focusing on the episodes with discoveries and explanation, as well as storytelling aspects interlinked to them.

3.1. Observations, discoveries, and explanations while playing with a mirror world

From the video data, it is evident that playing with +Andscape was an exciting and joyful experience for the children; there were no off-task activities where a child was not engaged in the playful inquiry. The excitement continued among all the participating groups and individual children for the entire time of their play session.

Within all groups, the children discovered continuous opportunities and means to collaboratively develop and share different ways to interact with +Andscape. The most commonly presented expression during the play sessions were 'look what happens when … ' and 'look what I am doing.'[3]

Children's first observations and related questions were about the digital features (light, colour, and sound) and technology (hardware) in relation to the physical material (sand and its properties).

C3: *Uhh—here comes red.*
C14: *Where these colors come from?*
C1: *Hmm—I almost got that* [light/sound dot] *out from the sandbox—how one could get it out from the box? I'll try to get it out from the sandbox.*
C2: *I don't, because it always gets inside my sleeve.*

Related to their observations, children started to create their own explanations and discoveries. Although children's own explanations were often incorrect, the AR sandbox triggered situational interest (Hidi and Renninger 2006) to not only collaboratively create explanations but also to test their own theories.

C1: *Where is the sound? Here!*
C1: *What? I saw that it was changing color!*
C2: *It changed to purple.*
C1: *Yes, always when it goes to a pit—hey, look what it has become now. It changed color again.*
C2: *Let's do—now I got it—don't make a deep pit, but a little hole, so it* [light/sound dot] *gets quiet, not big, but right where the dot is, so right there try to make a little hole.*

The light/sound dot circulating on top of the sand (Figure 5) in particular inspired exploration, testing, and interpretations. The relationship between the action and the impact was verbalized in several occasions.

C15: *Look—here comes a light.*
C15: *Is the light coming from there?* [pointing up to the projector]
C9: *Is the dot coming somewhere there?* [pointing up to the projector]
Researcher: *Yep, it comes from the projector.*
C9: *But it is very hard to catch, because if you throw sand on it, it just goes through it.*
C9: *Like if you put it like this* [tries to cover the light/sound dot with a hand] *it just goes through.*
C9: *It's a strange ghost.*

A big part of the children's excitement was related to the physical properties of +Andscape. The feeling and behaviour of the kinetic sand, its properties with the augmented colour and sound, was a frequent source of joy and imagination. The children often interpreted their bodily observation through imagination fuelled by +Andscape. The embodied experiences were also shared with others and expressed frequently.

C11: *Look, I'll put my hands just inside there.*
Researcher: *What happens when you put your hands there?*
C11: *I don't know what happens then.*
C11: *Hey look, there comes lava! Yeah, there comes lava—my fingers are burning.*

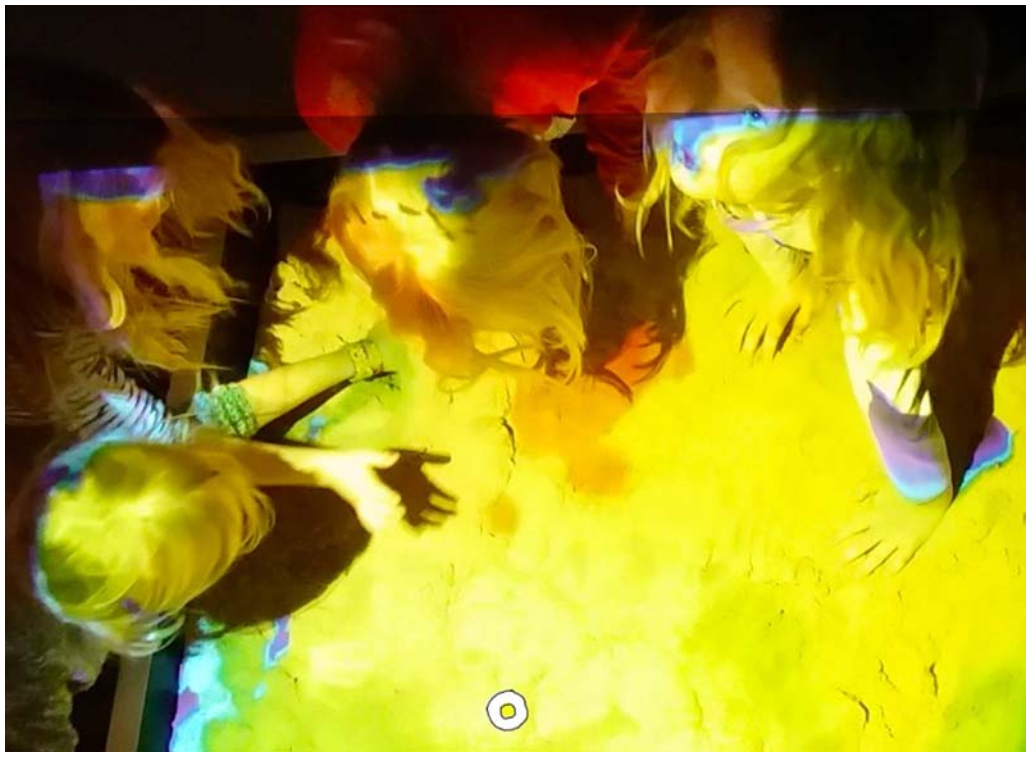

Figure 5. Children discovering the light source [projector above] of the light/sound dot [highlighted in the figure].

C1: *I came up with one thing—let's dig a big pit here—the biggest pit ever—like this.*
C3: [Giggles excitedly] [has made a high hill that the light/sound dot climbs, plays with it]
C1: *I'll dig one huge—huge pit.*
C2: *Let's do it.*
C1: *As big a pit as we can do—this kind of—huge!*

In sum, playing was a socially, digitally, and materially embodied experiment that emphasized collaborative observation and, to some extent, the exploration of questions and ideas. Children were also engaged in testing and gained some discoveries about the mirror world and the AR. The activity was driven from their own interest, but raised also questions about the connection between real and features of the mirror world. These topics were explored tangibly by building things with the sand and seeing how it would affect the mirror world.

It is, however, impossible to say how long lasting an impact this type of inquiry in a short play session will have on children. It is also very likely that a large part of the excitement among the children was due to a new environment to play with. Based on this experiment, although children were demonstrating their interest in playing with +Andscape AR sandbox, it is not possible to say if this interest would be sustained and well developed. We may speculate that most likely, children would develop more lasting forms of play—playing home or city, race cars, et cetera—with +Andscape AR sandbox as occurs with a traditional sandbox, too. The difference would probably be that the mirror world and the features of the tools in it would be integrated into the play. In the following section, we describe in more detail the actual play and stories created by the children during the sessions.

3.2. Play and storytelling of children within the mirror world

The most common situation igniting the children's imagination and storytelling was the interplay where the digital features were combined with the physical and embodied experiences. In the midst of their play, children often explained their observations and embodied experiences with small stories.

C6: *Look, a ball! This is an edible ball-bun! Let's play that this is a bun.*
C9: *Like this—I'm doing from this a meatball.*
C9: *Hey, you wanna know what came to my mind from this meatball—that once at home, two days ago I made a snowman from my own magic sand but then when I was adding things in it, it was all the time melting like this.*
C9: *Hey, you have a green hand, just like an alien—look what I brought here all the way from space.*
C12: *You didn't bring this from space, but from a shop.*
C9: *Yeah, I brought this sand here from space, because I'm from there.*

In one group, children were also tackling broader topics of wonder. Group 4's free play with the sand and the light/sound dot triggered them to collaboratively create a story related to current events reported in news.

The story was created around playing with the light/sound dot that circulates in +Andscape AR sandbox. When children discovered that the changes in the growling soundscape were related to the light/sound dot, they created a story from it. In practice, children started to pile sand in front of the dot, trying to stop it from moving. The soundscape was changing, from a light rolling sound when going downhill to a deeper growling sound when going uphill. Despite the sand obstacles, the dot kept moving as it was programmed to do so. The play was initiated by one of the children (C1), but the rest of the group quickly joined and further developed the activity.

C14: *Let's make a big blob on top of that.* [everybody is trying to hide the moving light/sound dot] [this play continues for a while]
C14: *Is it okay if this is an airplane where there is some Donald Trump—it shouldn't get to Finland!*[4]

The play continues with intensive piling of sand in front of the moving light/sound dot. Collaboratively, the children tried to stop the dot from moving, although they already knew that the obstacles did not have an effect on it. Regardless, the story and the play were built around the idea of stopping the dot from moving and continued with more storytelling:

C14: *Hey, is it okay if we don't take sand from those blobs—let's make the whole land red, so that it will kill it* [the light/sound dot]—*more red.*
C13: *Well now it* [the light/sound dot] *goes to the red.*
C15: *Okay, now let's kill it with red!* [throws sand over the light/sound dot]
C15: *Let's make a big pit where it will sink.*
C16: *Then it can't get out from there anymore.*
C14: *Let's make this kind of wall, too.*
C16: *So it's gonna have to climb.*
C14: *Now it climbs there, somewhere.*
C13: *How can an airplane climb?*

The group contributed to collaborative storytelling and play that lasted 21 min of the 25-minute play session. The light/sound dot was imagined by children to be U.S. President Donald Trump arriving on his airplane. Children attacked the plane with sand and built obstacles, holes, and walls, trying to stop it from moving. The aim was to avoid the 'evil president' arriving in 'our country.'

The children's play in group 4 demonstrates how a media event and daily news entered their play with +Andscape AR sandbox. This is not unique among children's play. In this case, however, it was not possible to influence the movement of the light/sound dot with a

growling sound. Regardless, the children endlessly tried to stop it from moving. The story created on a feature of the mirror world, on which children could have very little influence, represented their understanding of the news stories they had heard, most likely when discussed by their parents and other adults. They created a story where they were powerless but still tried resiliently to avoid the inevitable catastrophe.

The exploration that children presented was collaborative as a premise. Children continuously shared their ideas, observations, discoveries, and plans. What inspired the children tremendously was the sound dot, which was circulating the surface of the sand. Children tried to catch the dot, hide it, throw it off the box and into jail (a pit), bury it, and make it climb uphill.

4. Discussion and conclusion: inquiry and storytelling with mirror worlds

We may conclude that the AR sandbox, mixing the real-life events and mirror worlds, initiated inquiry that connected the social, material, and virtual worlds through collaborative play and storytelling. Through embodied experiences, the children engaged in playful exploration with technology (Resnick 2006), where they made multisensory connections within and across multiple modalities. The children could also connect their interests, previous knowledge, and experiences to the situation (Johnston 2009) and jointly change the process and environment of action. In essence, this created positive experiences that we believe promote children's sense of agency and feeling of production-oriented participation with the digital and computational world (cf. Ito et al. 2013; Papert 1980. Papert 1993). Part of the excitement for children was that they were constructing imaginative stories together, and thus they were both hands-on and mentally engaged in pursuit of a shared purpose of activity.

Based on earlier research and our own experiments we conclude that such free-form play with the AR sandbox engaged children to consider how real-life events and a computational mirror world can be connected. In some parts of the play experiences, children were also using the AR sandbox as a tool for externalizing their ideas about the real world and the mirror worlds for each other. Moreover, their shared interactions with the sandbox triggered children's imagination and opened for them the story world for exploration. From these observations, we offer a formulation of a model for further research (Figure 6).

Children's play with an AR sandbox can be a *tool* for *participants* (children) to *externalize* their thinking about their *real-world* experiences to a *mirror world*. This helps them to deploy their *imagination* to *play* in a *story world* and have an *exploration* between their real and imagined experiences. In line with Vygotskian theories, children's cognition is distributed (Cole and Engestrom 1993) between themselves, artefacts and tools shared as well as several real and imaginary worlds, including mirror worlds.

Children also presented some of their own explanations and hypotheses on the function and meaning of a mirror world, but not as much as we expected. It is possible that the play and bodily interaction with the AR sandbox was so immersive that there was little room to dig deeper into the explanation and reasoning within this first encounter. However, we suspect that children's own explanations could be facilitated after the play session, for example, through joint discussions and reflections (c.f. Bulunuz 2013; Vartiainen, Leinonen, and Nissinen 2019). In a similar vein, experimenting and discovering with the AR sandbox was rather limited as children became more engaged in the play and storytelling. Therefore, it is fair to say that the play itself did not make children literate about AR and mirror worlds but should be seen as a step in the journey of understanding the phenomena.

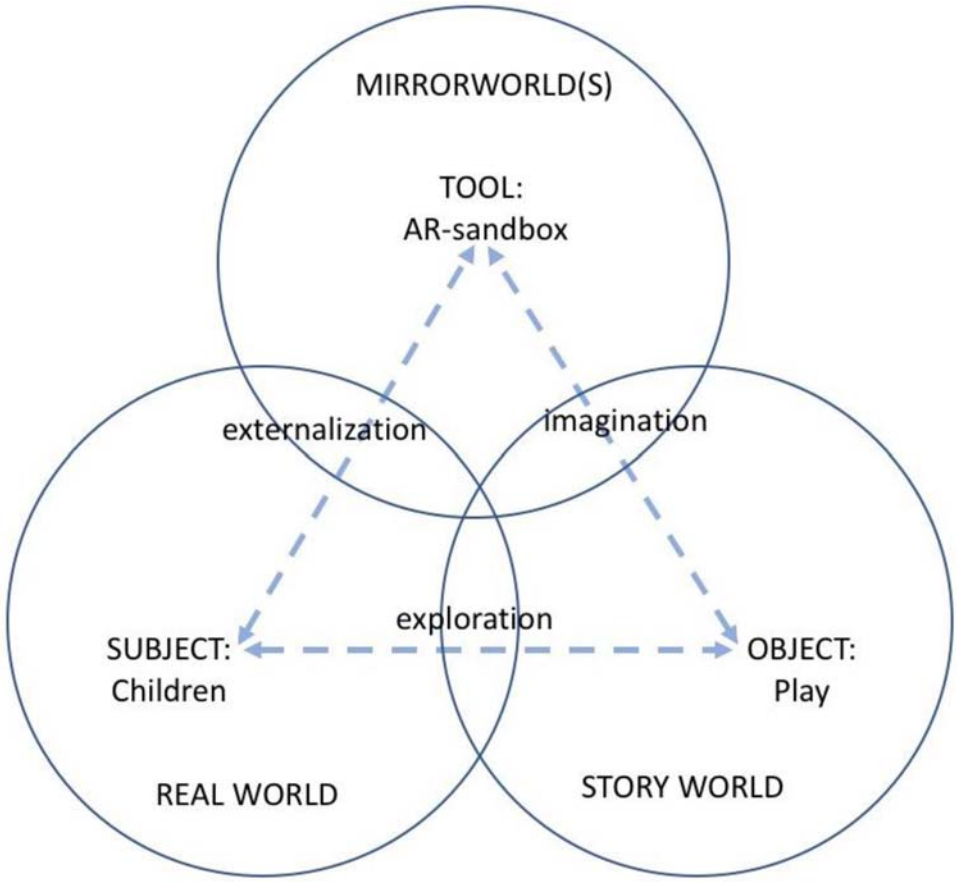

Figure 6. interplay of child, AR sandbox, and play in the intersection of mirror worlds, story worlds, and the real world

The play and storytelling included aspects of creative inquiry and imagination with strong emotional commitment. The mirror world created connections to children's everyday life experiences that were evidenced when the children played with the colour-changing sand and the circulating light/sound dot patterns by integrating them with stories of their surrounding sociocultural environment. In particular, these multi-modal interactions and projections created narrative storylines for play. Moreover, the children unexpectedly included in their play a story related to real-world news events and thus dealt with demanding sociocultural topics during their play with the mirror world.

We see that when introducing AR and mirror worlds, everyone should have the opportunity to co-design and make their own AR experience (Bower et al. 2014). In the creation of the technological platform for mirror worlds we should rather learn from the Open Web platform and Open Source than from the closed social media platforms. This way the platform could be used for empowerment rather than for manipulation. Therefore, at this point, we consider that the topic of AR and mirror worlds requires critical research considering the possible future scenarios.

In this research, there are some limitations to consider. For instance, as a qualitative design research, the results are more describing a

phenomena, than providing results that could be generalized. The participating children were all from middle-class families and in generally culturally homogeneous. The experiment was also conducted with an AR exhibition installation that does not necessarily represent what will be a common way to create mirror worlds.

We, however, dare to conclude that when introducing AR and mirror worlds for children, the focus should be to have a platform for active participation, play and collaborative exploration. People should have access to study not only what is projected but what is going on behind the mirror: the functions of the mirror, the fundamentals of creating imaginative mirror worlds and narratives emerging from them.

Notes

1. In this article, we use the plural form mirror worlds, to emphasise that it is not one mirror world but many worlds. We consider that the phenomena are not only about replicating the existing physical word, but enables to have many different kinds of worlds that are constructed by adding different kind of layers on top of the physical world.
2. The original video data can be provided by the authors if requested.
3. The participant quotations are translated from [language] by the authors. The original transcripts can be provided by the authors if requested.
4. U.S. President Donald Trump was arriving to Helsinki to attend a Summit with the President of Russia Vladimir Putin, the same week when the play session took place. His visit was highly publicized in the local news media.

Acknowledgements

+Andscape installation was produced in cooperation with the City of Helsinki (Insights into Early Childhood Education project) and Aalto University School of Arts, Design and Architecture. Design by Authors. Execution by Labbers Oy Ltd/ Niklas Pöllönen & Jason Selvarajan. Acknowledgements for the participant children and educators in the design workshops. The original Augmented Reality Sandbox was developed by the UC Davis W.M. Keck Center for Active Visualization in the Earth Sciences (KeckCAVES, http://www.keckcaves.org), supported by the National Science Foundation under grant number DRL 1114663.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

The original Augmented Reality Sandbox was developed by the UC Davis W.M. Keck Center for Active Visualization in the Earth Sciences (KeckCAVES, http://www.keckcaves.org), supported by the National Science Foundation [grant number DRL 1114663].

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