Abstract
The study is situated in the Design-Based Research paradigm, emphasizing the inclusion of practitioners throughout an iterative development cycle.

The study was carried out in Southern Jutland, Denmark in collaboration with the pedagogy-education at UCSyd. Five kindergartens participated in the study as part of the practice based process.

The development cycle is documented in three overarching phases: Idea Generation, Concept Development, and Implementation.

The focus of the final evaluation and analysis was on playful learning. Results indicated that the environment showed possibilities for playful learning but had weaknesses in providing a balance between the skills of the children and the complexity of the system. The findings also indicated that the role of the pedagogues as the more knowledgeable other in the learning process is at question when it comes to technology.

Keywords: Early Years Education, Playful Learning, Design-Based Research, Technology-Enhanced Learning
Technology-Enhanced Playful Learning

Through the lens of design based research

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Lastly, I would like to dedicate this report to my dog Calvo, which sadly died of cancer shortly before the completion of the project.
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Introduction

With the rapid development of consumer technology traditional resources for children’s play and learning have undergone major changes (Buckingham, 2000). Despite these developments, studies show that the use of digital technologies in early years educational settings have not impacted pedagogical development (Jernes, Alvestad & Sinnerud, 2010; Plowman & Stephen, 2005; Plowman, Stephen & McPake, 2010).

In this study the purpose is to investigate how children in early years education in Denmark explore and play with digital technology, and to let this knowledge feed into a practice-based design of a playful interactive environment. The focus of the study is to see if such a system supports playful learning, and it will describe, evaluate and discuss in depth the different steps in the design cycle. The first cycle have consisted of multiple chronological iterations where specific attributes aimed to inform the design have been filtered for redundancies. The iterations have focused the on-going work towards emergent design principles for an interactive playful environment targeted at children in early years education.

This study has been carried out following the Design-Based Research paradigm (DBR). Firstly coined by Brown (1992) as design experiments, in DBR there is an emphasis on merging research, practice and design into one entity aimed towards extending current methodologies and theories in educational science (Wang & Hannafin, 2005). DBR underlines an iterative design process (Figure 1) and allows for flexible and mixed methods (Andersson & Shattuck, 2012).

FIGURE 1 THE ITERATIVE DESIGN PROCESS (REEVES, 2006, AS CITED IN HERRINGTON, MCKENNEY, REEVES, & OLIVER, 2007).
In the process methods will be drawn from the field of interaction design, which bear commonalities with DBR when it comes to the iterative design approach. In interaction design there is an emphasis on the user-centred design approach including methods such as design metaphors, interview with users, usability testing, visual ethnography, use of focus groups, think aloud sessions and development of user personas (Antle, 2008), all of which the results intend to inform the iterative design process. A challenge of these methods is that they are designed for adults and do not necessarily lend themselves to inquiries with young children (Read & Markopoulos, 2013). As also discovered in this project the conceptual framework and terminology of children is inherently different than those of adults (Antle, 2008).

Interaction design with children (IDC) and child-computer interaction (CCI) are emerging fields (cf. Druin, 2002; Veale, 2005; Antle, 2008; Iversen & Dindler, 2013) where design researchers strive to meet some of the challenges of designing for and with children (Read & Markopoulos, 2013). Read and Markopoulos (2013) underline however that while the researchers working within the area of CCI believe in the great potentials technology have for learning, collaboration and entertainment there is a lack in empirical research backing the assumption. They also highlight that their meta-study implies that CCI literature neglects to consider the importance of the gatekeepers and the context and space of the inquiries that is unique to CCI. In addition, it is applicable for many CCI-papers that they rarely give thorough descriptions of the methods applied and hence difficult to build from. Moreover they only seldom work with preschool children. This study will try to meet some of these challenges.
1. Theoretical Framework

In this study learning is considered from a social-constructivist perspective based on the theory of Vygotsky (Vygotsky, 1978). In his interpretation learning occurs when humans construct knowledge and make meaning from the interactions with others and with objects. In this way, Vygotsky’s theory focuses on learning as a social construct that develops with peers and more knowledgeable others (Smith, Cowie & Blades, 2011). In this sense children can construct knowledge together that they would not have been able to construct alone. In the words of Wood, Bruner and Ross (1976) the more knowledgeable other scaffolds the learning of the child and takes the child to a higher level of understanding.

In a constructivist view, play is a crucial element in children’s cognitive development and it is considered key to learning (Santer, Griffiths & Goodall, 2007). Play and learning are dimensions that stimulate each other and could be seen as an indivisible entirety, which is a part of children’s experiencing, and which helps them create an understanding of their surrounding world in a lifelong process (Pramling-Samuelsson, 2009). Vygotsky (1966) elaborates that play is the leading source of development in the preschool years. Play is commonly used as a motivator in learning situations where the adding of play elements to an activity is supposed to afford an increased engagement and learning and, thereby, motivation to participate in the specific activity (Dansky & Silverman, 1973; Wood, 2004). This is in line with Resnick’s (2004) description of playful learning as situations where play is an integral part of the learning experience. Petersson and Brooks (2006) describe how toys had a potential to aid learning in a playful way. Rather than being useful, resources designed to support playful values are rich, ambiguous and open-ended (Petersson, 2006; Petersson and Brooks, 2006). Thus, environments that promote playful learning should not be concerned with achieving clear goals, or be overly structured with defined tasks (Gaver et al., 2004). It is however important that a given system creates a perfect balance between the skills of the user and the complexity of the system in order to obtain a flow state for the user (Csikszentmihalyi, 1990).

Price, Rogers, Scaife, Stanton and Neale (2003) defined a range of elements that are essential for playful forms of learning, e.g. exploration through interaction, engagement, reflection, imagination, creativity and thinking at different levels of abstraction, and collaboration. These elements can be related to how children in their everyday life naturally, and often playfully, explore the world (Howard, 2010; Howard, Bellin & Rees, 2002). It is
envisioned that such playful explorations, based on children’s own motives, interests and incentives, elicit learning opportunities through their involvement with the world. Working from a social constructivist Vygotskian perspective, the playful learning elements derived in Price et al. (2003) will be at the core of the interpretation of the data in this project.

1.1 Related Work

Current research in Danish academia shows that technology supports collaboration and enables understanding between children. Sørensen and Meyer (2007), working from a social-semiotic perspective, found that when designing for educational games it is of importance to aim informal learning with play as the main motivator. They also pointed out that the social learning facilitated by technology led to individual learning in the children. This is in line with Jessen (2011) who noted that technology has become an integral part of school children’s play culture and that technology promotes social play. He emphasised that children transfer narratives from digital media into play themes and in that sense digital media enriches children’s play rather than limits it. Johansen (2010) had similar experiences when investigating toddler’s (1-3 years) use of media. She analysed how the toddlers made meaning of media through gestural expression. She found that what the children experienced in media is directed to their play or is reflected in their bodies.

Brooks and Borum (2014) investigated the use of KidSmart Computers. A KidSmart is a regular IBM computer mounted in a Little Tikes® furniture containing software especially targeted young children. The study was carried out in Early Years Education and in libraries in Southern Denmark with a similar sample of participants as the current study. It was found that the technology facilitated peer learning but also that the ecological setting affected the children’s interaction with computers.

While technologies are used for a variety of activities in early childhood years, the use of computers for playing games is the most common activity (Plowman & Stephen, 2005). Research shows that technology has been considered as a supplement, rather than a resource with qualities that can enhance and renew a pedagogical practice (Cuban, 2001). This is in line with a Norwegian study of Jernes et al. (2010) who also investigated use of computers in kindergartens. Their field studies suggested that the technological training (or lack thereof) of the pedagogues affected how much the children would learn from technology.
TECHNOLOGY-ENHANCED PLAYFUL LEARNING

With a point of departure in findings that support that embodiment, physical movement and multimodal interaction play important roles in learning (Antle, 2007; O’Malley & Stanton, 2002) and similarly that gesturing aids thinking skills (Shaer & Hornecker, 2010) the design in this project will be targeted for a Tangible User Interface (TUI).
2. Experimental Design

The research in this project has been carried out following an iterative user-centred life-cycle model in line with Reeves’ model (see figure 1) of the approach in Design-Based Research (Reeves, 2006. Retrieved from Herrington, McKenney, Reeves, & Oliver, 2007). The process consisted of three phases e.g. Idea Generation, Concept Development, and Implementation (see illustration of the work process in figure 2).

The Idea Generation phase concentrated on methods utilised in the efforts on understanding and specifying the context of use of the environment, the specification of the user group and the organizational requirements to the product development. The phase was initiated with a set of field studies of which four personas was developed. The phase was concluded with a Co-Creation Workshop together with pedagogues. The work from this day led into a set of design guidelines for the Concept Development phase.

![Figure 2: Model of Workflow in the First Design Cycle, Which Is Presented in This Report](image-url)
The Concept Development phase constituted the iterative design process. It consisted of the initial concept development and the following four iterations on the design, which was evaluated, in four kindergartens. For each completed iteration the studies were followed up with a summary of the lessons learned that informed the consecutive iteration.

The Implementation phase focused on the accumulating the findings of the three iterations into a system design that was implemented in a kindergarten over 2 days. The study in the Implementation phase focused on the system’s potential for eliciting playful learning.

The work presented in this report focuses on the first design cycle of a technology-enhanced playful learning environment which is part of a larger project in collaboration with UCSyd called Playful Learning, innovation og viden digitale multimodale læringslege I dagtilbud. A second phase was initiated, however doing the Implementation phase it became apparent the new hardware utilized produced a user-experience far inferior to the implementation used in the first design cycle. As such the second design cycle was halted before testing could be conducted.
3. Idea Generation

The first step of the *Idea Generation* phase revolved around gaining an understanding of the children and kindergartens as contexts for play through a set of field studies.

3.1 Field Studies: Participants

When including children in a design process Druin (2002) differs between four roles the children can employ: *user, tester, informant, and design partner*. The main difference is the distribution of power between the children and the researchers. The first two terms is what Druin (2002) constitutes as reactive users. It includes methods such as video probes (Hutchinson et al, 2003), children observing other children (Druin, 2002), play sessions (Marco, Cerezo, Baldasarri, Mazzone & Read, 2009), peer tutoring (Labrune & Mackay, 2005), co-discovery (Bruckman & Brandlow, 2007), post-task interviews (Baauw & Markopoulos, 2004).

The last two terms, *informant* and *design partner*, Druin (2002) categorises as participate users. Iversen and Dindler (2013) emphasise that participation is not necessarily equal to actual generation of knowledge but the term also covers “a means to end of exchanging and negotiating values among participants in a highly dialogic and iterative process facilitated by designers.” (Iversen & Dindler, 2013, p. 26). In this sense children come to understand not only their own values, but also the values of their peers. Similarly Bødker, Ehn, Sjögren and Sundblad (2000) pointed out that participation in itself could be considered as a way of learning. The design process from this perspective includes techniques such as cooperative low-tech prototyping (Druin, 1999), drawings (Veale, 2005), technology immersion (Druin, 2002), and mixing ideas (Guha, Druin, Chipman, Fails, Simms & Farber, 2005).

In this project the children and also their pedagogues have functioned as testers, informants, and design partners depending on the stage of the development process.

Overall the project had several types of participants and all participated in the field studies:

- Pedagogues: 9 (7 female, 2 male) coming from five different kindergartens all volunteered to participate. The pedagogues, in general, had an interest in digital play ware and innovation.
• Student pedagogues: 25, (13 female and 12 male) came from the pedagogical educations at UCSyd in Esbjerg, Kolding, and Haderslev. The student pedagogues functioned as facilitators of the sessions. In the context of this report they are referred to as play agents.

• Children: 55 boys and girls between 3-5 years of age came from five different kindergartens in Southern Jutland, Denmark. The children were chosen for participation by the pedagogues on the basis that they should neither be shy nor overly active, and that they should want to participate. The children played a prominent role in the process. They functioned as the main user group, as co-designers in the Idea Generation phase, and as main informants in the usability focus groups in the Implementation phase.

3.1.1 Field Studies: Procedure
As the first step in the design process a set of field studies was carried out. The intention of the field studies was to inform the design process of the current state of the children’s use of technology. It was also to build a shared knowledge between the researchers, the student pedagogues and the pedagogues.

The field studies consisted of a three-day programme in the five different kindergartens. In each kindergarten the children were divided in two groups with around six children in each. The groups were formed by the kindergarten pedagogues and were mainly divided based on age or personality-types. The activities during the session was carried out and planned together with a group of student pedagogues. The aim was that they should function as play agents to build trust and confidence within the children. The activities were video recorded. For all days and all kindergartens it was applicable that the programme took approximately two hours.

The first day had two sessions that were dedicated to breaking the ice. The first session was aimed towards building trust and friendship between the play agents and the children. In order to do so, the play agents played and sang with the children and the children presented their favourite spots in the kindergarten.
Furthermore, the activities were also aimed to build ownership of the process in the children. As a means to not be invasive in the icebreaking process, the first session was not video recorded and data from the session consist only of verbal feedback from the student pedagogues. The second session was aimed towards gaining insights in how the children currently interacted with digital tools.

On day two the emphasis was on the borders between analogue and digital play. The activities on the second day revolved around introducing the children to multimodal electronic and digital play ware. The play ware and how it was used differed in each kindergarten but it can generally be put in three groups: A) play ware and related software that supported being creative (i.e. drawing, telling stories) in the physical world and turning it into digital content on an Apple iPad; B) play ware that supported audio recordings; and C) electronic play ware that allowed for simple programming.

The third day revolved around virtual environments and co-creation with the children. It had two sessions. The first session introduced the children to a Kinect-based game aimed towards developing spatial understanding. In the second session the children did not have specific guidelines. They were provided with similar play ware as on day two, and also with means to express themselves such as crayons, LEGO© and costumes. The aim of the session was to see how the children would interact with the play ware in free play and also to elaborate on some of the play themes that had emerged during the first two days.

In line with Ylirisku and Buur’s (2007) video review sessions the pedagogue students and the researchers looked through the video material together and discussed emerging themes. In addition, the researchers conducted a semi-structured in-situ interview with the pedagogues who also participated in the sessions. There was an emphasis on informality so that the atmosphere should feel more as a conversation than an interview. The focus of the conversation was the recent play session and also how the kindergartens usually have implemented digital play ware and tools, and in general how the culture and everyday life in the kindergartens was.

3.1.2 Field Studies: Ecological Setting

As stated by Jernes et al. (2010) and Plowman and Stephen (2005), children’s interaction with technology is dependent on the facilitation of the session. In the current project the field studies indicated that the kindergartens on the larger scale and the pedagogues on the smaller
scale had different approaches to technology. Interviews with the pedagogues revealed that all kindergartens approached the process of digitalisation with caution and hesitation resulting in all decisions-making taking place in plenum\(^1\).

### 3.1.3 Field Studies: Establishing Design Requirements

The video data from the field studies, the interview data from the pedagogue interviews together with the six major themes in the pedagogical learning goals as stated from the Danish Ministry of Education (EVA, 2012) has formed the Design Requirements. The learning goals promote that children should develop knowledge and understanding within the following themes:

- Personal development and competences
- Social competences
- Language
- Body and movement
- Nature and its phenomenon
- Cultural norms of expression and values

The learning goals played a highly emphasised role in the everyday pedagogical practices (see figure 3). Every kindergarten is to form their own specified goals but they should comply with the major themes.

In all kindergartens there was an overlap on which learning goals the pedagogues saw potentials for technology to support. They were A) body and movement, and b) social competences. In the former the pedagogues expressed that they would like to support kinaesthetic play by bridging physical and digital play so that play in one mode could be carried over and grow in the other mode. In the latter, the pedagogues expressed a need for an environment that promotes social play. They emphasised that they do not consider

\(^1\) Exact term from pedagogue interview meaning that all decisions regarding technology were only made when all pedagogues were present and all had a vote in the matter.
FIGURE 3 THE 6 LEARNING THEMES HANGING ON THE WALL AS THE FIRST THING TO SEE WHEN YOU STEP INTO THE KINDERGARTEN IN KOLDING

computers asocial and that the children often collaborate around a KidSmart computer. However, as also noted in Petersson Brooks and Borum (2014), only one child can take action at the time due to the WIMP (Windows, Icons, Menus, Pointer) interface. From the field studies it was noted that the children were skilled in sharing Apple iPads where everybody could interact simultaneously, but the interaction was however closed since every child who cannot find room around the screen.

Summing up on the insights from the field studies and adding that the organisational requirements for the designed environment is that it should be safe, reliable, inexpensive, and easy to setup, it was decided to focus on the Microsoft Kinect sensor as the vehicle for the design.

3.1.4 Field Studies: Children Personas

Based on the observations in the field studies a set of four personas was the derived in accordance with the Child-Persona Framework (Antle, 2008). Personas are archetypical representations of a user group that enables the designers of a product to empathise with the user. They do not necessarily need to be rooted in thorough user studies but they should concisely and accurately represent different user types (Norman, 2004). Antle (2008) has
emphasised that when creating child-based personas it can be difficult to transfer pedagogical, developmental and psychological theory into concept design.

Chapham and Milham (2006) bring to light another concern regarding personas and pointed out that personas are a tool for designers to better understand their user derived from large data sets and hence can easily result in the designer taking a step away instead of closer to the user. In the case of the current project the intention of the personas was to keep the Co-Creation Workshop with the pedagogues and student pedagogues focused and effective. The pedagogues were the designers and were presented with personas of children they know and work with everyday, hence utilising the personas mainly ensured that the concept design was aimed for a diverse sample of children.

![Diagram of the four personas mapped on the children's behaviour types grid](image)

**FIGURE 4 THE FOUR PERSONAS MAPPED ON THE CHILDREN'S BEHAVIOUR TYPES GRID (ADAPTED FROM GIELEN, 2010)**

To complete the four personas (see figure 5) they were formed and refined in accordance with the different behaviour types outlined by Gielen (2010) (see figure 4) and in line with Smith et al.’s (2011) categorisations of play types. The chosen play types were partially based on field observations questioning how did the children play and what play types could
This was combined with interview data with the kindergarten pedagogues focusing on which play types they wished to emphasise in their kindergarten. The play types that were derived were:

- **Fantasy play**: The children’s ability to decontextualize substitute objects into playing out scenarios. Fantasy play (or pretend play) is often of a social nature.
- **Rough- and-tumble play**: Includes play fighting and play chasing.
- **Play with objects**: Object play is often solitary but when social is requires shared attention and promotes for understanding of others.
- **Physical activity play**: Often occurs at playgrounds and includes exercise play such as jumping and running.

### 3.2. Co-Creation Workshop

The formed personas were used in order to kick off the development process at a co-creation workshop. All adult participants from the Idea Generation phase (45 participants in total) were invited to participate in a full day co-creation workshop where the aim was develop lo-fi prototypes of the environment together in mixed groups. The workshop was initialised with a presentation of the findings of the field studies, an introduction to low fidelity prototyping, and
an introduction to how play can inform design. The participants were divided into groups of approximately four people in each.

The task of the day was to create play frames (in Danish: “legerammer”) and games together in groups. Each group was assigned a specific persona and two play types that they should link together in a play frame. They were encouraged to consider how the specific persona could be motivated to engage in the specific play type. The personas and play types, along with the major learning goals from the ministry, were placed on the groups’ tables to refer to during the process (see figure 6). The participants also had a wide range of miscellaneous resources available for the production of the prototype including pens, paper, glue, LEGO®, toys etc. (see figure 6). During the day the participants were briefly introduced and had hands-on with design and technology driven prototypes in an effort to spark their imagination. The participants could decide to design for Kinect or any other of the play ware that was played with in the field studies. Four groups took on the task of designing for the Kinect. The Kinect groups had access to a researcher knowledgeable about the possibilities and limitations of the Kinect and hence could guide them through the process. The day ended with presentations from all groups.

3.2.1. Co-Creation Workshop Design Guidelines

The suggested game designs from the Co-Creation Workshop differed from one another and it was not possible to decide on one single design concept. The different suggestions did however bear commonalities, which were summarised after the workshop together with insights
from the field studies into a set of design guidelines for the environment development. The guidelines derived that the environment should:

- Be open-ended
- Support social learning and collaboration
- Promote spatial understanding
- Link digital and physical play in an easy accessible manner.
- Have a natural integration in the kindergarten
- Allow children to form personal narratives
- Support elements of construction play and creative expression
- Support elements of role play

In order to strengthen the concept design, the guidelines were combined with insights from literature. Antle (2007) emphasised that empowerment of children should be a design goal. She stated that children want to be in control of technology and hence an environment should provide options for the child to own and conquer. In addition, she explained that children are “natural born artists” (Antle, 2007, p. 6) who want designs that supports their creative expression. She also found that children use technology to build relationships and as means for strengthening their existing relationships. Gielen noted that when designing for children the aim should be towards creating coherence between the child’s motor, sensor, cognitive and emotional skills and the complexity of the system (Gielen, 2010). Reflecting on this, it was decided to narrow the target group and aim the environment design towards the oldest children in the kindergartens (age 4-5 year.)
4. Concept Development

The Concept Development phase included four iterations of which three were tested in four different kindergartens. The first couple of sections will cover the prototype concept and hardware. In the sections, presenting the individual iterations only changes and additions will be covered. Each session was video recorded from two angles and field logs were created immediately after. In addition, informal semi-structured interviews were conducted with pedagogues and student pedagogues. The interview focused on the pedagogues’ immediate feedback towards specific design attributes and the environment concept in general. The student pedagogues only participated in the first iteration as they lacked time for the following iterations. In the three iterations, there was a specific emphasis on usability of the environment. Each session had a specified game/system element in target to focus the evaluation.

4.1 Concept for Prototype

Insights from the field studies showed that often when the children stepped away from the activities guided by the play agent, they would tend to dress up and play out different roles e.g. as superheroes, pirates or princesses. In some instances, they would assign different objects as a makeshift stage to act on; other times they would just imagine the stage. This inspired the working design metaphor of an old-fashioned table theatre (see figure 7).

![TABLE THEATER AS DESIGN METAPHOR](image-url)
The resulting environment concept was an open-ended 3D drawing game, where the children could draw on a 2D plane, and then step behind the drawing, being covered by it or go in front of the drawing covering the drawing. As a consequence they could design and create their own theatre stage. The environment had three planes for the children to draw on (see figure 8). To promote a playful feel and easy integration in the kindergarten the digital "crayon" were balls. The intention was that it would emphasize the social interaction when passing the tangibles between participants and invite play.

![Diagram of interactive space](image)

**FIGURE 8 THE INTERACTIVE SPACE SEEN FROM ABOVE**

The concept idea was communicated through a mood board with a complimentary slide show to student pedagogues and pedagogues to enable practice-based feedback. The feedback was generally positive but also entailed considerations on the children’s ability to understand the spatial dimensions of the game. To accommodate this concern the colours on the screen were designed to gradually be lighter or darker dependent on where in the space the children draw as a means to guide their interaction.

### 4.2 System Specifications

The system can be categorised as a tangible augmented reality with an augmented mirror (Shaer & Hornecker, 2010). The hardware is a Microsoft Kinect that detects the balls through a
camera and depth map using computer vision. The augmented mirror is projected on a nearby white wall using a regular projector. The benefits of using an augmented mirror are that it creates a link between the person and the virtual self, so that so-called selfpresence emerges. According to Ulrike (2010), self-presence is when one perceives the avatar in a virtual world, as one’s own and the connection between avatar and a person is just an extension of the person. Self-presence relates closely to the feeling of agency when a person identifies oneself with an avatar one has control over. Mirroring is the feeling one gets when looking in a mirror or watches a projection of the self in e.g. digital games for the Microsoft Kinect. Mirroring is related to self-recognition and selfpresence and is believed to have a positive effect on the selfperception (Brooks-Gunn & Lewis, 1984).

4.3 First Iteration

The study in the first iteration was carried out early in the process and included a rapid prototype of the environment.

4.3.1 Setting, Setup and Participants

The first design iteration included a study that was carried out in a Kindergarten in Haderslev with three boys and three girls, 4-5 years of age. The prototype was installed in a physical play room, which allowed the installation to use a foam play mat to denote the interactive area. A projector was located behind the play mat. Codiscovery (Bruckman & Brandlow, 2007) and focus group interview (Sharp, et al., 2007) was utilized as the methods of inquiry. Three student pedagogues and one pedagogue assisted the children, carried out the interview and facilitated the test. Before the test, the pedagogues were introduced to the environment and provided with subjects of interest to talk with children about. After the session semi-structured interviews was conducted with the pedagogues in order to obtain their thoughts on the environment.
4.3.2 Usability Study

The focus in the first iteration was on two core functionalities of the game: a) size, shape and affordances, in other words the possibilities for actions (Norman, 1988) of the tangibles and b) the children’s understanding of the depth layers.

In the beginning, the children showed disbelief that the balls could be used for drawing:

“Writing with a ball, I don’t believe it” -Girl, age 5

The children were encouraged to explore the environment. One girl tried to control the game with body movement and was puzzled when it did react. The participants did not immediately associate the tangibles as input devices, however when the association was understood, the interaction was effortless (see figure 9).

The children quickly started painting and covered the screen in a big colourful blob. A problem occurred when the screen was filled because the only possibility for a clean sheet was to restart the system. There was no evident difference in how the children used the differently sized balls in the environment, but the larger balls elicited more play and exploration than the
small balls. The children used them to bounce on, roll on and involved them in their play (see figure 10). In general they seemed to get more immersed in the games with the bigger ball. The 3D space proved difficult for the children to navigate. It took some time for them to realize that the 3D space had three separate planes to draw on. With the facilitation of the student pedagogues they located one plane, which afterwards fostered different play activities with peek-a-boo as the most dominate in regards to time and engagement from the children. The children seemed to find it confusing with the additional planes and did not express any notice of the depth dependent colour graduation.

4.3.3 Insight for Second Iteration
The findings from the first iterations informed the second iteration with following points:

- Keep the balls as tangibles. They promote social play as intended.
- Use only large (soccer) sized balls. The smaller ones were difficult for the system to read, and did not elicit the same playful behaviours in the children
- Reduce number planes. The children found it difficult to navigate between three planes.
• Implement modular objects to support constructive play and creative expression. The children had difficulties with drawing specific objects.
• The depth dependent colour graduation does not add value to the environment.
• Incorporate a reverse or eraser function to keep the children engaged in the environment.

4.4 Second Iteration

The findings from the first iteration fed into the design of the prototype in the second iteration with a study conducted four weeks later.

4.4.1 Concept for Prototype

The concept of the prototype was the same as in the first iteration, however with adjustments. The number of planes was reduced to two to enable the children to easier navigate in the 3D space. The depth depending colour graduation was removed, as it did not seem to provide higher understanding. Two new functions were added:

• A Green ball functioning as an eraser
• Paper markers functioning as stamps on the screen.

A variety of symbols were chosen for the stamps with the general aim of them being generic and thus not effecting the creative expressions of the children and leading into specific themes. In this iteration the environment was scaled down to be suitable for three children at the time with one green ball, one blue ball and one red ball available to them.

4.4.2 Setting, Setup and Participants

The second iteration constituted two test sessions that was carried out in a Kindergarten in Ølgod with five girls and ten boys, age 4-5 years and in a Kindergarten in Kolding with three girls and three boys, 4-5 years of age. The setup was similar to the setup in the first iteration. The test was conducted in the kindergarten’s room for physical play. In Ølgod a foam mat and in Kolding a limited floor area indicated the interactive area of the environment and the projector was placed behind the children elevated above their heads to avoid shadows on the screen. In Ølgod one pedagogue took part in the introduction of the game to make the children
feel safe towards the researchers, but did not take part in the actual play session. In Kolding a pedagogue took part in the facilitation. In order to establish knowledge of the children’s understanding of the environment, the sessions were carried out using peer tutoring (Labrune & Mackay, 2005) and co-discovery (Bruckman & Brandlow, 2007) as methods of inquiry.

4.4.3 Usability Study

The focus for the evaluation of the second iteration was on the children’s understanding of the markers and on their understanding of the eraser function.

The children quickly understood the marker function and were excited about it. Some exclaimed that “it must be magic” and all elicited joy or curiosity when the markers were introduced which in all instances was well into the play sessions. However, while finding it fun and exciting the children seemed to quickly be bored with the markers. They had some difficulties with controlling the papers that the markers were printed on (see figure 11). They found that the system recognised the markers too slow and they expressed that they wanted to be able to change the markers to whatever they wished for. The intention with the markers was that the children would include the stamps in their play or that the stamps would open for the children creating playful scenarios. The children did not use the stamps as inspiration for play nor did they try to construct with the stamps. Rather it seemed that the children only found them interesting for a short while and would return to the balls hereafter.
The eraser function proved to be a great mediator for new play activities in the game. Often the children would initiate a tag-like game where the two children with the painting balls should hurry and cover everything up in colour, and the child with the eraser ball should prevent them from it by erasing everything (see figure 12). The ball was not introduced as an eraser ball but merely the children was encouraged to figure out what its function was through codiscovery. They often stated that the green ball must paint green, however it did not seem to frustrate them when finding out the true function of the ball. In line with Antle (2007) it came into play that the terminology and conceptual frameworks of the children are inherently different than those of adults.

Researcher: “What if you draw something you do not like?”
Boy, age 4: “Then I take a new paper sheet.”
Researcher: “What if you do not have a new paper sheet?”
Boy, age 4: “Then I draw on the other side of the paper.”
After talking back and forth with the boy it was discovered that erasers were an item the children collected and traded with each other and which function they did not think of. They instead considered the feature in the environment a “make-it-go-away-ball” or an “undo-ball”.

4.4.4 Insight for Third Iteration

Summing up on the play sessions, the children’s general impression of the environment was positive. The eraser function fostered playful interaction and initiated new play activities. The children did not find the marker and stamps iteration interesting for more than a few minutes. In addition the children noticed a few times that the system was lagging and a bit unstable, as a result of scanning for markers, and it affected their interaction to a smaller degree. Also the two planes did again prove difficult to the children. They would mostly play around one of the planes and only interact with the second plane by coincidence. This was the case even though the parameters of the planes (the position of the planes in depth and the overall depth of 3D space) were experimented with during the two sessions in order to see if it would make a difference. Building on this the next iteration should have:

- Reduced planes, so that the children should only focus on navigating between two layers and one plane
- Optimised programming to reduce lagging
- Optimised aesthetics and improve the reactivity of the System
- Taken out markers and stamps since it added no value to the children’s play experience

4.5 Third Iteration

Before the third iteration was carried out about two weeks later it was decided due to time constraints that this iteration would be the last play session before the final evaluation of the first design cycle. The aim was therefore to heighten the fidelity of the prototype and decide on functions that were redundant.

4.5.1 Concept for Prototype

Based on the findings in the second iteration the marker/stamp function was removed. In addition another plane was removed so the environment only contained one plane and two layers. Visuals and optimisation in the programming was added so that the drawing function worked more fluently. Instead of the children drawing directly on the augmented mirror, a visual skin was added so that it seemed as if the children were drawing on paper with themselves walking around on.

4.5.2 Setting, Setup and Participants

The study in the third iteration took place in a kindergarten in Oksbøl with 14 girls and five boys between 3-5 years of age. The setup was similar to iteration one and two. The area of activity was visibly marked and the projector was elevated above the children’s height. Using peer-tutoring (Labrune & Mackay, 2005) as a mode of inquiry, three children played together and should afterwards instruct the next three children. Each session, of approximately 20 min, was video recorded from two angles and afterwards a field log was created. One pedagogue took part of in the facilitation together with the researcher. A semi-structured interview with the pedagogue finalised the day.
4.5.3 Usability Study

A usability study was carried out to check if improvements in the programming and aesthetics of the interface eased the interaction for the children. It was also of concern how the interaction was affected by having only one plane to draw on.

The optimisation in the programming resulted in fewer exclamations from the children and less frustration about the system not reacting properly. Especially an optimisation in the code of the draw function enabled the children to draw a more intended line seemed to improve their interaction with the game. As indications of the change, the children would stand longer trying to draw a specific thing instead of just colouring the screen.

Another progress in the environment was the addition of a white background to improve aesthetics in the game. This addition however seemed to affect the affordance of the space. The children would in several instances walk up to the wall and try to draw there instead of in the space showing a discrepancy between the interaction possibilities and affordance of the environment. During the sessions the children would also drift towards the screen to an extend that was not seen in the other play sessions. The children also needed more explanation on how to draw in the space and found it difficult to navigate when drawing. The children elicited enjoyment towards the environment, but there was not any play activities emerging from the planes and layers. In this session play activities emerged from the tangibles instead.

The children would make up small games with sharing the balls and wordplays around changing balls with one another.

The conversations with the children and the afterwards interview with the pedagogue revolved around how auditory elements could be added to the environment. Both the children and the pedagogue had not noticed that there was not any audio in the environment. The children mainly suggested audio cues related to the tangibles such as “boing” and the pedagogue preferred that is should stay without auditory elements because it was different compared to other toys in the kindergarten. From the observations it was displayed that the children created and added their own sounds to their movements in the environment and from that new games and play activities could and would emerge. Based on these observations and statements, it was decided to not develop any soundscape for the environment in this cycle.
4.5.4 Lessons learned

Only minor elements were implemented for the final evaluation. They were:

- Take away white background as it produces a discrepancy between the affordance and interaction possibilities of the environment
- Further improve on programming
- Add a physical marker to the physical space to aid the children in locating the plane

4.6 Summary of the first design cycle

The three first iterations constituted the Concept Development phase of the first design cycle. In total 25 girls and 21 boys between 3-5 years from four different kindergarten play tested the environment in three iterations. In each iteration there was an emphasis on the evaluation of specific functionalities or affordances from the environment (see figure 13). Generally the findings from the studies in the iterations suggested focusing the system and having only few functions that supported open-ended play.

4.6 Fourth Iteration

The fourth iteration was designed to have identical features with the third Iteration, using the Kinect v2 hardware and SDK, is would work as a foundation for further development.
4.6.1 Concept for Prototype

The focus for the fourth prototype was to test the effects of the increased fidelity from the Kinect v2 sensor. The increase primary included improved resolution and accuracy of depth and colour frames from the sensor.

4.6.2 Evaluation of the Fourth Iteration

The increased resolution of the colour frame resulted in a decreased performance on available hardware, combined with the difficulty of obtaining compatible hardware for the Kinect v2 sensor, as a result; the fourth iteration was found unfit for further testing.
5. Results and Discussion

The design cycle concluded with an *Implementation* phase where a final evaluation of the accumulated changes applied over the first design cycle was assessed. With this being the last play session, the analysis moved beyond usability studies and instead focused on the learning potentials of the system.

This chapter will firstly present methods and procedure of the studies and move on to discuss the findings from the final evaluation in connection to related theory. The section will proceed to also question the methods applied in the design process and in the evaluation of the end product. Lastly, the significance and relevance of the study will be investigated.

5.1. Unit of Analysis

In order to evaluate the environment, two play sessions were carried out at the same kindergarten as the third iteration over two consecutive days. The session lasted two hours the first day and three hours and 15 minutes on the second day. In all 18 children (11 girls, 7 boys) between 3-6 years of age took part in the test. The children averagely spent 18 minutes and 54 seconds in the space. The children were accompanied by a pedagogue the first day but not the second day. The session on the first day was partially to create a sense of security in the children towards the researchers and the system so that the session on the second day could elicit a more natural interaction and partially to assess if the environment could produce interest beyond novelty effect. The children had no instructions apart from an encouragement to use the space as they wanted to and from the naturally emerging conversations between the children and researcher. The sessions were captured on video and a field log was completed. The video material was content logged and sequentially transcribed.

The video material was analysed for the children’s interaction with the system, with each other, and with the space surrounding them following a framed interpretation in line with Buur and Ylirisku (2007). The frame was derived from the grounded analysis (Buur & Ylirisku, 2007) of the field notes-and observations where it was evident that the five topics at the heart of playful learning developed by Price et al. (2003) was also represented in this study. The decision was supported by having prior experience with a framed interpretation in line with Price et al. in the assessment of children’s interaction with tangibles (cf. Borum, Kristensen,
Brooks & Brooks, 2014). The elements Price et al. deemed fundamental to playful learning were:

- Exploration through interaction,
- Excitement and engagement,
- Reflection,
- Imagination, creativity and thinking at different levels of abstraction, and
- Collaboration.

Utilising the five aforementioned frames as units of analysis a set of patterns in the interaction dynamics emerged. The children’s experience of the system and their demands (directly and indirectly) towards the system seemed dependent on whom they experienced it with. The children took on different roles in the interaction with the system and their learning outcome of the system appeared to be dependent on whether they were younger children together, younger and older children together, only older children together or children and adult together.

5.2. Learning Potential of the System

In chapter two it was presented that in the context of this project learning is to be viewed from social-constructivist perspective based on the theory of Vygotsky (1978). In Vygotsky’s interpretation learning occurs when humans construct knowledge and make meaning from the interactions with others and with objects. Vygotsky stated that learning is a social construct that develops with peers and more knowledgeable others and in close connection with the overarching surrounding culture of the child (Smith et al., 2011) (see figure 14). The notion of Vygotsky was supported in many instances during the study, as it was evident that there was a difference in the children’s interaction depending on whom they played with in the environment. The difference was clear when analysing for collaboration between the children. The focus here was on the sharing of artifacts, the children’s skills in receiving and giving instructions; their skills in turn taking and sharing roles, their skills in encouraging each other, and on their ability to scaffold on other children’s ideas.

In the design process it was decided to only include one of each type of ball as it encouraged collaboration and improved communication between the children. In several instances it also
led into play as the action of switching balls sometimes became almost a choreographed dance and other times became a game of tag.

5.2.1. Younger Children Together

With the younger children, the findings suggested that shared play activities were difficult without guidance from older peers, the pedagogue or the researcher. The environment did not assist them in reaching beyond their limits. This is a process that in Vygotsky’s perspective is crucial to learning as it advances a child from what they already master to what is next to be learned what Vygotsky termed the Zone of Proximal Development (ZPD) (as cited in Smith et al, 2011). Vygotsky (1966) argued that it is through play, where children can act out, that the ZPD is created and stated, “In play a child is always above his average age, above his daily behavior; in play it was as though he were a head taller than himself” (Vygotsky, 1996, p 16). Since the complexity of mastering the balls was difficult for the young children they seldom engaged in any peer activities or any play activities and hence it was difficult for them to progress their learning. The design goal for the system to be openended mistakenly affected the design so that there was not any support tools for younger participants. The system should have constituted a dynamic frame for the children to interact with (termed by a pedagogue in Danish: “at spille bold op imod”) including feedback that supports them in small advances in the
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development with the game. In that way the system enables a process that is referred to as Microdevelopment (Granott & Parziale, 2002).

Granott and Parziale define microdevelopment as the “the process of change in abilities, knowledge, and understanding during short time spans” (Granott & Parziale, 2002, p. 1). It is the small developments in expanding skills in a specific topic, which in this way relates closely with Vygotsky’s ZPD. In both microdevelopment and the ZPD, learning is considered to be a process that is aided by others, however in the instance with two younger children of equal skills being together in the environment, this aid should instead be substituted by the system. The present environment did not have aiding implementations which resulted in the younger children often only making use of a third of the screen where they were standing (see figure 15) and did not manage to engage in play activities with others.

5.2.2. Younger and Older Children Together

When the children in the space were of different ages the interaction with the system was richer. The older children guided the younger children and the younger children took their advice and advanced their play. The children engaged in a form of interim cognitive apprenticeship (cf. Rogoff, 1990), where the older children were masters and the younger were apprentices. In line with Bruner (Wood et al., 1976) the older children scaffolded, the younger children’s interaction and helped them engage in play activities. Based in the social-constructivist theories of learning and the theory of ZPD, scaffolding is the range of activities that the more knowledgeable other “build up” in the learning situation in order to support the learning of the child and to encourage the child to progress. In the current studies the use of peer-tutoring (Labrune & Mackay, 2005) established an effective foundation for the children to take on roles where they could help their peers. The children were eager to pass on their knowledge and a sense of ownership towards the situation was clear from their willingness towards the task. The tutoring children felt empowered in the learning situation.
5.2.3. Older Children Together

When older children were in the space together the play activities that emerged were often of a rough-and-tumble nature. Their movements were larger and their voices were higher. They often initiated goal-oriented play activities and were energetic in reaching the goals. They would often only be attentive to the environment for shorter time spans and seemed to quickly bore with possible actions of the system implying that the children did not feel properly challenged by the environment. Bruner (as cited in Smith et al., 2011) emphasized that learning happens through active participation with the world and Rogoff (1990) underlined that interest towards an activity is the prerequisite to flow (Csikszentmihalyi, 1990). According to Csikszentmihalyi (1990) a task should provide a balanced level of challenge in relation to the users skills in order to obtain a state of flow. A factor that was detrimental to the older children’s engagement with the environment was the lack of specific goals or interaction possibilities inside the environment. The challenge in the environment was to master the balls as tools for creative expression. The system however failed to move beyond that challenge. There were no additional challenges or tasks afforded by the environment.
5.2.4. Mastering the System

The system consisted of an interactive space provided by a Microsoft Kinect, a projected screen and three balls as input devices for the program. In this way mastering the balls was crucial to experience of the system. For all children they initiated the experience with a period of testing the balls. The older children quickly became acquainted and secure and started to explore the system by testing if the could read other objects. Bruner (1976, as cited in Smith et al., 2011) considered exploration to be involved in the mastery of tools. In line with Bruner’s notion of empowerment (as cited in Smith et al. 2011), the immediate response of the system lead the older children to repeat and practice with different objects giving them a sense of control of the system which in return empowered them through the mastery of the objects. This loop was indicated from the older children’s behaviour afterwards. They showed more confidence towards the environment and engaged in tutoring the younger children. They had clearly mastered the environment. As aforementioned, having mastery the balls as key to the interaction, the younger children were negatively affected. Many of the 3 year old children found it difficult to engage themselves if they were not guided by either the researcher or their peers. It was beyond their skills and level of abstraction to fully master the balls and it limited their experience.

FIGURE 16 GIRLS EXPLORING THE SYSTEM BY BALANCING THE BALL ON THEIR FEET
Another type of exploration was that the children investigated how they could interact with the balls in order to control the system. A common thing was to bounce the ball against the wall, to roll the ball across the floor, to bounce the ball up and down and similar actions, which a ball affords naturally (Norman, 1988). When the environment acknowledged their action, also referred to as meaningful play (cf. Salen & Zimmerman, 2003), the children generally showed signs of enjoyment and continuation desire (such as repeating the action, engaging in a new action). When the system did not respond to their action, they would generally show signs of frustration, boredom, or excessively repeat the action. The children also investigated if they could control the system with other than the natural interaction scheme of a ball. Especially the younger children tried to sit on the ball and roll on in with their whole body. The older children experimented more by utilising the ball in alternative ways by e.g. balancing it on their heads or feet (see figure 15). They also explored if the system was able to read any other objects in the room (see figure) The duality of the functionality of the ball, as a play object and an input device, was easy to understand for the older children whereas the younger children were puzzled by it and to some extend had difficulty using the ball as an input device. On the other side the duality also opened up for the younger children to engage inside the system even though they did not succeed in understanding intended functionality.

**FIGURE 17 GIRLS EXPLORING DIFFERENT OBJECTS AS INPUT DEVICES**
5.3 Limitations to the Experimental Design

During the three phases, Idea Generation, Concept Development and Implementation numerous choices have been made and hence numerous implications are open for discussion. In the scope of this report only a few selected are presented.

5.3.1 Method in the Design Based Research

The present study was carried out following the Design Based Research (DBR) paradigm, which presented itself with both advantages and limitations in the process. In DBR there is an emphasis on merging research, practice and design into one entity aimed towards extending current methodologies and theories in educational science (Wang & Hannafin, 2005). In order to reach this goal DBR research is often conducted in one setting, with one participant sample over a longer period of time (Wang & Hannafin, 2005). A limitation to the current study, especially in the development and implementation phase, was that since it was carried out in collaboration with the overarching Playful Learning Project orchestrated by UCSyd, a set of preselected test beds had to be utilised to an equally distributed extend. This meant that going in depth with the iterations was difficult. Some time had to be spent building trust and comfort with the children in each iteration. The change of test beds possibly also posed a higher risk of Hawthorne effect (Adair, 1984) and novelty effect (Fraenkel, Wallen & Huyn, 2011) than if repeated studies at one test bed had be carried out.

However posing a limitation to the last two phases of the process, the large participant number and diversity in test beds, made it possible to broaden the understanding of on-going practices and establish grounded requirements in the Idea Generation phase resulting in empirically based personas and a strong basis for the Concept Development.

A ground principle for DBR is that it underlines an iterative design process and allows for flexible and mixed methods (Andersson & Shattuck, 2012). As pointed out by Dede (2004) the many iterations open for possible weaknesses in the design process when it comes to deciding whether or not a decision was right. A number of choices were made during the process; some empirically based, some design based (functionally vs. aesthetics) and a few based on prior experience from working with children through the years. Dede (2004) calls for standardised methods on how to assess that each design decision is effective. In the present study the attempt to overcome this obstacle was to qualitatively test each design decision on-site with the children.
from the Idea Generation phase. However having the limitation of a new test bed in each iteration, it was an advantage that DBR allowed for flexible methods as each test bed needed to be approached differently. For each play session a thorough plan A and B was laid out before going, and in many instances plan B came to play. Regardless of thorough plans improvisation was still needed in a few instances and in this regard it was necessary to have a mental map of different methods ready at hand. As noted by Veale (2005), working with younger children calls for equal amounts of preparation and flexibility. In order to ensure to be effective and for surprises to not be detrimental to the research, in future studies such a mapping of tools should rather be sketched out to function as a real toolbox in the tests.

5.3.2 Grounds for Biases

As outlined earlier in this document by Read and Markopoulos (2013) one of the major challenges in Child-Computer Interaction (CCI) and Interaction Design with Children (IDC) is to include the gatekeepers of the children (pedagogues, parents, teachers etc.) in the design process and hence give empowerment of the development and thus also ensure long term implementation of the design outcome in the setting. Having this in mind; inclusion of the kindergarten personnel was an aim during the whole process of the project. Again having the large participants set challenged it, but it was especially accommodated in the Idea Generation phase where each kindergarten had three field observations and all pedagogues were invited to take part in the co-creation workshop. A challenge in this regard was to keep all pedagogues included and interested in the project even though their idea was not necessarily picked for the further development. In the Implementation phase it was noticeably easier to make appointments with pedagogues whose ideas were visibly part of the final development. Even though the pedagogues seemed to have a pedagogical focus in the interviews after the sessions, it poses a possible risk for bias in the findings.

Another risk of bias that attention is needed for is researcher bias. In this project the researchers have taken on roles as both designer and facilitator. Staying objective to both the design process and evaluation process has been of high priority but it still constitutes a risk. In order to minimise the risk in the Idea Generation process, the pedagogues took part in sessions with video reviews of data. In the Concept Development process and the evaluation of the
iterations the pedagogues were interviewed for their immediate feedback after the sessions. In
the final Implementation phase video review sessions would have been carried out again, but it
was not possible to arrange with the pedagogues.

5.3.3 Sample
A final limitation to the study to be discussed here is the sample of participants. The study
was carried out in Southern Jutland Denmark in five different towns and villages with 55
children and their pedagogues. The children were chosen for participation by their pedagogues
on the basis of subjective criteria. As such, the findings in the final evaluation are only
applicable to this sample and should only with great care be transferred to other studies. Often
studies within the DBR paradigm result in a set of design principles or a model for the field it
investigates but I do not see the empirical grounding in developing such principles yet.
Tendencies from the findings outlined in the discussion should constitute the foundation for
further investigation. The findings related to the Idea Generation phase, including the
experience from utilising methods inside the DBR paradigm and CCI framework, were
grounded empirically in repeated settings and are hence open to replication if the selection of
the sample is taken into consideration.
5. Conclusion

This report set out to investigate how children in early years education in Denmark explore and play with digital technology, and to let this knowledge feed into a practice-based design of a playful interactive environment.

The findings from the field studies were derived into four children’s personas, which then informed the development of a playful interactive environment. The pedagogues were included in the design process. The first design cycle consisted of three iterations where different functionalities were checked for redundancy and usability, and new generation hardware was assessed for further development. The resulting prototype was play tested and analysed for playful learning potentials.

The play sessions indicated that the children’s experience and interaction with the system was reliant on whom they played with and to what degree they succeeded in mastering the tangible input devices. The tentative findings also showed that there is a need for an environment aimed towards kindergarten children to support different levels of complexity in the gameplay in order to stimulate children at different developmental steps.

In this project there was a goal of promoting social and kinaesthetic play through the environment. Having this as a foundation the systems should ideally support both novel and expert users to engage and include various types of children. In addition, for all children to be able to master a new input device such as the balls in this system, introduction is needed in the form of a playful tutorial within the environment. If the pedagogues should provide the directions, the environment hardware must be provided with clear instructions for the pedagogues.

There was a visible need from the children for the pedagogues to step in and guide them in the interaction. In order to advance the children’s learning the system should be able to substitute for the lack of knowledge (or self-confidence) in the pedagogues.

Due to limitations in the experimental design the findings in this project should only be referred with care.
6. References


years with “the Scandinavian IT Design Model”. *Proceedings of NordiCHI 2000*, 1-9.


