Summary of TableCanvas: Supporting Remote Open-Ended Play in Physical-Digital Environments

After the COVID-19 pandemic, numerous remote communication technologies arose and researchers from the field of Human-Computer Interaction continue to investigate how to improve remote communication by combining video conferencing with other technologies. One of the aspects is looking into how shared tabletops can enhance remote communication and further support collaborative play remotely. As play is important for children's development and they are used to digital devices, we wanted to explore how technologies support play remotely.

For this project, we aimed to research how physical-digital environments can support open-ended play remotely. To do so, we took a basis in our preliminary study, in which we had developed and evaluated two concepts that let users play together remotely, using the shared tabletop system SurfaceStreams. In the first iteration of this project, we selected one of the previous concepts and created two variations of it. These two variations were called *WallWizard* and *TableCanvas*, and both consist of a tablet application. The basis of the two variations is to enable children to play together remotely while one is manipulating the digital surroundings of their play environment, and the other is playing with physical objects on a shared tabletop: *WallWizard* lets the user design a vertical background for their play scenario, and *TableCanvas* lets the user design a horizontal background. The tablet application for both variations includes the following features: choosing a background; drawing on the background; and placing stickers.

The two variations were evaluated in a pilot test with two children aged 9 and 10 to get an understanding of how the children perceived the system; if they would be able to use the system, and if it could support open-ended play. Even though we discovered some challenges, both variations showed potential. To further evaluate the concept, an expert review was conducted with eight experts from the Kids Technology department at the LEGO group. These experts were chosen as they are familiar with creating and improving digital products for children. After getting the experts' view on the two variations, *TableCanvas* was selected for further iteration seeing that this showed the most potential in supporting remote open-ended play.

A second user study was conducted at Dokk1 in Aarhus at the creative festival, Maker Faire. This location and event was chosen as we wanted an informal setup rather than a typical laboratory setup, and the event allowed us to recruit families with children constantly. The goal of this second study was to further explore the potential of the concept while also validating the remote aspect of the system. Two tables were placed in front of each other with a partition screen between them. The SurfaceStreams system was placed on one table, and a tablet was placed on the other. This allowed us to simulate a remote setup where the participants were not able to see each other physically but were still able to communicate verbally. Different tools were placed on the SurfaceStreams side of the partition screen, e.g., LEGO bricks, paper and pens that the participants could use freely.

28 users participated in the test, including pairs of friends, families and siblings. The test was conducted as a semi-structured workshop. Each test session started with a game of Tic-Tac-Toe to familiarise the participants with the system and the tablet application. Following this, the participants were nudged to use the system as they saw fit, while we, as facilitators, observed the test sessions. Throughout the test, the participants found the system intuitive and enjoyed playing with their playmate on the other side of the partition screen. They invented different kinds of games by either elaborating on the Tic-Tac-Toe game or using the given tools on the table and the features on the tablet application. This suggested that the system succeeded in supporting open-ended play in a remote scenario. Additionally, the system attracted some secondary observers, and they could see the potential of using the system in other scenarios, e.g., board gaming, education, and work, either co-located or remotely.

Some notable problems that were observed in the second study indicate that some of the participants lost interest in using the system. The users that were most successful in creating open-ended play and kept playing were the ones that kept communicating. A reason why this might have occurred was that the video feed did not work properly, and the participants were not able to see each other's social cues.

For further development of *TableCanvas*, we suggest enabling manipulation of the digital elements on the shared tabletop side, as it was observed in the second study that some participants tried to do so. We also suggest further development on the tablet application by animating the digital stickers and/or making it controllable by the user. For future work, emphasis could also be on creating and maintaining stable and functional communication by, e.g., implementing proper video feed.

In this paper we conclude that there is indeed potential in using a similar setup to support remote open-ended play through physical-digital environments. The participants showed great interest in using the system, and even though there is still work to be done, we believe that the project shows great potential in further research into the area, and using the same setup in other use cases, such as education, board games, and work. This can be in both remote as well as co-located settings.

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

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ABSTRACT

Interest in remote communication technology has remained following the COVID-19 pandemic, as researchers in the field of Human-Computer Interaction continuously investigate how digital technologies can benefit our everyday lives. Meanwhile, children are getting more used to digital devices at an early age, but studies indicate that physical play is vital for their development. To support the involvement of physical play, while still making use of digital technologies, we developed two concept variations by iterating on a concept from a preliminary study. These concept variations, *WallWizard* and *TableCanvas*, both allow users to play together remotely by combining physical and digital elements with the use of the shared tabletop toolkit, SurfaceStreams. The two variations were evaluated via a user study, and, based on this study, we chose to elaborate further on *TableCanvas*. Following this, we conducted a second user study with an updated version of the concept, focusing 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. Furthermore, user feedback indicated that there were potential use cases for board gaming, education, and work-related tasks.

Author Keywords

Human-Computer Interaction; Co-play; Physical-digital play; Phygital; Remote play; Play types; Open-ended play; AR.

INTRODUCTION

Play takes on an important role in children's upbringing as it contributes to the development of their capabilities of creativity and problem-solving, 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. [9]

One example of this is Whitebread's definition of five play types. David Whitebread et al. argued in their report, *The Importance of Play*, that play types can be divided into five broad types of play. The five types are: physical play, play with objects, symbolic play, pretend play, and games with rules. [38]

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 Minifigures. Symbolic play is when using sounds, words, objects, etc. to convey meaning. One example of this could be using a banana as a telephone. Pretend play is, i.e., playing out imaginary scenarios, such as playing the floor is lava. This is sometimes referred to as pretence/socio-dramatic play. Lastly, games with rules include anything that involves rules, whether these are set from the beginning, like in board games, or if children make up the rules as they go, i.e., deciding in the middle of the game that one can touch the "lava" once. [38]

Pretence/socio-dramatic play is also sometimes described as free play [38]. 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 [9].

Open-ended play applies simple rules and provides players with the freedom to create their own challenges and goals [10]. Bekker et al. conducted a study [6] 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, the notion regarding physical play between children was challenged. During the pandemic, children had to socially distance themselves from friends and family, including 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 COVID-19 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 [19].

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 [28], 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 [25].

Nowadays, physical-digital play technology is making its way into children's lives in the form of smart toys or augmented play spaces. As several studies have shown that there can be negative consequences when playing video games, such as a reduction in physical activity and decreased attention span, it has raised a stronger interest in exploring how digital aspects can enhance traditional physical play contexts. [33]

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 [22]; 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 remote physical-digital environments support open-ended play?"

To investigate this, we conducted two studies. 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 for play [1]. In the first study, we evaluated two variations of a concept from the preliminary study [17] through an initial user review and an expert review. Based on the insights from the reviews, one variation was chosen and iterated upon. This variation was then evaluated in the second study with a focus on the remote aspect.

RELATED WORK

This session 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

Within the realm of HCI, several studies have investigated how to stimulate open-ended play. Bekker et al. [6] developed LEDball - an interactive play object created to examine the influence of open-ended play on children's social interactions as well as their experience of fun. Through observations of play sessions with six groups of children, from ages 7 to 11, playing with the prototype, they concluded that with simple behaviour and unspecified goals, children were able to make up diverse games with LEDball. The open-ended play process stimulated various kinds of social behaviour such as negotiating, and creating shared stories. By reviewing Bekker et al.'s study together with other related studies that examined interactive objects for open-end play, Valk et al. [10] introduced a design approach for open-ended play. They suggested that when designing for open-ended play, a balance between structure and spontaneity, and the relation between ambiguity and complexity should be considered so that it encourages users to create their own game rules.

Looking into supporting open-ended play remotely, Rinott and Umanski presented and evaluated the Drawbox project that supports open-ended play over distance [32]. 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 [15]. 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. Furthermore, the participating parents wanted additional features, e.g., drawing together with the children.

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.

For instance, Keil et al. designed a personalised interactive experience using augmented reality in museums. By creating an easy-to-install mobile application and not replacing existing physical exhibitions, they succeed in creating stories tailored to each visitor, improving their experience. [23]

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. [36]

Another study investigated supporting co-located play for children by creating an interactive play space: KidsRoom [8]. 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.

Other studies have focused on how physical-digital hybrid systems can be used to improve collaboration. One example of this is the use of projectors, tangible user interfaces (TUIs), and screens in Fender et al.'s study. This study focused on making it possible for every participant to have equal control in meetings by creating an omni-directional display tool. [14, 4, 5]

In the context of games, projector based systems have been used in several studies. Both studies [7, 41] explored how this kind of set-ups could contribute to remote collaborative play. Benko et al.'s [7] 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 [41] concluded that projector based systems have the potential to support social interactions, and they highlighted alternative improvements for better social experiences.

Haqq and McCrickard conducted an exploratory study [18] of a digital-physical game called Planet Runner. This game enabled people to share outdoor running experiences with their game partners by augmenting the runner's real-world route to a virtual game environment, while the runner's partner controls a crosshair to defend the virtual runner from falling debris in the game. From user interviews with seven participants who had seen a demonstration of the game, all participants showed interest in playing this game with their partner remotely.

Exploration of combining physical objects with digital content in play can also be seen in the hobby market where augmented tabletop games have been introduced, e.g., Unlock! [2]. Kosa and Spronsk [24] investigated players' attitudes towards these games through a qualitative content analysis of 928 posts across 15 threads from BoardGameGeek.com[1]. Both negative and positive attitudes were identified. Most of the negative attitudes were due to technical issues, and the positive attitudes revolved around the digital part enhancing the play experience while still keeping the fun of playing with traditional physical objects. Another study from 2020 [27] 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.

Some interesting examples of physical-digital interaction in play are Nintendo Wii and Ring Fit Adventure from Nintendo Switch. Livingston and Pothong conducted a case study [25] of Nintendo Wii and Ring Fit Adventure through a survey with more than 1000 children aged 6 to 17. The study revealed that combining physical objects with digital games provides a stimulating and immersive play experience, and it furthermore enhanced social interactions. Based on the analysis, the study also suggested that reducing high-tech demands, i.e., giving it a lower barrier to entry in terms of complexity could improve children's intrinsic motivation to play and with an open-ended design it would make the gameplay even more diverse and creative.

Enhancing Remote Interactions

Regarding remote interaction in the field of HCI, Yuan et al. conducted a study [41] 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. The customisation aspect relates to the diversity and open-ended aspect of free play. [25] This can be further associated with the freedom of open-ended play. [10]

There are several systems and toolkits that support the mix of physical and digital elements remotely, tabletop sharing being an interesting example. ShareTable [37] 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. Other works have focused on how projectors can be used to manipulate physical objects, by projecting, e.g., height maps, colours and elements onto a surface. [31, 29, 39]

Junuzovic et al. did a user study where they recruited eight pairs of children between the ages 9 and 11 to play with the authors' shared surface device, IllumiShare. The authors analysed what benefits their shared surface offered [21]. 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. To summarise, IllumiShare allowed the children to interact naturally and was easy to understand.

Furthermore, Yarosh et al. conducted an exploratory study with children [40], 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. The findings also concluded

[1] https://boardgamegeek.com

that "a shared task space created through top-down projection supported movement and physical activities together" and "providing the children with a mobile device for controlling the partner's view encouraged turn-taking and narrative play" [40].

STUDY 1: EVALUATION OF THE ITERATED CONCEPT VARIATIONS

Taking into account the results from the preliminary study [17], we chose one of the concepts and iterated on it, as this concept allowed more freedom in play, i.e., supporting open-ended play more successfully than the other concept. The iteration resulted in an improvement of the digital interaction and two variations of the concept were proposed. We then evaluated these variations through an initial user review with children, and an expert review with LEGO employees from the Kids Technologies department.

The Concept and its Variations

In our preliminary study [17], we explored the co-play experience supported by the shared tabletop system SurfaceStreams. We evaluated two concepts: one focusing on combining a shared tabletop with a VR headset, and the other focusing on combining digital interactions on a tablet with the shared tabletop. To provide more freedom in play and better support open-ended play, we chose to iterate on the tablet interaction with additional features. This concept allowed one of the users to manipulate the projected surroundings via a computer and thereby create a more personalised play scenario for the other user sitting by the shared tabletop.

Iteration on the digital interaction

In consideration of the suggestions and insights from the preliminary study, the further iteration of the digital interaction resulted in providing the user with additional digital elements to manipulate. This includes draggable stickers, visual effects, and backgrounds (see Figure 1).

The ability to manipulate the projected surroundings was the main interaction of the initial iteration of the concept [17]. We iterated on these projected surroundings and generated a selection of three generic backgrounds as well as draggable 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 - a tap effect. This allows the user to select an effect, e.g., an explosion or a fire. When the user chooses an effect by tapping on the screen, the selected effect will be shown on the screen. This provides the user with additional opportunities to play together with the other user using the shared tabletop.

Variation 1: TableCanvas

This variation allows the tablet user to view the tabletop from a bird's point of view. With the tablet application, the user is able to design their own play environment using the features mentioned above. This was especially inspired by the case that children build their own environments when playing 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 have built.

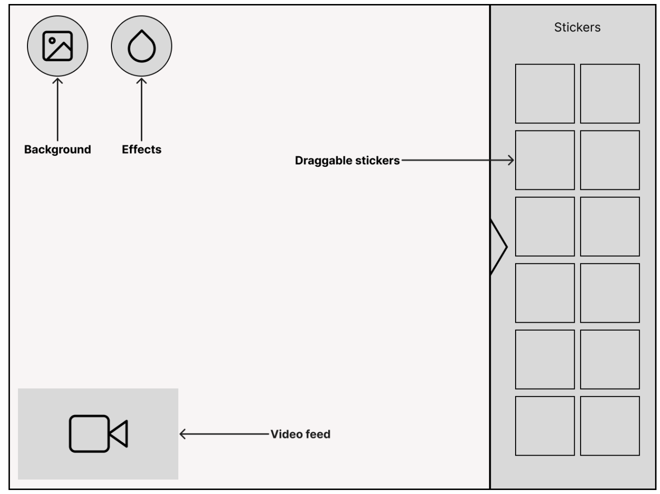


Figure 1: Wireframe of the tablet application's UI, including draggable stickers on the right-hand side, backgrounds and effect features at the top left corner, and video feed at the bottom left corner.

Variation 2: WallWizard

Besides iterating on the interaction for the digital part, we also iterated on the physical setup. As it was revealed from the preliminary study, the user who interacted with the digital part had difficulty seeing the depth of the physical elements. Therefore, we suggested this variation of the concept, *WallWizard*, having the projection from the side view instead of the bird's point of view. 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.

Prototyping

To explore how open-ended play can be supported by remote physical-digital environments, we decided to utilise the SurfaceStreams toolkit [12]. For the demonstration of the variations, we developed a tablet application that allows interaction on tablets remotely, which we combined with SurfaceStreams. The reason for choosing to incorporate a tablet is that it is the favourite digital device for young children. [33]

SurfaceStreams

SurfaceStreams [12] is a display-camera system that records and shares visual content for assembling shared interactive tabletops. It is built on widely used libraries and it supports different input devices. SurfaceStreams is suggested to be used in scenarios, e.g., projected interactive surfaces and shared remote tabletop settings, which is suitable for the setup of our concept. As SurfaceStreams is content-agnostic, it allows for rapid prototyping.

On a HTML web page connected to SurfaceStreams, besides showing the stream of the tabletop surface, the user interface also displays a video feed that consists of all user front cameras placed side-by-side. The user can also draw on the canvas, and the drawing will be projected on the shared surface. [13]

Tablet application

Besides the use of SurfaceStreams, we developed an application using the open-source online code editor CodePen [2], and ChatGPT [3] for optimising the coding process and implementing advanced features. This application runs on a HTML web page connected to the SurfaceStreams system. The application allows the user to play together with another user through SurfaceStreams by streaming the shared tabletop and providing a number of features that enables the user to interact with the stream. These features include adding backgrounds; applying visual effects; and placing stickers, as well as rearranging, resizing, and rotating them (see Figure 1).

Two versions of the application were developed with different visual contents. One for *WallWizard*, focusing on remote play with a projected picture on a vertical surface and the other one for *TableCanvas* focusing on a horizontal surface.

Initial User Review

To evaluate the two concept variations, a user review was conducted with two children aged 10 and 8 using a prototype demonstrating the two concept variations.

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 [11] and a co-located setup, seeing that some features were not implemented yet. We believed conducting an initial user review of the prototype 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 a laptop that ran the SurfaceStreams system and displayed the shared digital 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 there were still bugs in the system that caused latency, and 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.

[2]https://codepen.io/
[3]https://chat.openai.com/

Insights

The 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. On the other hand, based on the observation, the most used feature was the effects. The effects were used eagerly to tell stories and create virtual effects to highlight what happened in their stories. The ability to change background was described as being "fine".

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 in the later play session, and they might have lost their attention, this could suggest that further customisation would be a valuable addition to the tablet application. Consequently, a drawing feature could be implemented in the next iteration of the application.

The use of LEGO sets seemed to be a distraction for especially one of the participants. Further tests could include different forms of toys, e.g., board games, wooden cubes, or pen and paper, to explore if different toys would have any 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 need to be added for a more satisfying experience for open-ended play.

Expert Review

We evaluated the concept variations with employees from LEGO´s Kids Technologies department as they are experts in developing digital interactive products for children. The expert review took place in the LEGO Campus in Billund. Eight employees from LEGO joined the expert review. The employees had different roles in the company, but all were related to digital product development (see Table 1).

A portable version of SurfaceStreams, 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 (see Figure 2). A camera and projector were placed on an adjustable camera stand that allowed for quickly switching between bird's point of view and side view projection for demonstrating the two concept variations.

Participant	Education	Job Title
P1	PhD Behavioural Sciences	Sandbox Researcher
P2	BA in Arts, Media & Communication	Product Manager
P3	MA in Technology based Business Development	Senior Engineer
P4	MA in Computer Applications, Information Technology	Lead Engineer
P5	PhD Digital Design	Digital Product Designer
P6	MA in Interaction Design	Senior Digital Product Designer
P7	BFA Graphic Design	Senior Design Manager
P8	MA in Information Technology	Associate Digital Product Designer

Table 1: Demographics of participants from expert review

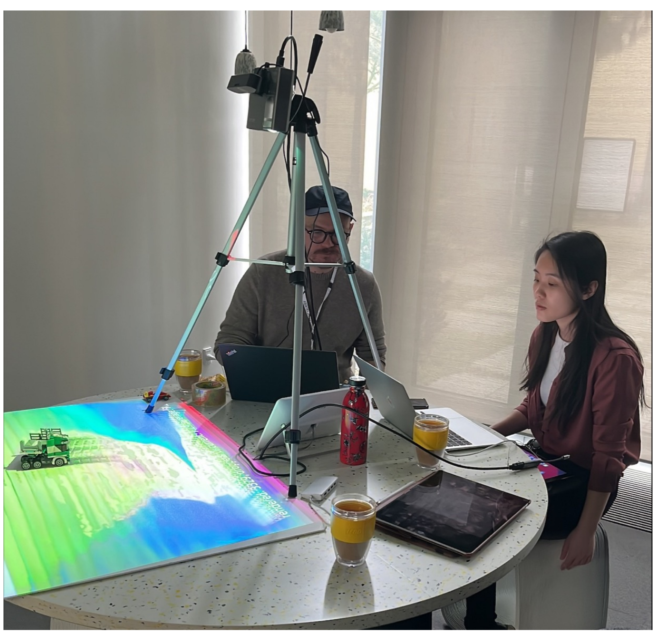


Figure 2: Setup for the expert review

As there were still a few bugs in SurfaceStreams and problems with its server, an interactive prototype was made using CodePen that runs on a browser, enabling us to quickly change the setup, should any errors occur with the system.

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 for the LEGO train.

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.

In spite of the positive feedback, some participants also raised some technical improvements for the prototype. P3 recommended including a "clear all" feature so that the user would be able to clear all the stickers at once on the digital canvas. He also found that the stickers were overlapping each other and therefore he was not being able to remove the exact sticker he wanted to.

STUDY 2: TESTING TABLECANVAS REMOTELY

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

Prototype Refinement

Taking the insights from the first study into account, we decided to iterate on *TableCanvas*. This iteration resulted in a refinement of the physical setup and an improvement of the tablet application.

For the physical setup, instead of having SurfaceStreams run on a separate computer and connected to an external projector and a camera, SurfaceStreams ran on a standalone system consisting of a raspberry pi that connected to a monitor, along with a projector and a camera. This way, the prototype is more portable and SurfaceStreams is more stable.

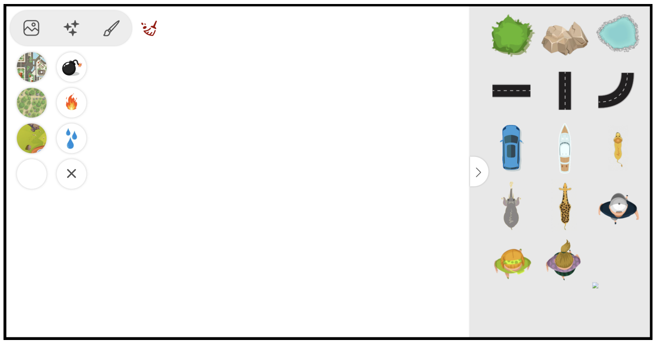


Figure 3: User interface of the refined tablet application prototype: added brushes at the top left corner and the clear all button next to it.

For the application, we implemented two additional features (see Figure 3): 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.

User Review

The study took place at the main library in Aarhus, during Maker Faire, which is described as a creative festival. The festival was meant for children to explore crafts, art, and technology with a hands-on approach. Therefore, we decided that this would be a great 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 2). Since it was a public event, we aimed to make 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 4). This way, the participants could only see each other through the webcam but could still talk together.

This allowed us, as facilitators, to observe participants on both sides and provide help if some of the features would break or if the participants had any 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.

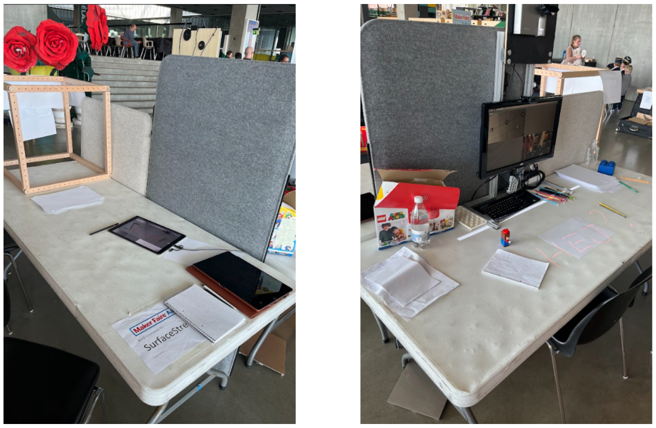
To familiarise the participants with the system and encourage them to play with each other, we started each test session by prompting them to play Tic-Tac-Toe using the system. Afterwards, the participants were encouraged to start their own game and use the system the way they wanted to.

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: drawing after the digital elements on the table; playing games

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 2: Demographics of participants from Study 2



(a) The tablet application side

(b) The shared tabletop side

Figure 4: The test setup at Maker Faire in Aarhus

Figure 5: Child playing remotely with his sister, showing her where to place digital elements on the table.

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 5).

Some of the younger children had difficulties understanding that the physical elements would show on the tablet and vice versa. We allowed the children to move between the two sides to see what showed up on the other side of the partition screen, which excited them.

It was easy for the participants to play together and see the elements on both the tabletop side and the tablet side. The biggest obstacle was that some of the elements on the tablet were misaligned, but the participants quickly overcame this. Even though the prototype had a latency varying between one to two seconds we did not observe a significant impact on the interactions.

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 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 consists of a few of the 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 2). 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 Super Mario 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 asks 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.

An unforeseen upside of facilitating the test session at a public event was that a lot of secondhand research information was gathered. Many people who we had not originally thought of as potential test participants observed and tried out the system and gave feedback on what they could see as potential use cases. Three distinct ideas came from the secondhand observers on how the setup could be used in other scenarios than collaborative play with children:

1) Playing Dungeons & Dragons (DnD) locally: one of the secondhand observers asked if it was possible to download the software for private use. His idea for a use case was focused on co-located play. This scenario involved a group of players around the table, controlling physical figures or avatars while one game master would control the digital elements to create the game setting. They would use the effects to change the storyline as the game progresses.

2) Homework and education: several adult testers (as well as some children) saw great potential in using the system for remote homework and education. If a student is sick it would be possible for them to do their homework together with others or get help from the teacher without feeling alienated through a computer screen. Naturally, many started this conversation by talking about how great the system would have been during the COVID-19 pandemic.

3) Remote meetings: one adult working as an architect joined one of the test sessions with his son and told us that there is potential for this device in the architectural business. He could specifically see the potential in this when working on a floor plan with external stakeholders because it would allow the customer to stay home while still giving feedback and watching the architects make changes in real time.

Overall, all 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.

DISCUSSION

This section presents a summary of noteworthy discussion points regarding the concepts and study setup, as well as by implications and future work. Discussion around the study setup focuses mostly on Study 2, as this is an in-depth concept evaluation with target users and focuses on the remote setup, whilst Study 1 focuses on validating the usability of the two concept variations.

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., elaborating the Tic-Tac-Toe game. This suggests that *TableCanvas* can provide children with freedom for open-ended play and facilitate collaborative play. Nevertheless, to support and enhance children's open-ended play, it will be valuable to implement the effects feature on the application that was not implemented for this study.

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 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 forcing them to communicate 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. A possible reason why the communication stopped could be that the children started building something on their own side or had an idea that they wanted to complete before continuing the game. Several papers that have investigated remote play have also noted the trend of losing interest or focus during the use of remote multi-interactive tools. Svetlana et al. described the problem as Managing Attention and Managing Intersubjectivity [40]. Intersubjectivity is defined as the capacity of establishing and maintaining a common ground of engagement among participants involved in an activity together. This challenge can possibly be resolved by highlighting the new changes using animations and sound.

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[40]. 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 see their playmate and notice their social cues. The tablet application also had a problem in that the webcam streaming was shown below the user interface, which meant that the tablet user had to scroll through the interactive elements to see the video feed. 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. [16] 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 tools to the second user review, e.g., paper, pencils and LEGO bricks. Another aspect to consider regarding this is the fact that the participants had never met before this day. 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.

Implications

Beyond the scope of our research area, our insights suggest additional implications that can be translated to separate use case scenarios. As stated previously, one secondhand observer showed great interest in using the system for private DnD play, adjusting our tablet application's features to include, e.g., stickers that are more relevant to the DnD game universe. As DnD and the play sessions we have observed through our studies are all based on the same kind of play types, i.e., pretend play and open-ended play, this would be a natural aspect to investigate further. Several papers have already addressed this subject [3], and there are several software programs, e.g., Fantasy Grounds[4], Dungeon Alchemist[5] and Dungeonfog[6], that allow players to play together in an online setting, manipulate the environment, and add effects as their story unfolds.

Another aspect to consider outside children's play is education. During the COVID-19 pandemic, students were using remote communication software, e.g., Microsoft Teams[7] or Zoom[8]. It could be interesting to explore how incorporating a physical, manipulative space could contribute to education, whether this be remote or local education. In 2019, Salman et al. explored the use of Mixed Reality in education. [34] In their study, they investigated how projection-based Mixed Reality could aid in teaching non-symbolic number representation.

To expand on the more practical use of tabletop sharing, this can also be applied in work environments. Several papers have already explored this [14, 35, 30], focusing on work-related interactions, and not related to social-binding experiences. Isenberg et al. argue through an exploratory study of how users worked together around an interactive table, that it was well suited for complex problem-solving. The study also noted that it is important that co-located tools can be changed ad-hoc and adapted to new strategies. [20]

Future Work

To further develop the concept *TableCanvas*, one aspect would be the digital elements on the physical side. As our studies revealed that participants tried to manipulate the projection, e.g., resizing a sticker by pinching the projected image, this could be implemented through a TUI table. One example could be how Mendes et al. [26] have developed an application that can run on an interactive tabletop, allowing manipulations of a digital object through gestures.

To iterate on the digital elements, the projected stickers can be changed from still images into looping videos or GIFs that move around and inhabit the tabletop, similar to non-playable characters in video games. This could also be done by providing the tablet user with additional features for controlling and playing with the stickers, e.g., controlling a sticker of a person walking around on the digital canvas. This would result in a more dynamic play universe.

From a feasibility aspect, the physical setup of the concept can be scaled down to be portable. Furthermore, the tablet application can be turned into a downloadable app or a website that can easily be accessed and run on the client server.

CONCLUSION

Throughout the duration of this project, we have aimed to answer the following research question:

"How can remote physical-digital environments support open-ended play?"

To answer this question, we started by iterating one of the concepts from the preliminary study to better support open-ended play. Two concept variations, *TableCanvas* and *WallWizard*, were created and evaluated. 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

[4]https://www.fantasygrounds.com
[5]https://www.dungeonalchemist.com/
[6]https://www.dungeonfog.com/
[7]https://www.microsoft.com/en-us/microsoft-teams/group-chat-software
[8]https://zoom.us/

scenarios such as education, board games, and work in both remote and co-located settings.

While the system is still a prototype, there is great potential for further exploration of how remote play can benefit from a similar setup, using a projector, camera, and a web/mobile application for enhancing and facilitating open-ended play. Based on our insights, we suggest that *TableCanvas*, together with a project-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.

To summarise, while this kind of system can be further developed, this study shows great opportunity in using physical and digital elements together to support open-ended play remotely.

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