VRPaperCrafting: Exploring Child-Friendly Paper Crafting in Virtual Environments using Physical Proxies and Hand Gestures

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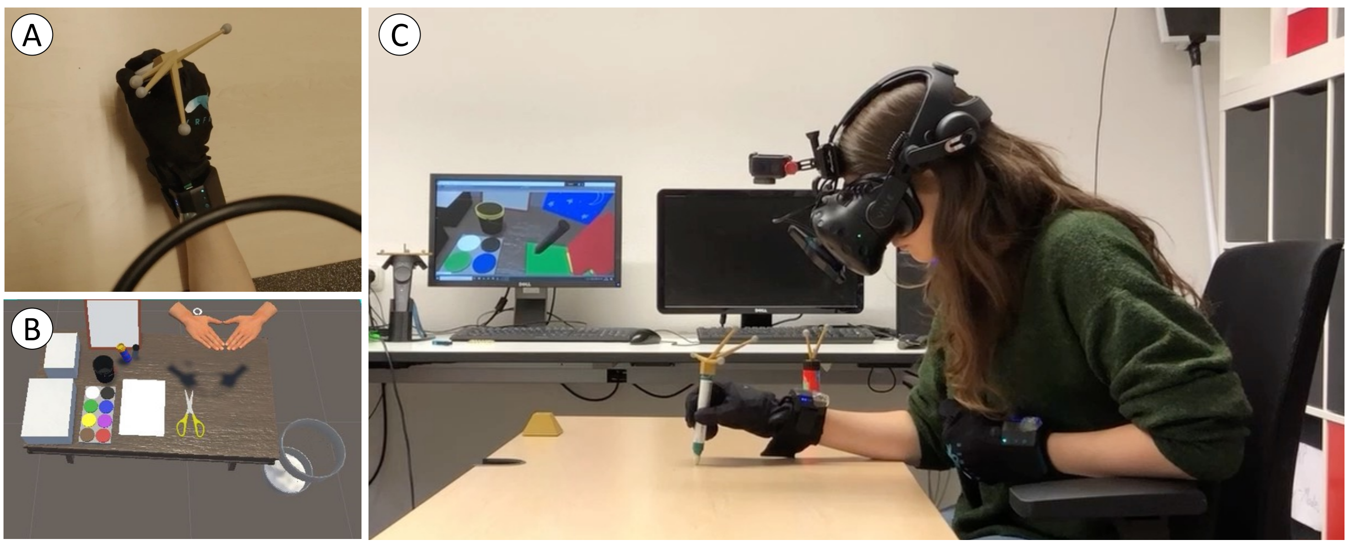

Figure 1: A participant draws on virtual paper using a physical pencil (as a physical proxy) tracked via Optitrack markers placed on 3D-printed extensions (A). She can choose different colors from a palette, pick a tool, get more paper, throw away parts of their crafting into a trash bin next to the table (B), and use the table surface as hand support (C).

ABSTRACT

Paper crafting is vital in children's fine motor skill development, problem-solving abilities, and emotional well-being. However, safety concerns related to paper crafting, e.g., gluing and cutting, might hinder children's creative exploration. Moreover, paper crafting only sometimes accommodates making mistakes, e.g., wrongly cutting paper. In this paper, we explore how virtual environments can facilitate safe and error-friendly paper crafting by proposing two interaction techniques based on (1) physical proxies and (2) hand gestures that accommodate paper coloring, gluing, and cutting. To investigate children's virtual and physical experiences with paper crafting, we conducted a controlled lab experiment (N=12) consisting of a predefined task and free play. Our results indicate that physical proxies and gestures facilitated a safe and enjoyable experience to express creativity. Moreover, children successfully performed paper crafting using the proposed techniques and found it more engaging and fun than physical paper crafting.

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CCS CONCEPTS

• **Human-centered computing → Empirical studies in HCI**; **Interaction devices**; • **Social and professional topics → Computing education**.

KEYWORDS

virtual reality, gestures, physical proxies, paper crafting, children

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1 INTRODUCTION

Paper crafting, which typically implies using paper to make various decorative items, artworks, and crafts, is crucial for children's development as it enhances fine motor skills, hand-eye coordination, and problem-solving abilities [53]. Moreover, it provides a creative outlet for children to express themselves, explore their interests, and take pride in their creations [35], contributing significantly to children's holistic development [25, 42]. Paper, due to its accessibility and versatility, is a particularly beneficial material for handcrafting [29] and activities involving paper crafts, introduced as early as preschool, enhance dexterity, attention, and concentration, and promote communication and social skills through collaborative projects [34, 44]. However, creating a safe and conducive environment for children's creativity can be challenging due to potential risks from craft materials, such as sharp objects or harmful substances, which may restrict children's ability to learn from mistakes. Therefore, in this paper, we explore the idea of creating a safe and error-friendly environment for children to practice paper crafting by employing the advantages of Virtual Reality (VR), given its immersive and digital environment capable of replicating close-to-reality experiences and accommodating users' mistakes.

Previous work has introduced various technological advancements, including 3D modeling systems, AR-based craft approaches [1], and VR sketching [10] to create safer, more immersive environments for fostering creativity. For instance, paperCraft3D [30] facilitates crafting intricate 3D models from 2D paper sheets, and Mobi3DSketch [23] and SymbiosisSketch [2] empower designers to generate 3D idea drawings in the real world. Other works have focused on employing Virtual Spaces. For example, VRSketchIn [8] offers an immersive drawing space that merges 2D input with 3D mid-air drawing. However, despite the potential of these immersive solutions, the assistance of children with paper crafting in virtual environments remains underexplored.

In this paper, we explore the idea of paper crafting for children in virtual environments. For this, we implemented two interaction techniques that include (1) physical (tangible) proxies as crafting tools and (2) hand gestures (Figures 1 and 2). By the physical proxies, we refer to physical (tangible) objects that provide input to Virtual Environments, and by hand gestures, we refer to hand gestures as an input modality. Children can craft paper projects in virtual scenes by either holding physical objects, in this case, a pencil, a gluing stick, and scissors, to interact with virtual paper or by using hand gestures, i.e., by mimicking a pencil, a gluing stick, and scissors with their hand gestures: a pointing finger, a fist, and moving the pointing and middle fingers. To evaluate the effectiveness of the proposed techniques in facilitating children's paper crafting and children's experience with them, we conducted a controlled lab experiment with twelve children aged between 8 and 12, focusing on three paper crafting tasks (coloring, gluing, and cutting, as exemplified in children's books[1]) using real-world interaction with paper without Virtual Reality support as a baseline, physical proxies, and hand gestures. Our results show that children have successfully completed all tasks without any external assistance and found that both proxy- and gesture-based methods facilitate making mistakes, are safer and more fun than real objects. Although children found interaction with real objects easier than with VR methods, we did not observe differences in influence on children's creativity among all techniques.

Our main research contributions include:

- Design and implementation of two interaction techniques to promote paper crafting in Virtual Environments by employing physical proxies and hand gestures.
- An empirical evaluation of the proposed interaction techniques with twelve school children that offers a view into the future improvements for VR educational systems for children, including creative work.

2 RELATED WORK

In this section, we provide an overview of existing work on using tangible objects and hand gestures in Virtual and Augmented Reality (VR/AR), followed by crafting and handwriting technology and VR/AR for children's education.

2.1 Tangible objects in Virtual and Augmented Reality

One common approach to facilitate interaction with paper in Virtual and Augmented Reality is to use tangible objects. VRSketchIn [8] is an example that employs an immersive sketching application using 6 degrees of freedom (DoF) tracked pen and a 6DoF-tracked tablet as input devices, allowing interchangeable usage of a 2D input (pen on a tablet) and 3D mid-air sketching (pen). On the other hand, Napkin Sketch [50] allows users to create 3D sketches using a tablet PC as the design tool and a piece of ordinary paper as the design medium. Keefe et al. [20] explored precise mid-air strokes using a haptic-aided input technique for 3D sketching, and Arora et al. [2, 3] investigated the impact of the lack of a physical surface on drawing inaccuracies. Their work explored 3D sketching in Augmented Reality (AR) using a mid-air pen-based drawing and 2D surface sketching. All the systems are based on touch sensors with low precision. The connection between the physical and digital worlds, known as a physical user interface, is often enabled via manipulating digital objects utilizing physical props as physical proxies [16, 38]. Another way to provide 2D input in VR is to use a prop like a tablet without a touch sensor. For instance, Lindeman et al. [24] demonstrated using a passive-haptic paddle as a 2D input device for widget selection in VR. Poupyrev et al. [33] used it for text-based applications (note-taking, text input, and annotation using a physical pen as a prop), and Szalavari et al. [43] utilized it for 3D modeling application. Previous research has also employed physical [17, 27] to allow children to build their virtual environments. By drawing inspiration from real-world artifacts, in this paper, we have also used real-world items to create tools for

[1]https://www.amazon.com/Color-Cut-Glue-Activity-Book/dp/B098FW4CFH, last access: August 14, 2024

interaction in an immersive environment, specifically for drawing, gluing, and cutting virtual paper.

2.2 Hand gestures in Virtual and Augmented Reality

An alternative to using tangible objects for interaction and creation in Virtual Environments is hand gestures. For instance, PaperCraft3D [30] employed gesture-based techniques, including folding, bending, extending, and cutting, to create 3D papercraft models. Moreover, Gangrae Parka et al. [12] created virtual figure models to enable the complete virtual figure model crafting (VFMC) process with natural gesture input using Leap Motion. They worked on virtual figure model crafting, noting limited handcrafting in VR environments to partial modeling and haptic feedback to build a system that supports the entire process of virtual figure model crafting (VFMC) with natural gesture input using Leap Motion. Haptic gloves extend the limits of the VR experience and often facilitate realistic touch and interaction through sophisticated tactile feedback. The haptic sensors and motors built into the gloves provide users a genuine sense of touch when used in a virtual reality environment [32]. While haptic gloves and Leap Motion controllers can be used for hand-based interaction in virtual Reality, haptic gloves provide a more immersive and realistic experience by simulating the sense of touch. With haptic gloves, users can feel virtual objects' weight, texture, and resistance, making the interaction more natural and intuitive. Thus, in this paper, we build on the success of using gloves in Virtual Reality to facilitate hand gesture recognition and accommodate playful experiences for children.

2.3 Crafting and Handwriting Technology for Children's Education

The field of educational technology for children has witnessed significant advancements through the introduction of a variety of crafting toolkits and techniques [1, 37, 40, 46, 52].These innovative tools and techniques aim to familiarize children with new technologies and methods, focusing on their application in crafting activities. The journey begins with an electronic sewing kit, a toolkit designed to teach children the fundamentals of electricity and circuits through e-textiles [7]. This kit enables children to create e-textiles by incorporating electrical components into the fabric, using supplies such as conductive thread, LEDs, batteries, and fabric switches. The e-textile construction kit provides a flexible framework for developing electronic textile prototypes [4]. It includes stitchable or fabric-based parts such as battery packs, infrared transceivers, sensors, actuators, and on/off switches. With the help of fabric-based PCBs and conductive thread, users can quickly connect these parts, simplifying the process of integrating computing and electronics into textiles for people of all ages and skill levels. Further enhancing the crafting experience, Quilt Snaps introduced a wireless, solder-free method for children to create dynamic light patterns using computationally augmented quilting pieces [6]. Each patch contains an LED, a microcontroller, and snaps for easy assembly, allowing children to create a variety of quilts with dynamic light patterns. The Stitching Circuits project takes a more academic approach, investigating how children aged 7 to 12 can learn electrical circuitry using e-textile toolkits like the LilyPad Arduino [31]. The project measures students' progress in understanding current flow, connections, and battery polarity. In addition to these toolkits, several techniques have been developed to facilitate crafting. Fabric PCBs present a technique for creating PCBs on cloth using conductive fabric and an iron-on adhesive [5]. Socket buttons offer a convenient solution for securely fastening microcontrollers and other pluggable components onto fabric-based electronic prototypes [5]. Electronic sequins transform electronic components, like LEDs, into sewable entities, enabling seamless integration into fabrics without the need for soldering [5].

Previous research has also explored technological assistance for handwriting and its influence on children's education. For example, Drey et al. [9] developed SpARklingPaper that combines the haptic feedback of a pen and paper with the digital support of apps. This way, children can write with any pen on a standard paper placed on a tablet's screen, augmenting the paper from below and showing animated letters. Their results indicate that a combination of haptic feedback and digital content while learning handwriting can facilitate children's skills. Although not evaluated with children, Klamka and Dachselt [22] have developed illuminated elements integrated into physical paper and potentially assist skill acquisition and interactive writing. Furthermore, Mayer et al. [28] have shown that handwriting with pencil fosters the acquisition of letter knowledge and improves visuospatial skills compared to keyboarding. Similarly, for word writing, Kiefer et al. [21] showed that handwriting was superior to typing training. These works indicate the potential of technology for skill acquisition using technology and the transfer of these skills into the real world. While these tools and techniques aim to educate children about new technologies and methods, they lack a specific focus on addressing children's motivation to engage in crafting and express their creativity. In contrast, in this paper, we aim to encourage children to participate in craft activities with paper within a safe environment by providing secure equipment and emphasizing avenues for creative expression.

2.4 Virtual and Augmented Reality for Children's Education

Pursuing a safer environment for children's education has led to exploring various 3D modeling systems [19]. One such system, PaperCraft3D, is designed for multi-touch interfaces like tablets, enabling users to create 3D models from 2D paper sheets through folding, bending, extending, and cutting. These models can then be assembled using pinning and taping, offering a unique approach to 3D modeling. However, the static nature of the design limits the mobility of the created models [30]. Augmented Reality (AR) has also been harnessed to provide a safer handcraft experience for children. Systems such as Mobi3DSketch and SymbiosisSketch allow users to generate 3D sketches in the real world using a single AR-enabled mobile device. These systems leverage the advantages of 2D tablet sketching and 3D mid-air drawing to create conceptual models in an AR environment. Despite these advancements, these AR-based tools do not provide an immersive experience for the users [2, 23]. Virtual Reality (VR) sketching presents another innovative approach that eliminates the use of potentially dangerous tools. VRSketchIn, an immersive drawing program, combines 2D input from a pen on a tablet with 3D mid-air drawing from

Figure 2: Proxy- (left) and gesture-based (right) techniques are used in VRPaperCrafting for (a) coloring, (b) gluing, and (c) cutting. To use physical objects in VR, we augmented them with Optitrack markers placed on 3D-printed add-ons. To enable hand gestures in VR, we used VR gloves by Sensoryx and a pointing gesture to enable a pencil, a fist gesture to start a gluing stick, and a two-finger (scissor-like) gesture to activate scissors.

a tracked pen. The authors argue that traditional tools, such as a pen and tablet, can offer a plethora of new opportunities in immersive situations despite the current VR input devices being less than ideal for drawing [8]. While these technologies offer significant support, they are not specifically designed for primary school children. Furthermore, they are device-oriented and cannot provide a real, tangible experience. The focus on child-friendly paper crafting in these immersive environments remains underexplored. We aim to create a safe environment through immersive technology that elicits real feelings and sensations and inspires children to engage in crafting activities to express their creativity. Although promising, creating an immersive experience for children for paper crafting using drawing, gluing, and cutting activities poses some challenges, which we outline in the following section.

3 CHALLENGES WITH COLORING, GLUING, AND CUTTING

Craft activities such as coloring, gluing, and cutting [34, 41, 44] benefit children's learning, but educators and parents face challenges. When using scissors, glue, and other materials handcrafting instruments, children can harm themselves [36, 39]. Ensuring the proper use of equipment is crucial to preventing injuries, and catering to each child's unique needs requires a grasp of developmental distinctions [49]. Furthermore, inclusive education calls for creating a welcoming atmosphere that considers the children's various requirements and motor difficulties.

3.1 Coloring

Coloring is a beloved activity that aids in developing fine motor and perceptual skills [41]. However, safety concerns in coloring include the potential ingestion of coloring agents, which may contain harmful substances like toxic metals. Water-based, cold-water dyes and some paints may contain chemicals that cause allergic reactions or formaldehyde, posing long-term health effects that have not been thoroughly studied [11]. Additionally, coloring can be messy, staining children's clothes and potentially getting paint on their skin and eyes [26].

3.2 Gluing

Gluing can enhance children's creativity, but it also poses challenges. Children often struggle with the pressure to squeeze glue bottles, leading to excessive or insufficient glue application. Glue placement can be problematic, with children frequently applying it too close to the edges or in one spot, affecting the quality of their projects. Safety issues with gluing include the risk of ingestion or eye contact, which can be hazardous [26].

3.3 Cutting

Cutting with scissors is a fundamental skill in early childhood development [44], but it presents several challenges. Selecting scissors is critical; they must be safe, comfortable, and appropriate for a child's hand size. Teaching the correct grip and usage is essential to ensure children can cut along lines and shapes successfully. Proper sitting posture and scissor positioning are also vital for effective cutting. Safety is a significant concern with cutting activities. There is a risk of children cutting themselves or others, especially if not supervised properly. This risk is heightened for children with motor coordination difficulties, such as those with Developmental Coordination Disorder (DCD), who may find cutting particularly challenging [13].

3.4 Overcoming Challenges with VR

Virtual Reality (VR) offers a unique solution to these educational challenges. VR can simulate the activities of coloring, gluing, and cutting in a safe and controlled environment, eliminating the risks associated with physical materials. This technology can stimulate children's independence from adults, as the dangers of traditional crafting are not present, allowing children to work autonomously. VR can potentially benefit children with motor coordination difficulties, allowing them to practice these skills without fearing injury or mess. Therefore, within the scope of this paper, we explore the idea of paper crafting in Virtual Reality due to the full occlusion of the real world and, thus, higher reliance on haptic rather than visual feedback from the real world.

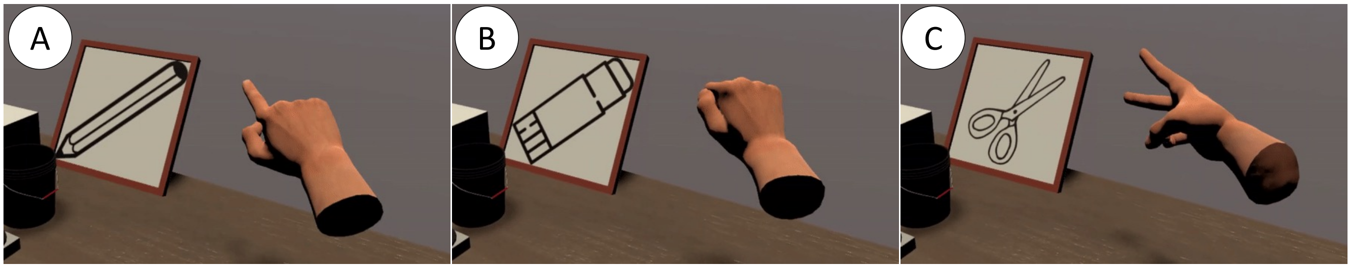

Figure 3: Switching modes with different gestures in Virtual Reality: (A) a pointing finger to enable drawing, (B) a fist to start using a gluing stick, and (C) two fingers to activate scissors.

4 EVALUATION

To explore the possibilities for enabling paper crafting in Virtual Environments, we conducted a controlled lab experiment with children. They experienced two interaction methods based on physical proxies and hand gestures compared to the interaction with real objects without virtual reality. Therefore, for this experiment, we had the following research question: *How do proxy-based and hand gesture methods influence children's paper crafting experience in Virtual Environments compared to interaction with physical objects in the real world?*

4.1 Participants

We recruited twelve children (8 F, 4 M) aged between 8 and 14 ($M = 11.58, SD = 2.44$). None of them had hearing deprivation or colorblindness. Participants with low vision were wearing glasses. Two of the participants had experience with the virtual reality system before. One had the experience of seeing Spider-Man in the VR system, and the other had experienced a VR setup shown to him by a relative. Eleven (out of twelve) children do coloring, gluing, and cutting out paper shapes from a couple of times per month to a couple of times per week.

4.2 Study Design and Tasks

The study was within-subjects, with two independent variables: *crafting method* and *tool*. The crafting method consisted of three levels: (1) real-world interaction without Virtual Reality support as a baseline, (2) physical proxies, and (3) hand gestures. The tool consisted of three levels: (1) pencil, (2) glue stick, and (3) scissors. For real-world interaction, children interacted with a physical pencil, gluing stick, scissors, and physical paper without any assistance provided by technology. With physical proxies, children used the same physical pencil, gluing stick, and scissors tracked in the virtual space to interact with virtual paper. The pencil used as the proxy object will change color depending on the color the user touches on the color palette when using the pen. Upon touch, the paper will change color to match the user's selection. By moving the actual pen in the correct direction, the user may create all kinds of lines in any shape on the virtual paper. The glue stick is represented as a virtual glue stick in the digital scenario. When touching the virtual paper, users can create lines with the glue stick in the appropriate locations on the paper and place another piece of paper. When both pieces of paper touch each other in the area marked by the glue, they stick together. To use the scissors, the users must open them and contact the virtual paper. When in contact, the scissors will go through the paper and divide it into two pieces at the end of the contact. Lastly, for the hand gestures, children used their hand gestures to perform coloring, gluing, and cutting virtual paper. Here, to activate the pencil, users have to stick their pointing finger out; to enable the gluing stick, they need to make a fist, and to activate the scissors, they stick out the point and the middle fingers (Figure 2 and 3). Both proxy- and gesture-based interaction techniques provide instant input for a virtual space. Each crafting method reflects one experimental condition. Additionally, children could use a trash bin option to throw away parts of crafting they do not need or like. They could grab a virtual object and place it in the trash bin, where it disappears. The order of the conditions was counterbalanced using a balanced Latin square. All three tools were experienced by the participants under each crafting method. For safety reasons, in the proxies method, the blades of the scissors were covered with a layer of tape, and so was the pencil's tip to avoid coloring the real-world objects.

Within each condition, children had to do (1) a predefined task and (2) a free play. For the predefined task, children had to construct a paper house by cutting necessary shapes, gluing them together, and coloring it by adding doors and windows. This task explored how children could solve a predefined task using provided interaction techniques. For the free play, children were encouraged to explore their creativity and interact freely with real objects, physical proxies, and hand gestures. They were free to engage in unstructured play, allowing for spontaneous expression and inventive use of resources. This phase aimed to assess their ability to be creative when allowed to play freely.

4.3 Apparatus

To facilitate the usage of physical proxies, we augmented a physical pencil, gluing stick, and scissors with 3D-printed holders to accommodate at least three camera-trackable reflecting balls (markers) (Figure 4). The markers are a component of the Optitrack system that allows the map of physical objects to be mapped to their digital models. We used Sensoryx's hand gloves to track both hands and three distinct gestures to facilitate hand gestures. We employed the HTC Vive VR headgear with tracking 1.0 through two HTC base stations, SteamVR assets, and Unity SDK (2019.4.1f1) to create a VR environment. We set up the crafting area mapped to a physical table tracked by the Optitrack system, which has a VR setup.

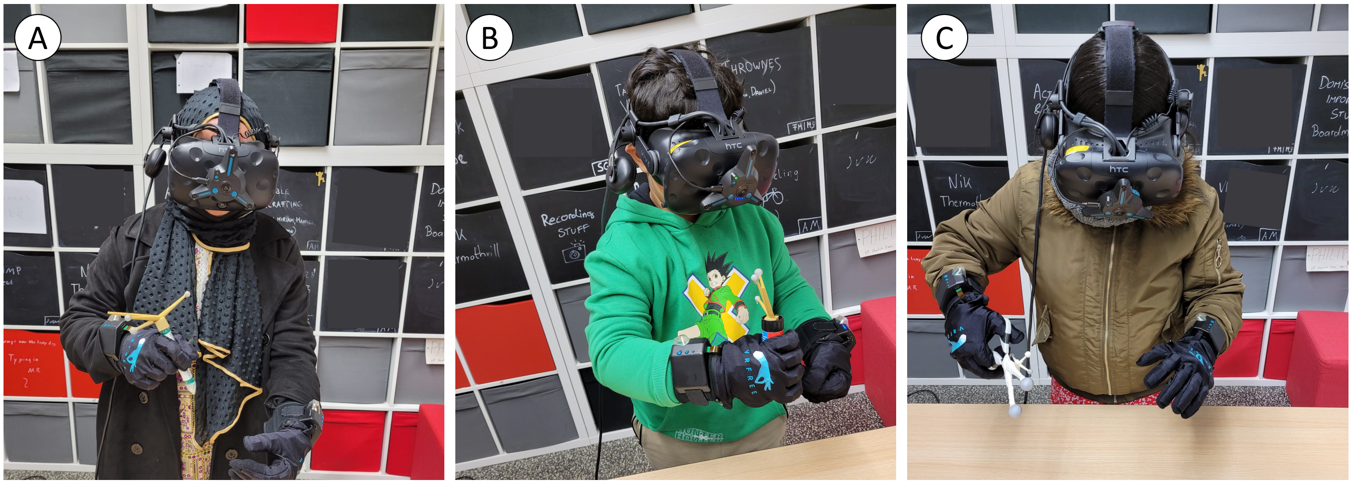

Figure 4: Children using physical proxies as paper crafting tools: (A) a physical pencil to draw on a virtual paper, (B) a gluing stick tracked with Optitrack to glue multiple virtual pieces of paper, and (C) physical scissors to cut virtual paper.

The physical and virtual tables were aligned to facilitate natural interaction, e.g., using a physical table for hand support.

4.4 Measures

To compare the proposed interaction techniques to the usage of physical objects for paper crafting, we measured the following dependent variables:

- **Task Completion Time**: Task completion time was evaluated as the duration participants took to finish the predefined task successfully.
- **Time with each tool**: We measured the time spent using each tool (pencil, gluing stick, and scissors). For this, we recorded each experimental condition, annotated video recordings for each tool, and calculated the total time children needed to use them.
- **Frequency of using each tool**: The number of times children used the pencil, the glue stick, and the scissors to complete tasks successfully. These data were also collected from recorded videos captured during participants' task execution.
- **Frequency of using the trash bin**: We counted the number of times children used a trash bin function to account for the number of errors or unwanted actions made by the participants while completing the tasks.
- **Method experience**: after each method, participants were asked to assess their experience by rating the following statements: (1) *I felt like I could make a lot of mistakes using this system*, (2) *It was easy for me to use the system*, (3) *I felt like I could not hurt myself using the system*, (4) *It was fun using the system*, and (5) *I felt creative using this system* using a 5-point Likert scale (1 – the lowest score, 5 – the highest score).

4.5 Procedure

After getting signed consent from the children's parents, we collected the children's demographics. Afterward, we introduced two interaction techniques and let children explore them. We also introduced them to the Head-mounted display (HMD) by calibrating the eye distance and the VR-free glove system by aligning both hands using the built-in functionality. This was followed by the predefined task, which required the creation of a house with windows and one door and an unstructured free-play part, in which they were free to do anything they wanted. We placed printed instructions on the table in front of them for reference. After children finished the predefined task, they were asked to explore the capabilities of each interaction method freely. The study concluded with a brief semi-structured interview to help children showcase their creations and gather overall impressions. The study followed the ethics and safety rules regarding HMDs and children and took up to 1.5 hours, with breaks in between requested by the children.

4.6 Data analysis

Given the non-parametric nature of the collected data, we applied the aligned rank transform for non-parametric factorial analyses [48]. Therefore, we applied an Aligned Rank Transform (ART) ANOVA for all statistical analyses presented below. For pairwise comparisons, we used a Bonferroni correction. For the qualitative analysis, we grouped the feedback based on three conditions and summarized the findings.

5 RESULTS

We found that children took about five minutes to finish a predefined task of creating a paper house, and eleven (out of twelve) children successfully completed all tasks without any external assistance. Moreover, participants found that both proxy- and gesture-based methods facilitate making mistakes and are safer and more fun than real objects. Although children found interaction with real objects easier than with VR methods, we did not observe differences in influence on children's creativity among all techniques. We outline the results from the evaluation in detail in the following.

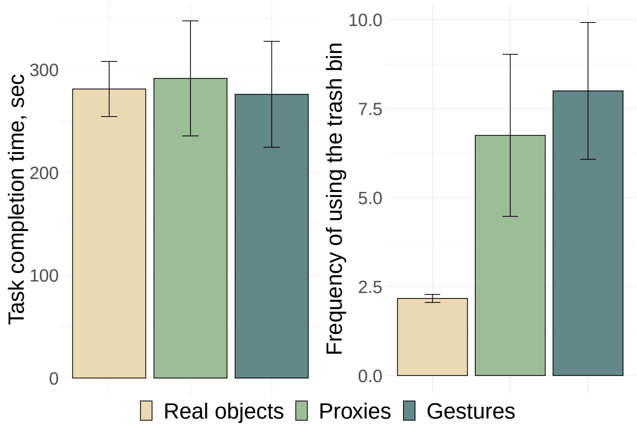

Figure 5: Task completion time per each method and the frequency of using the trash bin.

5.1 Quantitative results

5.1.1 Predefined task. We found that, on average, participants finished the predefined task in a comparable amount of time: the gestures ($M = 276sec, SD = 193$), followed by the real objects ($M = 281sec, SD = 76$) and the proxies ($M = 219sec, SD = 193$) (Figure 5 left). The children used the scissors for the shortest amount of time ($M = 52sec, SD = 68$), followed by the pencil ($M = 69sec, SD = 54$), and the glue stick ($M = 166sec, SD = 129$). Both of these findings were supported by the statistically non-significant main effect for the method ($F(2, 12) = 5.1, p > 0.05, \eta^2 = 0.46$) and a statistically significant main effect for the tool ($F(2, 12) = 52, p < 0.001, \eta^2 = 0.89$). The post-hoc analysis for the type of tools has shown statistically significant differences between all pairs ($p < 0.001$)(Figure 6 left). Finally, we did not observe a statistically significant interaction effect for method * tool ($F(4, 24) = 4.17, p > 0.05, \eta^2 = 0.4$).

As for the frequency of using each tool to solve the predefined task, the participants used, on average, the tools more frequently when solving the task with the gestures ($Md = 3, IQR = 4$) than with the proxies ($Md = 2, IQR = 2$) and the real objects ($Md = 2, IQR = 1$). The children used the glue stick ($Md = 3, IQR = 3$) more frequently than the pencil ($Md = 2, IQR = 1$) and the scissors ($Md = 1, IQR = 2$). Both of these findings were supported by the statistically significant main effects for the method ($F(2, 12) = 15.8, p < 0.001, \eta^2 = 0.72$) and the tool ($F(2, 12) = 16.6, p < 0.001, \eta^2 = 0.73$). The post-hoc analysis has shown statistically significant differences between all pairs ($p < 0.05$) for both independent variables (Figure 6 right). Finally, our statistical analysis revealed a statistically significant interaction effect for steering method*space ($F(4, 24) = 7.4, p < 0.001, \eta^2 = 0.55$). The post-hoc analysis has shown children used the real brush more frequently than the pencil with gestures ($p < 0.05$). The remaining pairwise comparisons were not statistically significant ($p > 0.05$). As for the frequency of using the trash bin, children used it more frequently with the proxies ($M = 6.75, SD = 7.88$) than with the gestures ($M = 8, SD = 6.6$). However, we did not observe statistical differences for this finding ($W = 81.5, p = 0.59$) (Figure 5 right).

Likert scale results. We found that participants felt like they could make a lot of mistakes using the proxies ($Md = 3, IQR = 1.25$) and the gestures ($Md = 3, IQR = 1.5$) system than with the real objects ($Md = 2, IQR = 1.25$). This finding was shown to be statistically significantly different using the Friedman test ($\chi^2(2) = 12.2, p = 0.002, \eta^2 = 0.5$). The post-hoc analysis has shown statistically significant differences between the real objects and both the gestures ($p < 0.001$) and the proxies ($p < 0.001$) but not between the gestures and the proxies ($p = 0.99$) (Figure 7).

As for the ease of using the system, children found the real objects ($Md = 5, IQR = 0$) easier to use compared to the proxies ($Md = 3, IQR = 2$) and gestures ($Md = 3, IQR = 2$). This finding was shown to be statistically significantly different using the Friedman test ($\chi^2(2) = 11.3, p = 0.003, \eta^2 = 0.47$). The post-hoc analysis has shown statistically significant differences between the real objects and both the gestures ($p < 0.001$) and the proxies ($p < 0.001$) but not between the gestures and the proxies ($p = 0.99$) (Figure 7).

As for the safety, participants found it safer to interact with proxies ($Md = 5, IQR = 1$) and gestures ($Md = 5, IQR = 0.5$) compared to the real objects ($Md = 4, IQR = 3$). This finding was shown to be statistically significantly different using the Friedman test ($\chi^2(2) = 4.2, p < 0.05, \eta^2 = 0.17$). The post-hoc analysis has shown statistically significant differences between the real objects and both the gestures ($p = 0.013$) and the proxies ($p = 0.002$) but not between the gestures and the proxies ($p = 0.99$) (Figure 7).

Similarly, children found it more fun to interact with proxies ($Md = 5, IQR = 0.25$) and gestures ($Md = 5, IQR = 0.25$) compared to the real objects ($Md = 4.5, IQR = 1.25$). This finding was shown to be statistically significantly different using the Friedman test ($\chi^2(2) = 3.6, p < 0.05, \eta^2 = 0.15$). The post-hoc analysis has shown statistically significant differences between the real objects and both the gestures ($p = 0.009$) and the proxies ($p = 0.009$) but not between the gestures and the proxies ($p = 0.99$) (Figure 7).

Lastly, for the feeling of creativity, the participants found themselves equally creative using the proxies ($Md = 4, IQR = 1.25$), the gestures ($Md = 3, IQR = 1.25$), and the real objects ($Md = 4, IQR = 1.5$). We did not observe statistically significant differences among the methods using the Friedman test ($\chi^2(2) = 0.2, p = 0.9, \eta^2 = 0.008$) (Figure 7).

Free play. The free play part lasted approximately five minutes per participant using each system. All children enjoyed this task and mentioned that it was fun. Many children invested a lot of time in providing details to their drawings. They primarily focused on the interaction with a single piece of paper rather than a combination of multiple pieces used in the predefined task. Examples of drawings from the free play part of the experiment are showcased in Figure 8.

5.2 Qualitative results

5.2.1 Real objects. Participants expressed confidence in avoiding mistakes when using the real objects system. Many children felt they could not make many mistakes during their tasks, as evidenced by their careful handling of the materials. Others shared a different perspective, emphasizing the constraints of the real world where mistakes could lead to significant challenges. Participants (P8, F, 13 years old) and (P9, M, 11 years old) highlighted this concern, suggesting that the real system allows less freedom for mistakes

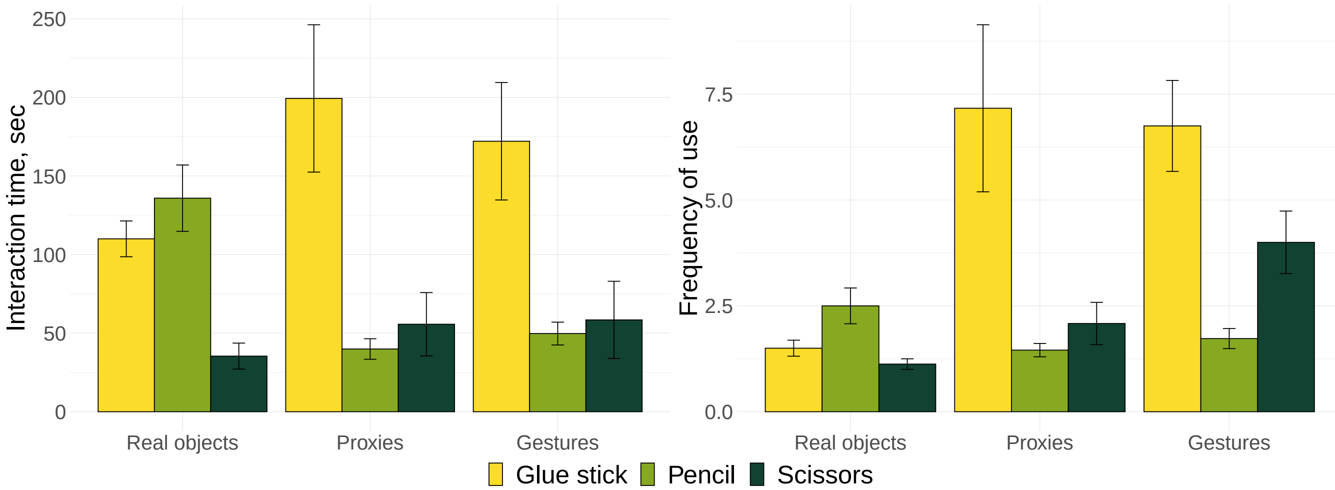

Figure 6: Interaction time and the frequency of using each tool spit by the methods.

or can be potentially more efficient. For example, P8 mentioned that *"Because in the real world, all the things will be finished at a certain time"* highlighting the pressure to complete tasks accurately and being efficient. Similarly, P9 expressed concerns about the time required for corrections, stating: *"If you make a mistake here, it cannot be corrected, you have to do it again, and it takes lots of time."* These participants underscored the notion that there is less room for error in real-world scenarios, and mistakes can lead to challenges in task management. Participants generally found the real objects system easy to navigate. P2 (F, 8 years old) mentioned *"I have been using this system as usual; it's not new for me"* while P4 (F, 14 years old) stated *"I have been using this system for a long time"* indicating their familiarity with the tools.

Regarding tool usage, participants identified scissors as the easiest tool to use, with six participants expressing proficiency in cutting paper. However, some participants found the gluing stick and pencil challenging due to issues with adhesive effectiveness and paint application. As P5 (F, 14 years old) mentioned *"There was a chance to cut my finger with the scissors and I could get glue on my hands"*, highlighting safety concerns. Additionally, P9 (M, 11 years old) shared a personal experience, stating that *"There is a possibility of cutting hands with the scissors, I cut my hands once."* Participants enjoyed using the tools and expressed satisfaction in completing tasks and indulging in activities like drawing. Only one participant reported feeling bored during the experience. Despite challenges, participants felt that using the real objects allowed them to express their creativity. P2 (F, 8 years old) described using different colors to color the flower, saying, *"I used different colors to color the flower,"* demonstrating her creative approach. Similarly, P6 (M, 9 years old) expressed his enjoyment of drawing and using various colors with a brush, commenting, *"I like to draw and I used lots of color with a brush."* P8 (F, 13 years old) expressed satisfaction with accomplishing what she wanted to do, mentioning, *"I was able to do what I wanted to do,"* highlighting the system's capacity to facilitate creative expression.

5.2.2 Proxies. Many participants expressed concerns about making mistakes, particularly due to a virtual environment's perceived lack of consequences. P5 (F, 14 years old) noted, *"I could make a lot of mistakes because I always get the paper and no one stops me,"* highlighting the freedom afforded by the system. However, others, like P8 (F, 13 years old), expressed concerns about the lack of accountability, stating, *"I could make many mistakes, but I have this independence. No one can scold me."* This echoes the sentiment of P3 (F, 8 years old), who shared, *"I have been used lots of paper. I have thrown many papers in the trash bin."* These comments suggest that participants felt they could make mistakes without consequences due to the virtual nature of the system.

Despite varying levels of ease, participants generally found the physical proxies system manageable. For example, P2 (F, 8 years old) felt confident in her abilities, stating, *"I understood the task and did it properly."*. Others, like P9 (M, 11 years old) expressed satisfaction, mentioning, *"I was able to build the house properly."* However, overall, the system presented some challenges, especially for unfamiliar ones. Participants encountered difficulties with tool control, as P7 (F, 12 years old) commented: *"I just wanted to draw the window, but the whole paper got colored."* Some struggled with positioning the paper; for example, P3 (F, 8 years old) remarked: "I could not keep the paper on the table properly." However, through trial and error, children overcame initial difficulties. As P1 (F, 13 years old) reflected that *"At first, it seems difficult, then it seems easy"* while P4 (F, 14 years old) noted that *"I was using the system again, and now I understand better."* These varied experiences highlight participants' diverse interactions with the physical proxies system.

Regarding tool usage, participants had varying experiences. While some found the pencil easy to use for its versatility, others encountered challenges with scissors. P1 (F, 13 years old) noted that *"I have faced a movement problem with scissors"*, while P5 (F, 14 years old) mentioned *"I was cutting in the wrong direction."* Safety concerns were minimal among participants, with most expressing confidence in the safety of the virtual environment. As P7 (F, 12 years old)

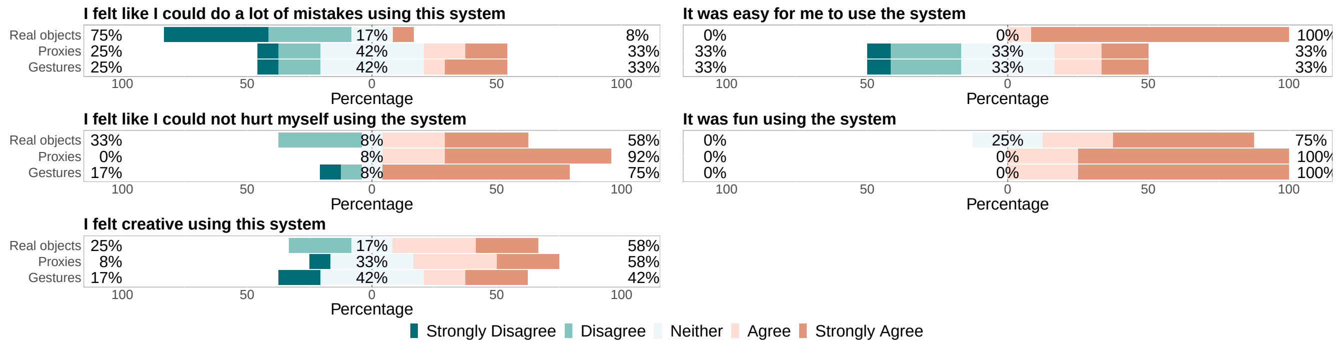

Figure 7: Likert scale results: after using each method, children were asked to assess their experience by answering the following questions: (1) *I felt like I could make a lot of mistakes using this system,* (2) *It was easy for me to use the system,* (3) *I felt like I could not hurt myself using the system,* (4) *It was fun using the system,* and (5) *I felt creative using this system* using a 5-point Likert scale (1 – the lowest score, 5 – the highest score).

asserted *"It's not real, it's virtual. There is no reason to suffer"* highlighting the understanding that virtual experiences do not carry the same risks as real-world activities. Echoing this sentiment, P1 (F, 13 years old) remarked, *"Because everything was virtual, there were no possibilities [of harming yourself]"*, emphasizing the perceived absence of physical harm in virtual tasks. P11 (F, 14 years old) further reinforced this belief, stating confidently: *"There is no way these scissors could cut my finger."* Many participants believed that the virtual tools posed no threat of injury. As P3 (F, 8 years old) noted: *"I felt a bit of pain in my nose from the VR headset"* acknowledging a minor discomfort unrelated to physical harm from the virtual tools. Overall, participants overwhelmingly believed in the safety of the virtual environment, with some attributing this assurance to the absence of sharp or dangerous physical tools.

Overall, participants found the physical proxies to be a novel and enjoyable experience. P9 (M, 11 years old) reflected on the immersive nature of the system, stating, *"If you play the game on the phone, it doesn't feel real, but here the task seems to be done in real,"* emphasizing the lifelike experience provided by the system. Similarly, P12 (M, 11 years old) described the experience as *"A new experience doing such activities in VR"* highlighting the novelty and excitement of interacting with the virtual environment. These perspectives underscore the participants' positive experiences and enjoyment of physical proxies.

Many participants expressed creativity and satisfaction with their task completion. P7 (F, 12 years old) proudly stated *"I drew a flag of Bangladesh"*, showcasing her ability to express national symbols within the virtual environment. P2 (F, 8 years old) embraced experimentation, mentioning, *"I used all the colors at once"* demonstrating her adventurous approach to art creation. Similarly, P4 (F, 14 years old) expressed her creative freedom, stating, *"I could draw whatever I wanted to draw"* highlighting the system's capacity to facilitate unrestricted artistic expression. P5 (F, 14 years old) emphasized attention to detail, mentioning, *"I used every point to do the art, which is necessary for the art"* indicating a thoughtful and meticulous approach to the creative process. These diverse perspectives underscore the participants' positive experiences and ability to unleash their creativity using the physical proxies.

5.2.3 Gestures. Participants expressed varying levels of agreement when asked about the likelihood of making mistakes. P5 (F, 14 years old) mentioned, *"I could make a lot of mistakes because I always get the paper and no one stops me"* highlighting the perceived freedom to err in the virtual environment. Similarly, P8 (F, 13 years old) noted, *"I could make a lot of mistakes, but I have this independence, no one can scold me"* emphasizing the lack of consequences for errors in the virtual realm. Regarding the ease of using the system, participants encountered challenges with the gloves, particularly when facing tracking issues. This unreliability sometimes hindered participants' ability to control the paper or execute gestures accurately.

When asked about the easiest tool to use, the majority of participants found the pencil to be the most user-friendly, with 7 out of 12 participants expressing proficiency. P9 (M, 11 years old) commented, *"I understood the task and did it properly,"* indicating comfort and ease with the pencil. Conversely, the scissors posed challenges for five participants, primarily due to difficulty accurately cutting the paper. Additionally, five participants reported issues with glue functionality, further complicating the task. Safety concerns were minimal, with most participants believing that there were no possibilities of physical harm due to the virtual nature of the tools.

Despite challenges, most participants found the gestures system to be a fun experience. P5 (F, 14 years old) expressed, *"I got the new experiences, and just used my hands to do the task,"* highlighting the sense of novelty and engagement. Additionally, P10 (M, 12 years old) emphasized, *"I love to handcraft but never used this system for handcrafting before, now have fun using it"* further illustrating the enjoyment derived from the creative process. Regarding creativity, while not all participants felt particularly innovative, some, like P2 (F, 8 years old), expressed a sense of accomplishment in using the system, *"because I have used all the colors in the rainbow"* showcasing her colorful and imaginative approach to the task. Similarly, P10 (M, 12 years old) remarked, *"I was able to draw what I wanted to draw"* indicating a successful execution of his creative vision.

5.3 Problems and Preferences

Most participants (eight out of twelve) preferred the gestures system, finding it engaging and immersive. P4 described it as *"a bit*

Figure 8: Collage of works children created (mixture of works) during the predefined task (first column) and the free play part of the experiment (columns 2-4) using the proxies (first row), gestures (second row), and real objects (third row).

funny and dramatic" indicating the enjoyment. The remaining four participants liked the proxies system the most, noting *"I have fun with this system the most."* [P1]. On the other hand, when asked which method was the easiest to use, most children (eight out of twelve) preferred the real objects. This preference stemmed from the familiarity and simplicity of tangible objects, as echoed by P6: *"Just used my hands, job done."* Nonetheless, the remaining four participants found gestures the easiest to use. P7 found the gestures effortless due to its intuitive hand movements: *"It was easy for me."* Moreover, most participants (seven out of twelve) found the gestures most fun. P2 described the experience as *"Somehow, I felt magical, like I could use my hand to do the task"* highlighting the immersiveness. However, positive experiences were also reported with the Physical proxies (four out of twelve), as P10 mentioned: *"I had the most fun using this system"* emphasizing the appeal of manipulating physical objects within the virtual environment.

The pencil emerged as the favored tool among the majority (eight out of twelve) expressing a preference for it. P5 stated, *"I like to draw"* highlighting the versatility and enjoyment of using this tool. However, the other four participants, like P9, favored the Gluing stick for its reliability and ease of use, stating, "Glue sticks have always worked well." Lastly, participants provided valuable feedback for improvement, from suggestions to enhance tool functionality to recommendations for system stability. For example, (P7) suggested, *"So that the glue does not spread too much on the paper,"* while P9 commented, *"The VR headset should be smaller so that it will be more child-friendly."*

6 DISCUSSION

6.1 Paper Crafting for Children in VR

Our research has demonstrated that combining a Virtual Reality (VR) headset with physical proxies (tracked physical objects) and gestures (gloves) successfully engages children in the VR world and enables them to complete predefined tasks. Most participants preferred the gestures (gloves) system, citing its immersive nature and intuitive hand movements as the primary reasons for their enjoyment. They appreciated the sense of agency and engagement that this system provided. Additionally, some participants found satisfaction in using the physical proxies system, particularly those who enjoyed manipulating tangible objects within the virtual environment. This system's tactile feedback and realism contributed to their enjoyment and sense of accomplishment. Furthermore, the participants' task completion time was shorter when using gestures and physical proxies than when using real objects. Given the higher frequency of using tools to accomplish the predefined task with gestures and physical proxies compared to real objects, most children found the real objects system much easier to use. They mentioned their familiarity with the real system, which they had used since childhood, while the VR system was relatively new. Based on this observation, a longer familiarization period for children might be necessary. It is worth noting that all of our participants were new to VR, and some of them experienced fatigue after wearing the VR headset for an extended period and had to take breaks during the experiment. However, the majority of children did not mention any difficulties with VR. They thoroughly enjoyed the permanent presence in the VR environment due to its potential for immersiveness and novelty. The novelty effect could affect our results since more of our participants did not have previous experience with VR, and more (long-term) experiments need to be conducted in the future. Only one child had difficulties understanding the system and could not complete the task. On the other hand, the remaining participants successfully completed the tasks using both gestures and physical proxies. Similar to other VR and AR systems for handcrafting, such as PaperCraft3D [30], Mobi3DSketch [23], VRSketchIn [8], and SymbiosisSketch [2], our proposed evaluated techniques provided a high level of immersiveness and facilitated assistance to children.

Another aspect worth considering within this line of work is that VR technologies, especially headsets, are rarely made with children in mind, with most headsets not recommended for children below 13 [2], resulting in poor HMD fit and user discomfort. Despite this precedent, previous work suggests the contrary [45, 51], but overall, the impact of VR on children's development is up for debate [18]. Our work has indicated that the use of VR has the potential to provide children with a safe and error-friendly environment, such as paper crafting in this paper, and can have a positive effect on their development, which needs to be further explored in the future. We admit that the sizing and fitting of VR headsets introduce a potential limitation for children. However, we did not observe many factors influencing children's experience while paper crafting, except for the headset's weight.

6.2 VR as a Safe and Error-Friendly Environment

In light of the challenges associated with traditional crafting activities such as cutting, gluing, and coloring [42], our study's results indicate that participants perceived the VR handcrafting system as a safer alternative. In real-world scenarios, there are significant risks associated with accidents involving sharp tools like scissors, glue sticking to hands, and colors staining clothes. Some participants even shared personal experiences of such accidents. However, these risks were virtually eliminated when using the VR system. These findings will be instrumental in guiding future enhancements to the system. Reflecting on the fear and demotivation children often experience when making mistakes in traditional crafting activities, our VR handcrafting system offers a potential solution. Our results show that the VR environment allows children to make mistakes without fear of reprimand or resource depletion. The virtual nature of the resources ensures there is no real wastage, addressing concerns about the limited access to crafting materials in real-world settings [14, 15]. Video recordings from our study revealed that children freely used and discarded virtual paper, demonstrating the liberating potential of the VR system for fostering creativity and learning through trial and error. All participants had some experience with paper crafting, which eased their use of the VR system. The question for future research remains whether such VR systems can potentially train paper crafting skills, e.g., for children with limited crafting experience, and whether these skills can be transferred to the real world and interact with real paper crafting objects. For instance, Mayer et al. [28] have shown that handwriting with pencil fosters the acquisition of letter knowledge and improves visuospatial skills compared to keyboarding. Similarly, for word writing, Kiefer et al. [21] showed that handwriting was superior to typing training. These works indicate the potential of technology for skill acquisition using technology and the transfer of these skills into the real world. However, in the case of VR paper crafting, more (long-term) research needs to be conducted to observe the effects.

[2]https://www.visionfountain.com/2022/08/01/assessing-the-impact-of-vr-virtual-reality-headsets-on-under-13-year-olds/

6.3 Fostering Creativity and Skill Transfer

One of our primary goals and concerns is fostering children's creativity through crafting activities. During the predefined tasks, we observed that children were more focused on completing the tasks properly within the given time frame. However, they expressed that there were no predefined tasks in the free-play round, and they could do whatever they wanted using any tools they liked. They were free to make their own creative decisions. Most participants said they felt more creative during the free play part because they could do whatever they desired. In comparison to other handcrafting techniques [5] and toolkits [4, 6, 7, 31, 47], which provide opportunities for creativity but mainly aim to motivate children to learn about various technologies for crafting, our system has the potential to facilitate creativity since it creates safe and mistake-friendly environment for making mistakes without wasting material.

Another important aspect is related to the skill transfer while using VRPaperCrafting. We employed paper crafting tools for the physical proxies without modifying their function or size. This aspect will help children practice without raising the issue of skill transfer. On the other hand, gestures are approximations of the crafting tools and might require further consideration and exploration regarding the skill transfer in future work. Previous work [9, 21, 28] has explored considerations and importance of transferring skills and underlines the importance of consistency of tools' function and shape, which is in line with our work.

6.4 Design Guidelines

Based on the results and the discussion above, we derived the following design guidelines (GL) guiding paper crafting for children in VR:

- **GL1**: Gestures ease switching between the tools and increase their frequency of use.
- **GL2**: Children prefer virtual disposal of their mistakes over a physical one.
- **GL3**: Virtual environments accommodate mistakes better than the physical space.
- **GL4**: Since children find real objects easier to use, it is important to maintain their familiarity with tools in virtual spaces.

7 LIMITATIONS AND FUTURE WORK

Despite the valuable insights gained from this study, we acknowledge several limitations. Firstly, each system's relatively short evaluation period might have limited participants' ability to familiarize themselves thoroughly with the virtual environments and tools. Extending the duration of the evaluation period and providing additional training or guidance could mitigate this limitation and enhance participants' comfort and proficiency with the systems. Furthermore, the scalability and accessibility of virtual systems for handcrafting activities should be considered. Ensuring that virtual environments are compatible with a wide range of devices and accessible to users with diverse abilities and backgrounds is essential for promoting equitable access and participation. Additionally, addressing concerns related to system reliability, such as minimizing latency and optimizing performance, is crucial for enhancing user experiences and promoting broader adoption of virtual handcrafting systems. We admit that children can typically engage in arts and crafts from the age of two onwards, and we could have potentially included children from the age of two. However, because today's VR headsets are rarely created with children as end-users in mind, we decided to focus on older children (8+) who can wear comfortable headsets for more than an hour.

Several avenues for future research and development emerge from the findings of this study. Firstly, addressing technical challenges, such as enhancing system reliability and optimizing performance, remains a priority. The Gestures (gloves) system, while favored by participants for its immersive nature, faced issues with tracking and system responsiveness, which affected usability. Research efforts should focus on refining these aspects to ensure smooth and intuitive interactions, enhancing user experiences. Expanding the range of tools and shapes available for handcrafting activities within virtual environments could enrich the user experience and foster creativity. A diverse selection of virtual tools and materials would allow children to explore different artistic techniques and styles, promoting engagement and skill development. Moreover, incorporating adaptive features into virtual systems could tailor the experience to individual preferences and abilities, enhancing user satisfaction and learning outcomes. Exploring the potential of collaborative and multiplayer features in virtual environments could also be beneficial. Allowing children to collaborate with peers or engage in group activities within virtual spaces could enhance social interaction and collaboration skills while fostering a sense of community and belonging. Furthermore, integrating educational content and curricular materials into virtual handcrafting experiences could provide additional learning opportunities and support academic objectives in art, design, and creativity.

8 CONCLUSION

We have designed, implemented, and evaluated a system that combines physical proxies and gestures to engage children in crafting activities. The system, set within a Virtual Reality (VR) environment, aims to stimulate children's creativity by providing a safe space to experiment, make mistakes without fear, and utilize unlimited resources. Our results demonstrate that children have gained an understanding of crafting activities in a fun and safe environment, where they can make mistakes without fear and use unlimited resources. Interestingly, our findings indicate that children found interacting with the VR environment using gestures more enjoyable than physical proxies, as it eliminated the need for physical objects. This suggests that the freedom and flexibility offered by gestures enhance the fun factor in the crafting activities.

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