TableCanvas: Remote Open-Ended Play in Physical-Digital Environments

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Figure 1: Collaborative play between spatially separate locations, using a projected tabletop (image 1/3) and an iPad (image 2/4). Left: the users have improvised a Tic-Tac-Toe game using physical Lego bricks and virtual stickers. Right: the iPad user is building a virtual road, which the child on the physical side uses as a drawing template.

ABSTRACT

Remote video communication is now part of everyday life, also for families. At the same time, children encounter digital devices at an early age, but studies indicate that physical play is still vital for their development. To support physical play at a distance, we introduce two prototypes build around projection displays, WallWizard and TableCanvas. Both allow users to play together remotely by combining physical and digital elements on shared surfaces. We evaluated our prototypes through an expert review, and, based on this study, we elaborate further on TableCanvas. We conducted a second qualitative user study with an updated prototype, focused on evaluating the remote aspect. The overall feedback was positive and suggested that the concept could facilitate and promote open-ended play, as well as support a successful remote play experience. Users also indicated additional potential use cases for board gaming, education, and work-related tasks.

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1 INTRODUCTION

Play takes on an important role in children's upbringing as it contributes to the development of their creativity and problem-solving skills, as well as the development of social and cognitive characteristics. It also plays an important part in children's enjoyment of life. Throughout the last century, there have been a number of researchers that investigated play from various perspectives and disciplines, e.g. Whitebread's definition of five play types: physical play, play with objects, symbolic play, pretend play, and games with rules [26] (which build on earlier seminal works by Huizinga [15] and Callois [6]).

Physical play includes everything using either the whole body, such as dancing, or fine motor activities, e.g., sewing or drawing. Play with objects links to physical play and can be anything from building models to playing with LEGO figures. Symbolic play is when using sounds, words, objects, etc. to convey meaning, e.g. using a banana as a telephone. Pretend play is playing out imaginary scenarios, such as "the floor is lava" (sometimes referred to as pretence/socio-dramatic play). Lastly, games with rules includes both rules that are set from the beginning, like in board games, but also when children make up the rules as they go, e.g., deciding in the middle of the game that one can touch the "lava" once.

Pretence/socio-dramatic play is also sometimes described as free play. Free play is often associated with open-ended play, as free play has a structure that is negotiated and developed by players throughout the game [7].

Open-ended play applies simple rules and provides players with the freedom to create their own challenges and goals [8]. Bekker et al. conducted a study [3] to investigate how interactive objects that facilitate open-ended play affect social interaction and fun for children between the ages of 7 and 11. The study revealed that children had the most fun when devising their own game rules and that they enjoyed playing their own games. As open-ended play with interactive objects allowed creativity, children found it more fun, and the fun lasted for a longer period of time.

When the COVID-19 pandemic started, opportunities for physical play between children became limited. Children had to socially distance themselves from friends and family, precluding hobbies and other social activities. Nevertheless, various online games and video conferencing tools allow children to play together and communicate remotely. As a result of the pandemic, remote communication has become increasingly common in today's world for people who work from home or have relatives in geographically dispersed areas. This allows individuals to stay connected despite physical distance. However, with the currently available video conferencing tools, remote communication has its challenges, such as a lack of nonverbal cues, and difficulty establishing trust and rapport [16].

Although currently available technologies support remote communication and online collaborative gaming, the physical aspect of play is lacking. As playing with physical objects is proven to positively affect children's fine motor skills, such as hand-eye coordination [21], this is something that should be considered in remote communication. Livingstone and Pothong also suggest that there should be a contemplation of combining the design of free play in physical and digital environments [19]. Physical-digital play offers a new opportunity that combines the best of both worlds, allowing players to engage with physical objects and spaces while also enjoying the interactivity and engagement of digital media. Examples of physical-digital play include games like Pokémon Go, which uses augmented reality technology to overlay digital characters onto real-world environments [18]; and board games that incorporate digital elements like interactive screens or companion apps, e.g., the escape room board game Unlock! [2].

Taking into consideration the importance of play for children's well-being and how play has been transformed through the technologies and circumstances we have today, this paper will aim to answer the following research question: *"How can connected physical-digital environments support open-ended play?"* We chose families with children between the ages 7 and 11 as our target group, as children at this age have developed the cognitive capacity for open-ended play, i.e., to create their own rules [1]. We first evaluated two concept variations through an initial user review and an expert review. Based on the insights from the reviews, we focused and iterated on the second variation, which was then evaluated in an in-the-wild study with a focus on the remote aspect.

2 RELATED WORK

This section presents related studies in the field of Human-Computer Interaction (HCI) that have investigated how to support open-ended play, physical-digital interaction, and remote interaction.

Open-Ended Play. Looking into supporting open-ended play remotely, Rinott and Umanski presented and evaluated the Drawbox project that supports open-ended play over distance [22]. Drawbox is an installation located across two museums that allows children to scan their drawings into a shared graphic world that is projected on a wall. Through observations, the authors concluded that Drawbox supports spontaneous playful dialogue. They also raised a design challenge that needs to be considered when designing for open-ended play over distance, i.e., maintaining the balance of interest and awareness of updates on the shared graphic space, while not taking away the focus from the local drawing experience. Follmer et al. introduced and examined three augmented games for long-distance family relations to play together while video chatting [13]. These games were simple games and consisted of, i.e., finding a specific object, dressing up like animals with digital masks, and peek-a-boo. The study concluded that augmenting open-ended games on video conferencing tools supports families to connect and enhance conversation over distance in a playful manner.

Physical-Digital Interactions. In terms of physical-digital interaction, several studies have explored what designers should focus on when designing physical-digital experiences for different contexts, e.g., museums, work, and games.

Jürgen et al. explored usage patterns of physical and digital media on an interactive tabletop. Based on the results, they recommended the need of supporting the physical interaction space in other dimensions and enabling efficient interaction with items, e.g., moving them in order to bridge the gap between the physical and digital world. [23]

Another study investigated supporting co-located play for children by creating an interactive play space: KidsRoom [5]. In this study, an immersive and interactive bedroom was created with movable furniture and projections on the walls and floor. They focused on augmenting digital elements in a physical space using images and music. KidsRoom provides a unique and immersive environment for children that combines fantasy and theatre, as well as giving the children the opportunity to collaborate. In the context of games, projector based systems have been used in several studies [4, 12, 24, 28], which explored how this kind of set-ups could contribute to remote collaborative play. Benko et al.'s [4] study validated that their projector-camera system can simulate play scenarios and support interactions from computer screens to a physical space. Yuan et al.'s study [28] concluded that projector based systems have the potential to support social interactions, and they highlighted alternative improvements for better social experiences.

Another study from 2020 [20] evaluated the use of shared tabletops for remote board gaming with 20 participants in pairs of two. The study concluded that the setup with a shared tabletop can serve as an equivalent alternative for face-to-face board gaming. This does, however, have the limitation that it is only working for games that do not require an exchange of physical objects. This will be decided by the game rules.

Enhancing Remote Interactions. Regarding remote interaction in the field of HCI, Yuan et al. conducted a study [28] investigating design opportunities for remote collaboration in tabletop games. Through a qualitative approach with 15 user interviews, they made several suggestions when designing a shared game space.

It should allow customisation of gameplay, e.g., being able to change the game rules in order to tailor the game experience to people's needs and preferences, thus, providing a better experience. There are several systems and toolkits that support the mix of physical and digital elements remotely, tabletop sharing being an interesting example. ShareTable [25] facilitates this by allowing users to project and share their tabletop with another person. This way, the user can use the physical objects in front of them, while also being able to interact with the digitally projected objects from the other person's tabletop.

Junuzovic et al. studied eight pairs of children between the ages 9 and 11 who played with the authors' shared surface device, IllumiShare. The authors analysed what benefits their shared surface offered [17]. The study showed that the children quickly understood how to use the device, and they were able to modify the rules of some of the games that they were presented with, so that the games would fit the shared surface.

Furthermore, Yarosh et al. conducted an exploratory study with children [27], exploring how 13 pairs of friends would play together using four different prototypes of video conferencing devices. The authors discovered that there was a lot of individual variability, and children were able to play together using video conferencing devices. This was, however, not as easy as in face-to-face communication. The authors argue that supporting free play across distance has the potential to increase social interaction.

3 CORE INTERACTION CONCEPT

Our core concept is based on the premise of "surface sharing", in which two or more devices (e.g. interactive tabletops, tablets, VR headsets) share a common interactive surface, and all actions from one user - whether physical or digital - are visible to all other users. This approach provides more freedom and better supports open-ended play than other, more structured physical-digital games with fixed rules.

For our scenario, we focus on an asymmetric setup with one projector-camera surface and one tablet, which represents e.g. a remote relative playing with a child at home, or a sick child in hospital playing with a friend. This concept allows one of the users to manipulate the projected surroundings through the tablet and thereby co-create a personalised play scenario with the other user at the projected surface. To this end, the tablet user can customize the projection view using draggable stickers, drawing tools, visual effects, and backgrounds.

We provide a selection of custom backgrounds as well as customizeable stickers. The stickers allow the creation of multiple instances; resizing, rotating and deleting them; being able to confirm so that the new sticker is "pasted" onto the background; as well as being able to rearrange the sticker if needed. Besides manipulating stickers and customising the background, we added another interaction to create temporary effects, e.g., lightning, rain, or fire, through tapping. This provides the tablet user with additional opportunities to play together with the other user on the projected interface.

Variation 1: TableCanvas. This variation allows the tablet user to view the tabletop from a bird's eye perspective. With the tablet application, the user is able to design their own play environment using the features mentioned above. This was inspired by the observation that children build their own environments when playing e.g. with LEGO bricks. With the tablet application, the user will be able to, e.g., add a digital lake to a physical dog park that they built.

Variation 2: WallWizard. Our second variation on the core concept, *WallWizard*, shows the projection from the side instead of from the top. This variation allows the user to make a vertical play environment together while one is using physical toys, e.g., LEGO builds, and the other is using digital elements on a tablet, and creates a "digital stage" for the physical play environment.

For demonstrating our two variations, we developed a web-based application that allows interaction on tablets remotely, using the aforementioned features such as stickers, drawing tools, and backgrounds. Besides showing the video stream of the remote tabletop surface, the web interface also displays a regular videochat. The system is built on the SurfaceCast platform [10, 11].

3.1 User Review

To evaluate these two concept variations, we conducted an initial user review with two children aged 10 and 8, using a prototype demonstrating the two concept variations. Parental consent was obtained before the study, and the children were given chocolates as a thank-you afterwards. The participants were introduced to both *WallWizard* and *TableCanvas*. The objective was to explore how the children would interact with the prototype and how they would perceive and act with the concept. We also wanted to explore how intuitive the concept is for children.

We chose to use the Wizard of Oz method [9] and a co-located setup, as some features were not implemented yet. We conducted an initial user review of the prototype at this early stage, as this would give us valuable insights for further exploration of the concept. For the setup, several LEGO sets were provided for the participants to play on the shared tabletop, and a projector was connected to the SurfaceCast system which displayed the shared canvas.

The participants were introduced to *WallWizard* and they then started interacting with the prototype. When testing *WallWizard*, one of the participants was asked to "just play and build" with the toys on the table as she saw fit, and the other participant sat with the tablet application and was prompted to try out the features on the application.

After the participants finished reviewing the *WallWizard* prototype, the *TableCanvas* prototype was introduced. When testing this, the two participants sat at a table with the SurfaceStreams system and were given the LEGO sets previously used. As not all features were fully implemented, the facilitators took charge of the tablet application to change the background and stickers on request from the participants.

Insights. The two participants quickly engaged in playing together after sticking to their own game for a while. When asked what feature was their favourite on the tablet application, they mentioned the stickers, as this allowed them to set up and customise their own world. However, based on the observation, the most used feature was the effects, which were used eagerly to tell stories and create virtual effects to highlight what happened in their stories.

When first interacting with the *WallWizard* prototype, the participant using the application quickly learned how to use the system without any major issues. Even though there were some problems in the beginning with the girls playing separately, possibly because it was their first time meeting, they quickly opened up to each other and engaged in collaborative play. The participants talked to each other about moving toys around or using a specific effect on the screen to make their own stories together. This suggests that the prototype supports co-located collaborative and open-ended play as well as a common understanding of the play session. When interacting with the *TableCanvas* prototype, the children engaged in collaborative play immediately after they started.

During the later stage of the play session, the participants chose to leave the tabletop and draw a more customised world on a nearby whiteboard where they continued their game. While this happened later in the play session, and they might have lost their attention, this suggested that a drawing feature might be a valuable addition to the application.

The use of LEGO sets seemed to be a distraction for one of the participants in particular. Further tests could include different forms of toys, e.g., board games, wooden cubes, or pen and paper, to explore their effect on the children's creativity. Overall, the participants enjoyed both concept variations, even though some features were missing or not performing optimally, and more features needed to be added for a more satisfying experience for open-ended play.

3.2 Expert Review

Following the initial review with two children, we also evaluated the concept variations with employees from LEGO´s Kids Technologies department who are experts in developing digital interactive products for children. Eight employees joined the expert review. The employees had different roles in the company, but all were related to digital product development.

A portable version of SurfaceCast, consisting of a small projector, and camera, was used for this review. The prototype was set up in a meeting room with a round table where the participants could easily move around and interact with the prototype from all angles.

During the review, each participant was introduced to the prototype and the idea behind the concept before they started interacting with the prototype. The participants were continuously joining the review at different times, and they were interviewed in an unstructured manner. They were encouraged to ask questions about the concept and think aloud while interacting with the prototype and trying out the different features.

Insights The feedback from the interviews was overwhelmingly positive and the participants could see the potential use cases of the concept. For instance, P1 mentioned that his son wanted to build a track for his LEGO train but he refused to build the track with LEGO bricks or cardboard. P1 suggested that this case would be suitable for utilising the *TableCanvas* to build a digital track instead.

Both *TableCanvas* and *WallWizard* were evaluated during this review, and seven out of eight participants preferred *TableCanvas*, as it is more flexible and easier in terms of the setup, and it inspires additional use cases. For example, one participant suggested that *TableCanvas* can be used not only in *playing* together, but also building LEGO together where the one with the tablet can help find the right bricks for the one that is building with the LEGO set. Moreover, the participants suggested alternative contexts of use for the *TableCanvas*, e.g., in kindergartens; between school classes; or as an installation in a public space.

4 STUDY 2: TESTING TABLECANVAS "REMOTELY"

In the initial user study, we received positive feedback when testing with parents and children in a co-located setup. Our second study focuses on the remote aspect, to validate if people are still positive about the system in a remote setup.

Taking the insights from the expert review into account, we decided to elaborate on *TableCanvas*. This iteration resulted in a refinement of the physical setup and an improvement of the tablet application. For the application, we implemented two additional features: brushes for drawing, and a "clear all" button for removing all the stickers and drawings on the digital canvas. The brushes enable additional creativity and freedom for playing together, and the clear all feature makes it easier and faster for the user to remove multiple elements at once. The study took place at the main library in Aarhus, Denmark during Maker Faire, a creative festival for families to explore crafts, art, and technology with a hands-on approach. Therefore, we decided that this would be a suitable environment for testing with children and parents instead of a laboratory setup. Over three days, 12 test sessions were conducted with 22 children and seven adults (see Table 1). Since it was a public event, we aimed to have each session last from 15 to 25 minutes.

To mimic a remote scenario, two tables were placed with a partition screen between them. The SurfaceStreams system with the shared tabletop was placed on one table, along with LEGO bricks, coloured pencils and paper, and the tablet was placed on the other table (see Figure 2). This way, the participants could only see each other through the webcam feed but could still talk together.

This allowed us, as facilitators, to observe participants on both sides and provide assistance or answer questions. Each test session was observed by one main facilitator and one observer. The observer was responsible for taking notes as well as capturing pictures of the interactions. To familiarise the participants with the system and encourage them to play with each other, we started each test session by prompting them to play Tic-Tac-Toe using the system (with physical tokens on the tabletop side, and drawings on the tablet side). Afterwards, the participants were encouraged to start their own play and use the system in whatever way they wanted.

Insights. During the study, we observed that there was great potential for open-ended play using a shared tabletop and a tablet. Some of the interactions we observed during the test sessions were: physical drawing by tracing the digital elements on the table; playing games using stickers and brush strokes; creating effects (e.g., explosions) using the brush feature; and creating a world together by combining physical and digital elements (see Figure 2c).

Another focus of this study besides the remote aspect, was to test whether the system is intuitive for new users. This was quickly confirmed, as all participating children within our target group seemed to grasp the concept fairly early in the session. Several participants did not even need an introduction before they started using some of the features on the tablet application. Some participants, however - younger children below the age of seven and some adults - did need a more in depth introduction. As soon as

(a) The tablet application side **(b) The shared tabletop side** **(c) Child playing remotely with his sister, showing her where to place digital elements on the table.**

Figure 2: The test setup at Maker Faire in Aarhus, Denmark

the participants understood the concept and its features, they had a tendency to elaborate on the Tic-Tac-Toe prompt by switching out the objects, e.g., by using the tree sticker instead of the brush feature. Other participants quickly began playing their own games, using the physical and digital elements, e.g., creating a track for the LEGO Super Mario. During the play sessions, some participants, both children and adults, were eager to see what happened on the other side of the partition screen when they either used the different features on the application or when they moved some of the physical elements around on the table surface.

Another noteworthy insight consisted of a few participants trying to manipulate the digital elements on the physical side of the setup, e.g., by trying to drag a sticker around on the table surface or trying to resize it by pinching the image.

When considering collaborative play, the number of participants and the relation between them varied. Through the 12 test sessions, we tested with different combinations of participants including children with their friends, their siblings, and their parents (see Table 1). From the seven test sessions we conducted with parents and children, we observed dynamic interaction and communication through the system, and we received positive feedback and high interest in using the system. For instance, in Session 4, the father drew tracks and boxes on the tablet and asked his son to place the physical LEGO Super Mario objects on the drawing. Another frequently occurring co-play interaction was parent/child dragging a sticker onto the digital canvas and child/parent drawing along it on the table surface.

Co-play between children using the system was also evaluated with four sessions. We ran two sessions with two children and two sessions with four children. In general, children had fun playing with their friends and got inspired by each other when using the system. However, there were more conversations happening with co-play between four children than between two children. This might be due to when sitting alone on one side of the table, the child was more afraid to speak loudly to his friend on the other side in a public space. When it came to the four children and having a friend sit by their side, they were more willing to speak up and start a conversation in the public space. For the sessions with four children, they were divided into two, sitting on each side of the partition screen. During the play session, we observed different ways of playing with friends through the system and dynamic communication both with the neighbour and friends on the other side, e.g., a boy asked his friend on the tablet side: "Place it [the sticker] on the paper so I can draw on it". They inspired each other on various ways of playing, and they were excited to get noticed and show their creations to their friends on the other side. For example, a boy from Session 1 said "We can make it [the sticker] big so they cannot avoid seeing it!". However, after 10 to 15 minutes, the communication and co-play with their friends on the other side decreased and they spent more time playing with their neighbour instead.

Overall, the participants understood the system and found it entertaining, and they managed to create their own games when playing together using the system. Furthermore, the participants and secondhand observers suggested alternative use scenarios for the system in relation to board games, education and work.

5 DISCUSSION & LIMITATIONS

Here, we summarize noteworthy discussion points regarding the concepts and study setup. We focus mostly on study 2, as this is an in-depth concept evaluation with target users and targeted on the remote setup, while study 1 focused on validating the basic feasibility of our concept. In both studies, we observed that the proposed concept, *TableCanvas*, enabled both children and adults to create their own games and play together. The test participants discovered different ways of using the digital elements on the tablet application and the physical toys to play with their playmates on the other side, e.g., by elaborating on the Tic-Tac-Toe game. This suggests that *TableCanvas* can provide children with freedom for open-ended play and facilitate collaborative play at a distance.

In study 2, most of the participants were successful in creating remote open-ended play. In the initial setup for this study, noise-cancelling headphones were meant to be used to best mimic a remote scenario. However, due to technical issues, we were unable to use the headphones for the test sessions. Hence, when a participant wanted to communicate with the other participant on the other side of the partition screen, they needed to raise their voice to be heard. This might have led to some participants being less willing to communicate with each other, and the communication was indeed less frequent in some test sessions. Without the headphones, the remote setup was less realistic for the user review which might affect the test results. Still, the partition screen effectively helped mimic the remote situation by blocking the participants' view of each other and requiring them to interact via the system.

During Study 2, we sometimes noticed a lack of communication and collaboration between the participants on the different sides of the partition screen, i.e., what started as social, collaborative play turned into solo play with digital and physical elements respectively. This sometimes led to the tablet user covering what the other person had created, e.g., with stickers or brushstrokes, not noticing the physical elements on the tabletop. We also noticed that it was easier to communicate with the neighbour than with the player(s) on the other side of the partition screen. In sessions 1 and 3 we observed that the play session started out by involving everybody, but as time passed, the participants began to focus on their neighbouring playmate, and they neglected most of what was happening on the other side of the partition screen. Several other papers that investigated remote play have also noted the trend of losing interest or focus during the use of remote interactive tools [27].

Playing together is a cognitively exhausting activity, especially when you also have to understand what the user on the other side is seeing and doing. The children that were most successful in creating a collaborative play session kept talking together and were curious about what happened on the other side of the partition screen. This taught them that when they moved one thing on the tablet application, this would also move on the projection on the tabletop. It is important to create a common understanding for the users of what is happening, and what they are seeing. While we were mostly successful in supporting this, there was still latency in the system that might have caused some issues in creating a common understanding. This might have been the reason why some younger participants ran back and forth to check what was happening on the other side of the partition screen.

The tablet used in study 2 was laying flat on the table, making it difficult for the camera to capture the face of the user. Therefore, the user on the tabletop side would not be able to immediately see their playmate and notice their social cues. Gaver et al. argue that even though most users of multi-display devices prefer a task-centred view, face-to-face interaction and social cues are still important for fulfilling a shared task. [14] Even though we got some insightful results and feedback, the experience could have been enhanced by better displaying the video feed, as well as placing the tablet on a stand or a tripod so it would be easier to get a front view of the participant's face to better support face-to-face communication.

Another observation we made in our initial user review was that some of the toys could be too distracting. For our first test, we used the LEGO Super Mario Set, which took too much attention from one participant. This led to her completely overlooking her playmate, and only focusing on playing with the toy. To avoid this, we brought several other items to the second user review, e.g., paper, pencils, and plain LEGO bricks. Another aspect to consider is that the two children participating in the initial user review had never met before. This could possibly have affected their willingness to engage with each other during the earlier play session, as they were more engaged in playing together later in the play session.

6 CONCLUSION

Throughout the duration of this project, we have aimed to answer the following research question: *"How can connected physical-digital environments support open-ended play?"*

To answer this question, we started with the core concept of "shared surfaces" and developed two variations, *TableCanvas* and *WallWizard*. With a setup focusing on mimicking a remote scenario, we evaluated the iterated version of *TableCanvas* with families and children. The participants found the system intuitive and showed great interest in playing together using the system and creating their own games. They also showed great interest in using the system in other scenarios such as education, board games, and work in both remote and co-located settings. Based on our insights, we suggest that *TableCanvas*, together with a projector-based shared tabletop system, can facilitate remote physical-digital play and support open-ended play, and we hope that this concept can inspire further research in this area and encourage alternative ways of using projector-based physical-digital communication devices.

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A STUDY 2 DEMOGRAPHICS

Session	Paticipant	Age	Relation
1	Child-1A	11	Friends
	Child-1B	11	
	Child-1C	11	
	Child-1D	11	
2	Child-2A	10	Friends
	Child-2B	9	
3	Child-3A	11	Friends
	Child-3B	12	
	Child-3C	11	
	Child-3D	11	
4	Adult-4A	-	Parent - child
	Child-4A	6	
5	Adult-5A	-	Parent - child
	Child-5A	10	
6	Child-6A	13	Friends
	Child-6B	14	
7	Adult-7A	-	Parent - child
	Child-7A	12	
8	Adult-8A	-	Parent - child / siblings
	Child-8A	6	
	Child-8B	9	
9	Adult-9A	22	Cousins
	Child-9A	11	
10	Adult-10A	-	Parent - child
	Child-10A	8	
11	Adult-11A	-	Parent - child
	Child-11A	12	
12	Adult-12A	-	Parent - child / siblings
	Child-12A	10	
	Child-12B	7	

Table 1: Demographics of participants from Study 2