P/REFERENCES OF DESIGN

ENHANCING CRAFTSMANSHIP THROUGH VISUAL GUIDANCE USING MIXED REALITY: A STUDY ON LEARNING ORIGAMI.

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ABSTRACT | In the contemporary educational landscape, the integration of mixed reality (MR) marks a significant shift towards more interactive and immersive learning experiences. The benefits include improved spatial awareness, a more context-specific and action-based experience and guidance, isolation, and focus. A current gap exists between manual operation and virtual assistance, where the actions could be supported in their embodied, physical context. Thus, this paper investigates the influence of MR on the learning process, particularly in the acquisition of craftsmanship skills, using origami as a case study. This research focuses on assessing how these technologies enhance understanding, engagement, and skill acquisition in origami, a craft requiring precision, patience, and spatial insight. The study encompasses a controlled experiment with five product development students with varying levels of origami and VR experience, assessed in a pre-test skill-level survey. They use a custom-designed MR application with the Meta (formerly known as Oculus) Quest VR head mounted display (HMD) to learn how to make the “exploded vertex” model, a model representative of David Huffman’s curved-crease folding techniques. This headset provides a pass-through option with an improved camera quality. The experiment is structured into six phases, including VR headset adjustment, alignment, drawing, instructional video and 3D model interaction, origami making, and a final satisfaction assessment. These are supported by an AR-assisted visualization presenting step-by-step guidance projected on the physical paper underneath, a prerecorded instructional video, and a 3D model to be grabbed and viewed from all angles. The results indicate that MR significantly enhances the learning experience, offering real-time guidance and a deeper understanding of spatial relationships crucial in origami. Increased engagement and personalized learning adjusted to the individual pace were noted by the participants. However, the impact remained nuanced, where prior origami experience aided in overall performance within the VR environment, it did not translate consistently into higher precision. The leap to MR, despite challenges like visual distortion caused by the quality of the Meta Quest 3, reveals the potential of these technologies in enhancing traditional learning methods. This paper aims to highlight the capabilities and limitations of MR as educational assistive technology. Underscoring the importance of balancing novel technological approaches with traditional methods, areas for future research might include long-term skill retention and optimization for diverse learner demographics.

1. Introduction

Integrating technology into educational and skill development processes has been increasingly prominent in the last few years. One of these emerging technologies that has gained attention in this context is augmented reality (AR). Augmented reality is a technology that blends the real-world environment with digital information, such as a virtually created object, creating an immersive experience for users. The difference with virtual reality (VR) is that the user is then fully enclosed in a virtual environment. Furthermore, it is necessary to acknowledge the difference between AR and mixed reality (MR). While AR provides a view of the real world with an overlay of digital objects, in MR these physical (user or object) and digital elements can interact (Tremosa, 2022). Acquiring new skills and the potential to enhance learning experiences has made this a subject of significant interest, especially in craftsmanship and hands-on skills acquisition. For instance, spatial awareness allows a person to visually discern the spatial relationship between two or more objects, including their connection to themselves. This capability has been confirmed to improve in correlation with the aforementioned technologies (Azarby & Rice, 2022).

Augmented reality learning could enhance students' understanding of concepts and processes compared to the traditional teaching materials. Increasing the participants' interest, focus and motivation in learning new skills are critical factors for effective learning (Hung, Chen & Huang, 2017). The hardware technology applied in this research will be the Meta Quest 3, which is a head mounted display (HMD). An HMD is a screen device that is positioned directly in front of the user's eyes through a head-mounted mechanism. This setup allows digital content to be overlaid onto their field of vision (FOV), offering an immersive user experience that has been useful for skills acquisition such as cognitive skills related to comprehending spatial and visual information and knowledge (Jensen & Konradsen, 2018). The Meta Quest 3 was employed over other available options due to superior pixel quality and full color passthrough.

To research how people, specifically Product Development students, acquire hands-on skills through using MR, the focus is put on the craftmanship of origami specifically. Which entails a high degree of skill, precision and patience. Origami, the East Asian art of paper folding, embodies creativity and expression, allowing artists to experiment with a flat sheet of paper and turn it into three-dimensional models (Chen, 2023). Traditionally, origami has been taught through paper books, diagrams and hands-on demonstrations. However, with the advance of augmented reality technology, there is an opportunity to foster revolution in how individuals learn and engage with this ancient art form. Technology has been used before for 3D origami learning. The use of video recording for instance is significant, in which the folding technique is shown (Kustiawan et al., 2021)

This research paper uses an origami model built by David Huffman; a man known for his curved-crease paper models. The initial documented mention of curved crease folding traces back to a Bauhaus student who participated in a course instructed by Josef Albers during the years 1927 and 1928 (Demaine et al., 2011). Huffman’s work is known for its significant field in origami and mathematical geometry, involving complex curved creases. Origami artists and mathematicians use his work to build upon his knowledge and try to develop a theory for Huffman’s knowledge (Demaine et al., 2011).

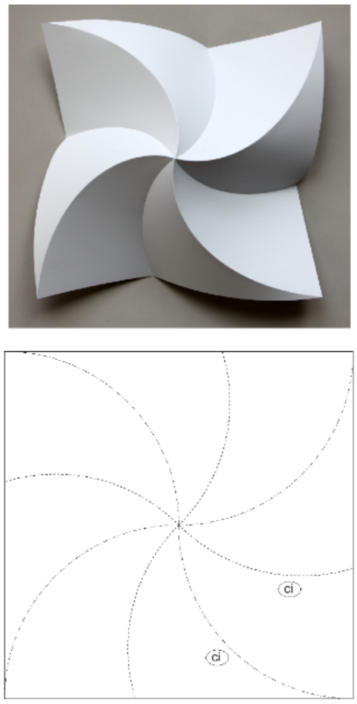


Figure 1. Exploded vertex pattern by Huffman (Demaine et al., 2011).

The specific model chosen for this research is part of a collection of patterns that include an “exploded vertex”, shown in Figure 1 (Demaine et al., 2011). The pattern consists of folding the paper so that all creases (in this exact case: circular arcs which alternate between mountains and valleys) seem to come out of a single point, usually located in the center of the piece of paper. This figure was chosen due to its specific pinching technique that would improve visual significance whether the participants were understanding the process and not just copying folds from instructions as in 2D origami.

The overarching research question in this study revolves around the impact of MR-enhanced learning experiences on the acquisition of craftsmanship skills, with origami as specific focus. Understanding the influence of MR on the overall learning process and engagement of individuals in acquiring such skills can have far-reaching implications in education. Not only in Product Development, including related in-print paper by Garcia (2024). But in numerous fields such as aerospace, mechanical engineering, skills development and even recreational pursuits (Yue, 2023; Turner et al., 2016). Prior research mentions the possibility that immersive technological experiences lead to higher levels of engagement and understanding of complex concepts and spatial relationships (Dede, 2009; Bodzin et al., 2020).

2. Method

The experiment explores the integration of origami and augmented reality in a six-phase process. Each participant first adjusts the headset and gets their first experience with an MR environment. The next phases include the making of David Huffman’s origami shape, with the exploded vertex. The final phase evaluates their satisfaction and completion of the task in comparison with the result of the expected outcome.

The think-aloud method for receiving feedback from the participants was utilized to acquire user insight and action reasoning. The think-aloud method is implemented in research when insights into participants cognitive processes during specific tasks are of importance. By having participants verbalize their thoughts, researchers get to understand the thought processes and decision-making strategies participants go through during their performance (Eccles & Arsal, 2017).

2.1 Participants

The study includes five participants, two males and three females, aged between 19 and 21 years. A set of pre-test questions reveals the following. All are Product Development students with up to three years of CAD experience in classes using SolidWorks, particularly in surface modelling. Their backgrounds in origami and VR experience vary, providing a diverse sample for the experiment. The participants' levels of origami experience ranges from very little or no experience during childhood and a general disinterest to a significant amount of personal engagement, folding during their free time as a hobby. Similarly, their mixed reality experience varies from no prior exposure to quickly using virtual reality to test a few functions and watch a video. More specifically, Participant 1 demonstrates solid origami skills but had limited VR exposure. Participant 2 has moderate origami familiarity and minimal VR experience. Participant 3 possesses basic origami knowledge and engaged in some VR activities. Participant 4 exhibits minimal interest in both origami and VR. Participant 5 has a higher origami skill level but was not actively practising and had no VR experience.

2.2 Apparatus and Materials

Apart from a table and a chair for the participant:

- VR Headset: Meta (formerly known as Oculus) Quest 3;
- MR Application: Specifically designed for the experiment within the game engine Unity and not based on existing layouts. It features functionalities for aligning paper with a virtual template, drawing over lines on paper, viewing instructional videos, and interacting with 3D origami models;
- Origami Paper: A4-sized paper cut in 21cmx21cm for origami crafting;
- A pen and standard stationery for the drawing phase.

2.3 Think-Aloud Method

During the experiment, participants are instructed to verbalize their thoughts, actions and feelings in real-time using the think-aloud protocol. This technique aims to capture their cognitive processes, problem-solving strategies and immediate reactions to the MR environment.

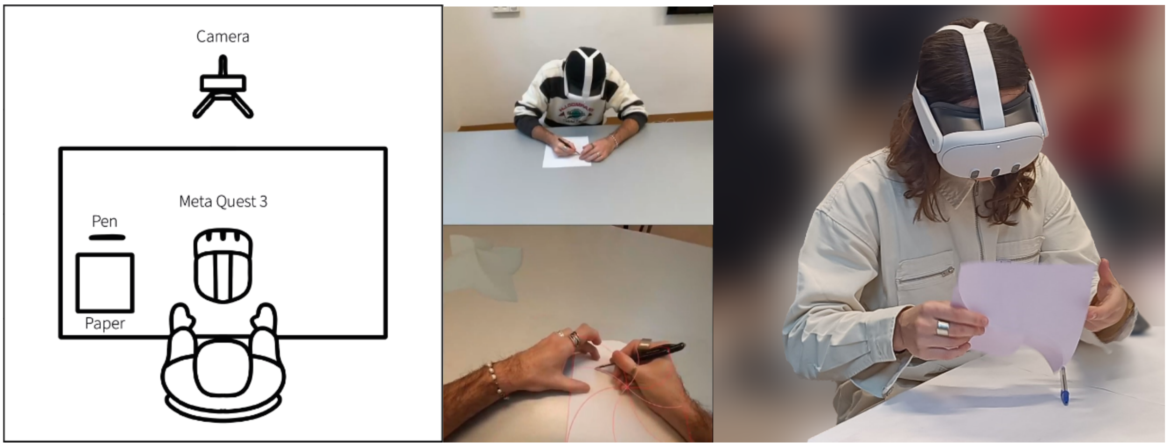


Figure 2. The test setup (left to right: illustrated top view; synchronized camera viewpoint (top), headset viewpoint inside headset (bottom); folding in action).

2.4 Procedure

The experiment is structured into six phases and pre-formed in an aforementioned setup, Figure 3 highlights the distinction between virtual and physical elements:

Phase 1: VR Headset Adjustment and Initial Task: Participants are asked to put on the headset. This phase assesses how participants adjust to the VR headset and their initial reactions, focusing on ease of use and interaction with the AR environment.

Phase 2: Alignment Task: Participants are instructed to take a piece of paper and align it with the template, visible in augmented reality. This phase involves observing precision, strategy and any adjustments made.

Phase 3: Drawing Task: Participants are asked to take a pen that is on the table and draw over the lines, visible in augmented reality. By doing so, the participants pre-crease the paper, effectively creating a guide for the folds in the next step. This phase focuses on their accuracy, method of tracing, and level of concentration. Time taken and normalized accuracy are documented.

Phase 4: Instructional Video and 3D Model Interaction: Participants are instructed to watch a small repeating video clip, showing the correct folding technique for the origami model. After which they are told to look at and grab a virtual 3D model of the final origami model. This phase focuses on observing engagement level with both the video and the 3D model, interaction style and comprehension of instructions.

Phase 5: Origami Making: Participants are asked to start making the origami model with no further instructions. This phase focuses on skill, technique, reference to instructions (technique video and the 3D model) and problem-solving strategies.

Phase 6: Completion and Satisfaction Assessment: Participants are instructed to end the test once they feel satisfied with their result or approve of a stalemate in their progress. This phase assesses when participants decide they completed the task and their satisfaction with the result, comparing the result with the expected outcome and noting the duration of completion.

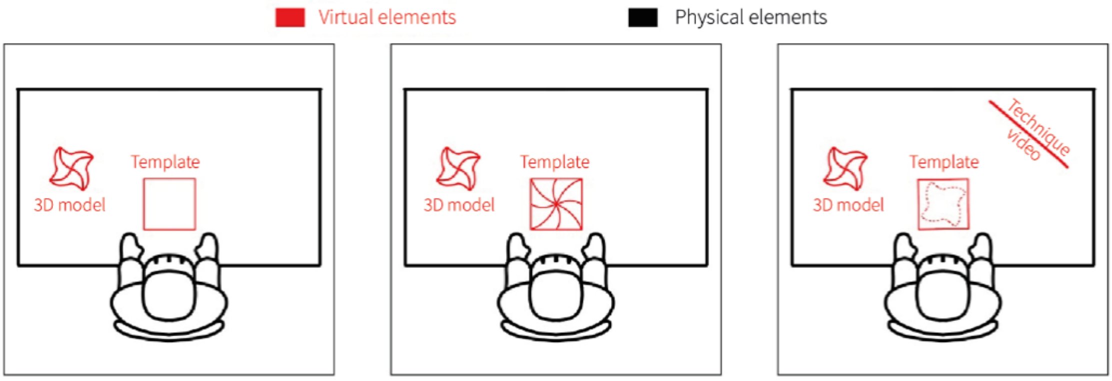


Figure 3. Visuals visible for the user in phases from left to right: phase 1, 2; phase 3; phase 4, 5, 6.

2.5 Post-Experiment Interview

A post-experiment interview is conducted to gather feedback on the overall experience, challenges faced, perceived usefulness of the MR technology in learning origami and any suggestions for improvement of the overall experience and the MR and real-life setup. The questions are inspired by the NASA Task Load Index (NASA-TLX) (Galy et al., 2018).

2.6 Data Collection and Analysis

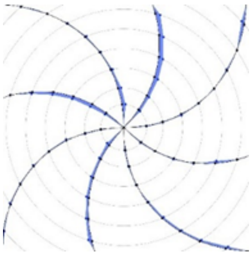
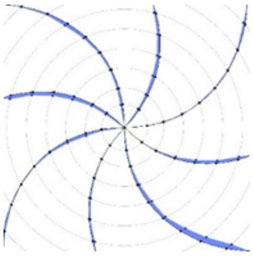
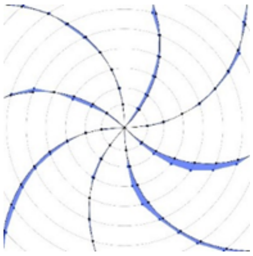
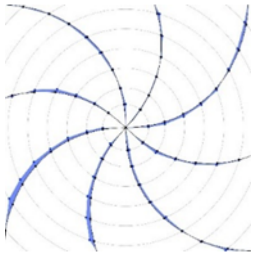
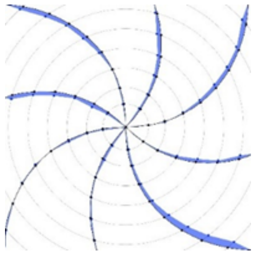
Quantitative data includes specific task times, normalized accuracy for the drawing task, and final scores of the origami models. Qualitative data encompasses observational notes from each experiment phase, think-aloud narrations and insights from pre- and post-experiment interviews. This comprehensive data collection aims to correlate participant backgrounds, in-task verbalizations and post-experiment reflections with their performance and overall experience. The final model score is decided by comparing the participant's result with the example model and placing them on a scale from zero to ten, defining 0 as a flat sheet of paper, and 10 as a perfectly folded model.

To assess the accuracy of each participant's drawings, we employ a method that quantifies the area between the participant's drawn lines and the template lines (Figure 3) shown in the overlay. This area represents the deviation from the desired line and serves as a measure of drawing accuracy.
We defined 100% accuracy, as a scenario where the participant's line perfectly overlays the mixed reality template, resulting in an area of zero deviation. Conversely, the worst-case scenario, representing 0% accuracy, was defined by the maximal possible area of deviation that could occur within the confines of the experiment's setup. To calculate the area of deviation, we digitize each drawing and apply image analysis software to measure the area between the drawn and template lines. The resulting area measurements are used to calculate the accuracy percentage by inversely scaling the measured area between the predefined maximum (0% accuracy) and zero (100% accuracy).

3. Results

Participants engaging with 3D models in MR report a more engaging learning experience and better understanding of spatial relationships. The immersive quality influences the participants' comprehension of complex shapes through the grabbable 3D model. The overlay for the drawing tasks received multiple enthusiastic responses from participants one, three, four and five. Stating that without the overlay they would have encountered more issues. Regarding origami skill acquisition, participants with prior experience demonstrated greater confidence in the virtual environment, though it did not necessarily improve drawing accuracy. Limited MR experience did not hinder performance significantly, but familiarity influenced task approaches. Participants displayed varying degrees of adaptation to the MR environment. In perceptions and interactions with VR features, participants recognized the utility of VR in enhancing learning, despite facing challenges like visual distortion. Quantitative results showed variability in drawing accuracy, differing approaches in task times, and variations in final model scores, reflecting differences in task execution and product quality. These can be found in Table 1.

Table 1. Point-to-point analysis, Think Aloud Method and Video analysis.

Participant 1	Participant 2	Participant 3	Participant 4	Participant 5
				
Self-rated origami experience 7/10,	Self-rated origami experience 3.5/10,	Self-rated origami experience 4.5/10,	Self-rated origami experience 2/10,	Self-rated origami experience 5.5/10,
limited VR experience	minimal VR experience	some VR experience	no VR experience	no VR experience
Phase 1: Adjusted well to VR headset, impressed by the virtual 3D model.	Phase 1: Adjusted well to VR headset with minor distortion noted.	Phase 1: Adjusted well to VR headset with no confusion.	Phase 1: Adjusted well to VR headset with no confusion.	Phase 1: Adjusted well to VR headset, impressed by the virtual 3D model.
Phase 2: Successfully aligned paper with AR template on first try.	Phase 2: Successfully aligned paper with AR template on first try.	Phase 2: Successfully aligned paper with AR template on first try.	Phase 2: Successfully aligned paper with AR template on first try.	Phase 2: Successfully aligned paper with AR template on first try.
Phase 3: Drawing Task - Time taken: 1min 5sec, Normalized Accuracy: 59.18%.	Phase 3: Drawing Task - Time taken: 48sec, Normalized Accuracy: 55.10%.	Phase 3: Drawing Task - Time taken: 20sec, Normalized Accuracy: 53.08%.	Phase 3: Drawing Task - Time taken: 20sec, Normalized Accuracy: 53.08%.	Phase 3: Drawing Task - Time taken: 1min 5sec, Normalized Accuracy: 59.18%.
Phase 4: Watched instructional video, did not pick up 3D model again after initial interaction.	Phase 4: Focused on instructional video, analyzed 3D model thoroughly.	Phase 4: Focused on instructional video, interacted with 3D model.	Phase 4: Focused on instructional video, interacted with 3D model.	Phase 4: Watched instructional video, did not pick up 3D model again after initial interaction.
Phase 5: Successfully picked up folding technique but caused unintentional wrinkles.	Phase 5: Quickly picked up folding technique, noted difficulty in visual focus.	Phase 5: Understood technique but applied it slightly wrong, made adjustments.	Phase 5: Understood technique but applied it slightly wrong, made adjustments.	Phase 5: Successfully picked up folding technique but caused unintentional wrinkles.
Phase 6: Final folding time: 7min 20sec, Final model score: 7/10	Phase 6: Final folding time: 4min 14sec, Final model score: 9/10.	Phase 6: Final folding time: 3min 37sec, Final model score: 5/10.	Phase 6: Final folding time: 3min 37sec, Final model score: 5/10.	Phase 6: Final folding time: 7min 20sec, Final model score: 7/10.

The Normalized accuracy ranges from 40.74% to 59.18%, indicating variability in precision during the drawing task (Figure 4).

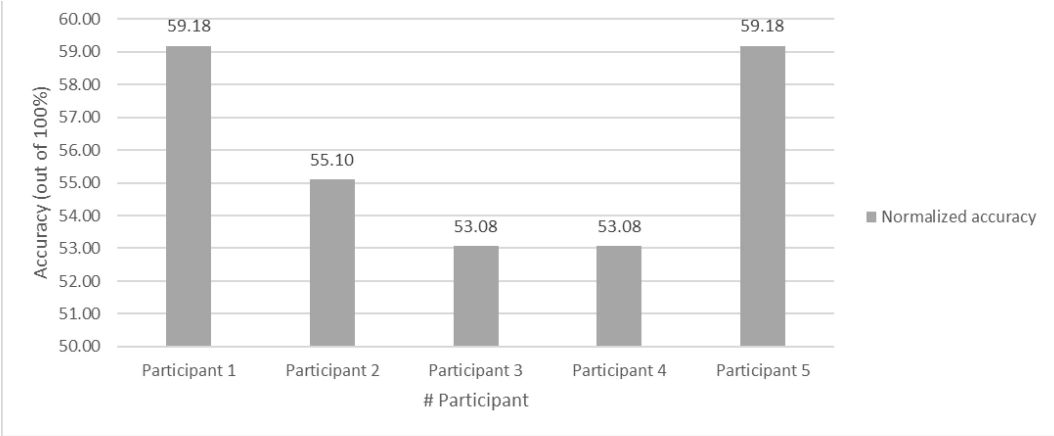


Figure 4. Normalized accuracy results.

Figure 5 shows the average time for Drawing Task, which ranged from 20sec to 1min 05sec, showing differences in pace and approach. However, the average time for Origami Making ranges from 3min 37sec to 7min 20sec, suggesting a generally consistent engagement with the task.

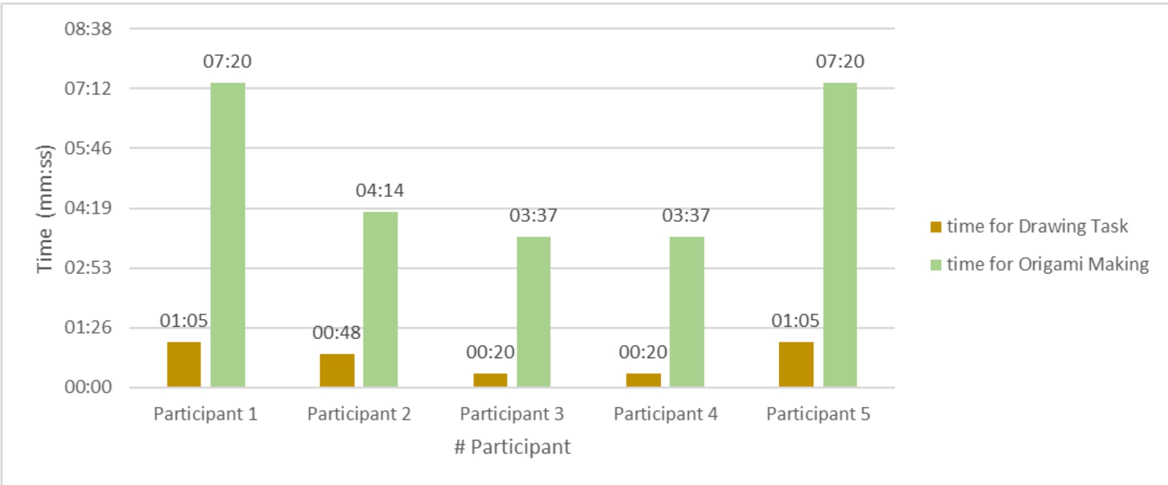


Figure 5. Time-based performance.

The final model scores, depicted in Figure 6, vary from 5/10 to 9/10, reflecting the differences in overall task execution and final product quality.

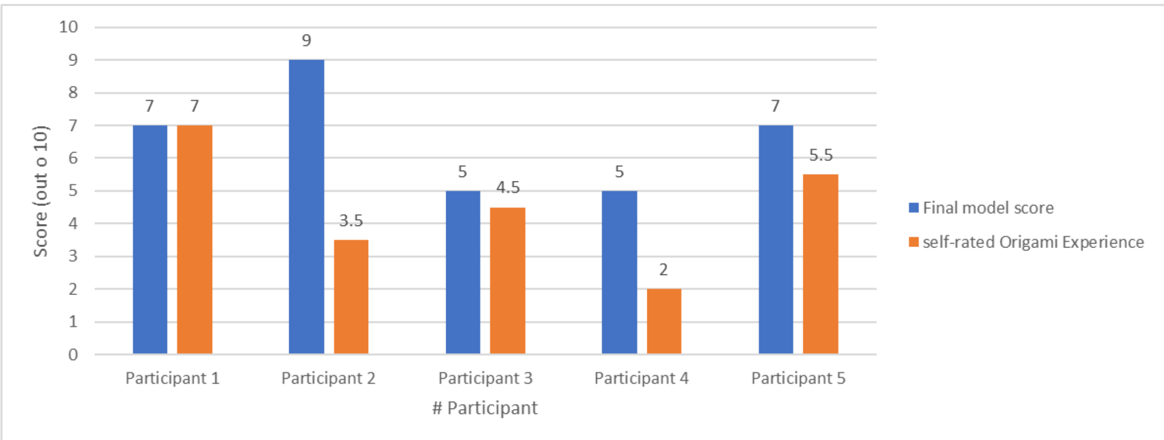


Figure 6. Quality-based results.

The post-experiment interview results indicate participants with higher self-rated origami experience, like Participant 1, showed more confidence and adaptability in handling tasks, despite initial VR adjustments. The participants additionally perceived the experiment to be mentally challenging. Only slight complaints purely about hardware-related issues were made such as warping of the view and dimness. The satisfaction of the origami creation result was mixed, some participants were not happy with their origami since their envisioned result was of higher quality. However, most considered their result fair enough and found the visual guidance helpful. The majority of the participants also found detail work tougher to perform than the general actions. Based on the instruction given through the MR setup, most participants were confident that they could recreate a similar origami design. Both with and without a headset, based on the gained knowledge. The repetition to perform the same sort of craft process with the use of the technology was however divided. Half of the participants saw this more as a one-time experience in its current state. In the end also half of the participants stated that they would use the virtual reference more. They focused most attention on the tutorial video, keeping the virtual reference more in mind would result in an improved execution and visually appealing origami product.

Across all participants the mixed reality setup was found to be a useful tool for certain aspects of the task, such as line drawing, but also introduced challenges like visual distortion and difficulty in detailed work.

4. Discussion

This study's findings contribute to the growing body of research on mixed reality (MR) as an educational tool, particularly in the realm of craftsmanship and skill acquisition. The immersive and interactive experiences provided by MR have demonstrated significant potential in enhancing the learning process for complex skills such as origami. However, this exploration extends beyond the mere affirmation of these technologies' effectiveness; it delves into the nuances of their impact on diverse learners.

The study underscores the benefits of immersive learning environments. MR’s ability to overlay instructional content onto the physical world creates a more engaging and intuitive learning experience. This finding aligns with prior research indicating that immersive technologies can lead to higher levels of engagement and a deeper understanding of complex concepts. The interactive nature of these technologies, as evidenced by the learners’ ability to manipulate 3D models, plays a crucial role in understanding spatial relationships – a key component in origami.

The findings suggest that learners benefit from progressing at their own pace, echoing the conclusions drawn in similar studies (Srithar & Selvaraj, 2015). This aspect of technology-enhanced learning is especially crucial in educational settings where learners' abilities and learning styles vary widely. The influence of prior origami experience and familiarity with VR on task execution was a critical aspect of this study. Interestingly, while prior experience in origami seemed to boost confidence in VR environments, it did not invariably lead to higher precision in skills requiring fine motor control. This observation raises questions about the transferability of traditional skills to technologically mediated environments, suggesting an area ripe for further investigation.

This study has its limitations. First, the sample size and demographic diversity of participants may limit the generalizability of the findings. Second, the study's duration did not allow for an assessment of long-term skill retention or the effectiveness of these technologies over extended periods.

Furthermore, the visual quality of the pass-through video was limited: participants frequently mentioned issues like pixelation and distortion, which occasionally broke the immersion and made tasks like line drawing more challenging. This underscores the current technological limitations of MR in delivering a consistently seamless and realistic experience.

5. Conclusion

Our study provides an examination of how mixed reality technologies impact the acquisition of craftsmanship skills. Focusing on origami as a test case, the study demonstrates the dynamic and engaging learning environment immersive technologies can create, offering significant advantages over traditional instructional methods. The use of MR allows for the overlay of instructional guides in the physical world and the manipulation of 3D models in real-time, enhancing the learner's grasp of complex shapes and spatial relationships critical in origami.

The effectiveness of MR in skill acquisition is influenced by factors such as the learner's prior experience with origami and their familiarity with immersive technology. While previous experience may increase confidence and adaptability, it does not necessarily correlate with higher precision or more effective performance. This underscores the importance of well-designed MR orientation programs to maximize the benefits of these technologies in learning contexts. Despite initial challenges like visual distortion or focusing difficulty, learners generally maintained their performance levels, suggesting that the potential benefits of MR in education outweigh the initial hurdles. The quantitative analysis shows variability in task outcomes, possibly implying the need for personalized learning approaches to accommodate diverse learning styles and paces. The post-experiment interview reveals that the line template was perceived exceptionally well, having a positive impression on all the participants and them stating its significant added value over the traditional video instruction. Most of the participants were not directly satisfied with the result of their origami creation, however found the MR experience pleasant and could see the implementation in the future with optimized visual capability and more support around the entire process in a step-by-step fashion of the craft.

By integrating MR with traditional learning methods, educators and learners can benefit from a more inclusive, adaptable, and engaging educational experience. Future research could explore longitudinal impacts of MR on skill acquisition and retention. Studies could also investigate how these technologies can be optimized for different learner demographics, including age groups and varying levels of technological proficiency. Furthermore, comparative studies between immersive learning and traditional approaches could yield deeper insights into the efficacy and adaptability of educational tools.

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