Reshaping Craft Learning: Insights from Designing an AI-Augmented MR System for Wheel-Throwing

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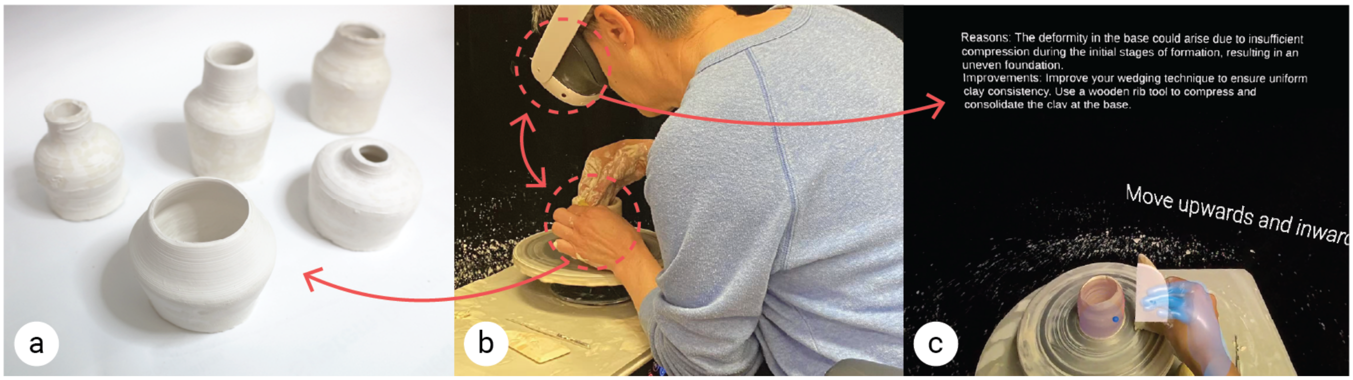

Figure 1: An overview of our AI-MR wheel-throwing guiding system: (a) ceramic pieces created by experienced participants; (b) system setup showing an experienced participant wearing the headset and shaping a ceramic piece under the system's guidance; (c) guidance interface displaying the suggestion functionality.

Abstract

The growth of media technologies and maker culture has expanded craft learning from instructor-guided models to diverse self-directed approaches. However, mastering crafts such as ceramics remains challenging due to their embodied nature and the difficulty of tacit knowledge transfer. While Mixed Reality (MR) and Artificial Intelligence (AI) have supported embodied task learning, their application in craft remains underexplored. We present an AI-augmented MR ceramic guiding system to investigate the interplay between these technologies and craft practices, including how they influence instruction design, shape user perception, and transform learning contexts. Our system provides immersive multimedia instruction and real-time shape-based feedback using computer vision and large language models (LLMs) to guide learners in wheel-throwing on a pottery wheel. Through a Research-through-Design process, we co-designed and evaluated the system with twenty novices and experienced ceramic practitioners. We offer design insights for AI-MR craft learning systems and identify opportunities to extend their application to creative, collaborative, and broader craft-making scenarios.

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CCS Concepts

• **Human-centered computing** → **Interactive systems and tools**; **Interaction design process and methods**; **Mixed / augmented reality**; **Empirical studies in HCI**; • **Applied computing** → **Interactive learning environments**.

Keywords

Mixed Reality, Interactive AI, Embodied Learning, Craft Learning, Personalized Learning, Instructional Design

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1 Introduction

Advancements in media technologies and the rise of maker culture have significantly transformed how people engage in craft learning [95]. On one hand, craft learning has expanded from traditional in-person instruction to various forms of remote and self-directed learning and practice. On the other hand, growing access to craft tools and communities has diversified pathways for engagement, allowing a broader audience to explore craft at different skill levels [93, 95]. However, achieving mastery remains difficult due to the challenge of acquiring tacit knowledge, a form of knowledge that is not easily articulated [22]. This includes complex and nuanced coordination of body, material, and tools (somatic); reflection on "critical incidents" [36] in complex craft processes [47] characterized by "workmanship of risk" [78] (relational); and the social dynamics of instructor-learner models in studio environments (collective).

Various technologies, such as sensors, multimedia, and Extended Reality (XR), have been adopted in various craft learning domains, such as cooking [82], pottery [4, 26, 65, 69], textile [43], woodworking [37, 74], and origami [91]. XR serves as an umbrella term that includes Mixed Reality (MR), Augmented Reality (AR), and Virtual Reality (VR). MR, in particular, offers advantages for self-directed learning by providing immersive experiences and overlaying rich information on real-world environments [96]. However, current MR applications fall short in addressing critical dimensions of embodied craft learning outlined above. We argue that integrating AI with MR technology can help address these challenges by offering context-aware, adaptive feedback that maximizes the benefits of in-person instruction. Ceramics, and particularly wheel-throwing, a foundational technique in ceramics and common starting point for beginners, is highly embodied and dependent on tacit knowledge, which makes it an ideal domain for investigating AI-MR for embodied craft learning.

While AI-augmented XR applications have shown promise in supporting embodied tasks in fields such as STEM education [18, 64, 107], medical procedures [75], skilled trades [14, 48], and emergency response [77, 108], little research has explored their potential in craft learning, particularly ceramics. Existing MR systems are largely focused on visualization and shape manipulation, often overlooking real-time guidance and material-sensitive interactions. To address this gap, we present an AI-MR ceramic guiding system as a design probe to examine its implications for craft learning, system design, and broader applications beyond learning. Our research aims to answer the following questions:

What does the interplay between AI-augmented Mixed Reality systems and embodied craft practices reveal about the evolving roles of systems, learners, and practitioners?

(RQ 1) How does the interplay between AI-augmented MR technology and the embodied nature of craft learning influence the design of instructions?

(RQ 2) How do novice and experienced ceramicists perceive the system's ability to support craft learning, and how do they envision its role in future practice?

(RQ 3) What broader impacts emerge as AI-MR systems and craft practices co-evolve to challenge existing roles and processes in craft practice?

To explore these questions, we adopted a Research-through-Design approach consisting of three phases: a formative study, system design, and user study (see Fig. 2).

In the formative study, we took a ceramic class for over a month and identified key steps and challenges to build an initial prototype. We then used this prototype as a design probe in an iterative inquiry process, including pilot studies and studio ethnography, to co-design with ceramists and learners and refine our design goals.

Based on the generated design goals, we developed and implemented our AI-MR ceramic guiding system in two modes: elementary and advanced. It is built on the Meta Quest 3 platform in pass-through mode, which allows users to engage in direct hands-on clay manipulation on the pottery wheel while receiving AI-augmented real-time guidance. We structured our system around the generated design goals, and it comprises two AI-augmented core components: (1) hand and clay holograms with gesture recognition function; and (2) shape-based feedback with computer vision and large language models (LLMs). Together, these components can be assembled and adjusted to match the skill levels of different learners, providing a personalized learning experience.

We invited two groups of participants, including 14 novices and 6 experienced practitioners and instructors, to use the system according to their skill level. Each group also watched a video demonstration of the alternate mode. After each session, we conducted semi-structured interviews and surveys to gather feedback on usability and the overall learning experience.

The Research-through-Design process enable us to examine how AI-MR systems shape embodied craft learning with virtual instruction overlays on the physical world, workflow and autonomy, real-time feedback, as well as their roles and use scenarios beyond the learning context. The findings prompt us to reflect on our system design, including how the processes of restoring, reconstructing, and augmenting reality enhance immersion and support craft learning; the value of detailed, hierarchical instructions; and the need for effective communication features. We also identify emerging patterns beyond our expectations during the study, such as a strong desire for spatial and motor-rich experiences and the importance of personalized learning that adapts to different skill levels and supports individual growth over time. Finally, we discuss new design opportunities by examining the dynamic relationship between craft practitioners and our system as both a creative support tool and a collaborative agent.

This work extends existing knowledge of how intelligent systems can support embodied learning and practice in ways that reimagine pedagogy, reshape learner-instructor collaboration, and change how learning and practice happen in craft communities. Our research makes the following contributions:

(1) We introduce an AI-augmented MR ceramic guiding system that enables embodied learning in wheel-throwing through interactive holographic feedback and adaptive instructions.

(2) We document an iterative Research-through-Design process with system designers and craft practitioners, and share insights into how users across skill levels engage with the system.

(3) We provide design insights into leveraging AI-augmented MR for embodied craft learning and discuss future development opportunities beyond learning settings.

2 Background

2.1 Craft and Ceramic Learning in HCI

Craft has been defined in multiple ways by researchers in different domains. According to the Oxford English Dictionary, craft is defined as "an activity involving a special skill at making things with your hands" [76]. As Adamson describes, craft can be understood more broadly as a "general process of making" [2]. Expanding on this, Kettley argues that craft can be fluid, serving not only as a means of reflecting the making process but also as an outcome in the form of a finished product [53]. Shiner offers a more comprehensive framework, defining craft as a combination of process

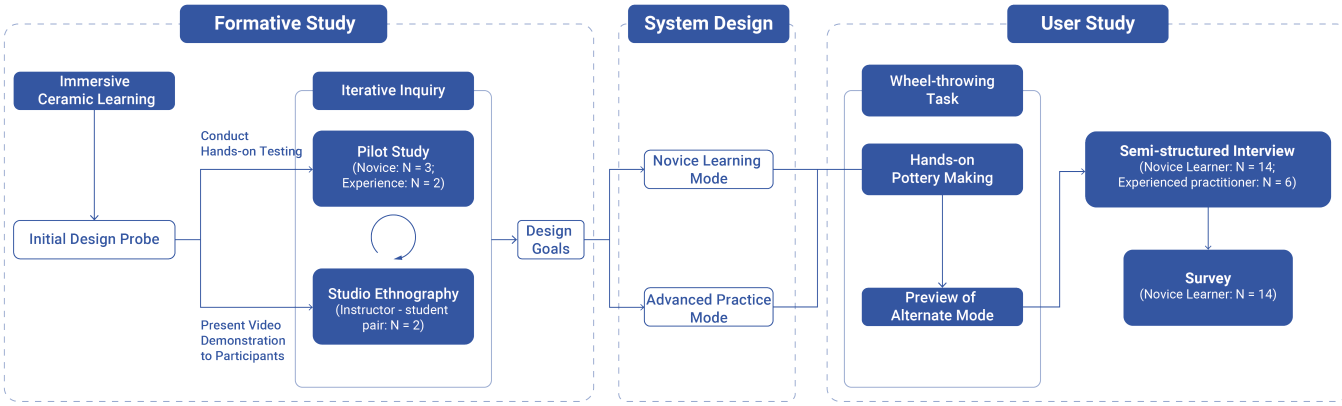

Figure 2: To explore our research questions, we adopted a Research-through-Design approach comprising three phases: a formative study, system design, and user study.

and practice to address its specificity in the modern context [93]. "Process" refers to disciplines such as teaching or cooking, while "practice" consists of three hierarchies: a general domain parallel to "art" or "design", conventions such as studio, amateur, or DIY, and specific activities such as pottery or masonry. Across these categories, all share four contestations: hand/body, material/medium, skill/mastery, and aims/functions.

In HCI, craft-based research is characterized by three key aspects: hybrid craft, aesthetically engaging artifacts, and knowledge gained through embodied engagement [27]. It has strong ties to materiality research, which explores traditions, material choices, and making through materials [34, 35]. Previous work has investigated the direct impact of materiality on computational tools [69, 84], as well as how such tools support production or raise critiques about their effect on traditional craft values [11, 69, 84].

In this research, we adopt Shiner's definition of craft to investigate learning-as-practice in amateur settings. We focus on how people learn wheel-throwing, a foundational technique in ceramics, by learning to control their bodies and materials, acquiring skills, and pursuing the aims of craft. In the context of ceramics, the making process is a complex task involving a sequence of steps that integrate materials, tools, and actions [47]. This process follows an iterative cycle characterized by a rhythm of action, rest, questioning, and further action [36]. At each stage, the body interacts closely with the material, developing an understanding of its properties, refining control over speed and pressure, and forming kinesthetic memory that translates into actionable skills [10, 55], ultimately achieving mastery with consistent practice. These intrinsic aspects of craft-making present unique challenges in designing computational tools to support the learning process.

2.2 The Shift in Embodied Craft Learning

Embodied learning, which involves acquiring knowledge through bodily activity [63, 94], resonates with our framing of craft as an embodied practice. Recent technologies have significantly altered how people engage in craft learning.

Traditionally, craft learning relied heavily on in-situ apprenticeship. The gradual transition from peripheral practices such as 'cleaning, organizing, and familiarizing with materials' to central tasks of making is seen as the 'spirit' of apprenticeship [30, 59]. Explicit teaching in apprenticeship is rare. Instead, learning usually occurs through 'careful observation, imitation, trial and error, and practice for improvement' [25, 58]. Other learning approaches, such as practice-led research [36] and the expert-learner approach [104], still adhere to the tradition, requiring knowledge to be passed down from master craftsperson to learners.

Today, learning craft has expanded beyond in-situ apprenticeship to self-directed learning. Educational technologies, including screen-based multimedia [24, 37, 82], sensor-based systems [4, 65, 74], and Extended Reality (XR) [47, 97, 98], have been introduced into craft learning to support self-directed practice and improve accessibility for a wider audience [95]. Wood et al. have demonstrated the effectiveness of online resources in acquiring complex craft skills [104]. As a result, the traditional apprenticeship model, and instructor-learner practices that build upon it, are no longer the sole pathways to craft learning. However, this shift calls for examination of how these new modes of learning affect the quality and nature of craft learning.

Thus, our research investigates how the AI-MR system mediates the transition from apprenticeship to self-directed, amateur learning and practice. We position our system as a design probe, a tool to initiate dialogue with the target group, deepen understanding of human experiences, and explore new design opportunities [33, 67].

2.3 Situating AI-MR in Embodied Craft Learning

In this section, we explain why we chose AI-MR by reviewing existing AI-MR systems and identifying research gaps in its application for embodied craft learning.

We selected the AI-augmented MR approach [42, 99] for our embodied craft learning system due to its ability to provide an immersive learning experience through virtual-physical interaction and context-aware real-time feedback. Technologies such as sensors and multimedia have been applied to craft instruction in various fields, including cooking [82], pottery [4, 26, 65, 69], textile [43], woodworking [37, 74], and origami [91]. MR offers a platform for integrating assistive information from various technologies into the augmented display. While there is no universal definition of MR, we adopt the concept of "strong AR," which emphasizes advanced interaction between users, virtual objects, and their environment [96]. Numerous studies highlight the advantages of MR in educational settings, such as STEM education [18, 64, 107] and professional training, including craft [9, 100]. The interactivity reduces reliance on active user control compared to other popular learning mediums, such as video, and demonstrates the potential to preserve the nature of the craft while deepening practitioners' understanding of the relationships between the body, materials, and tools [1, 72].

While MR is widely adopted in learning contexts, previous studies that evaluated the learning outcomes of XR in embodied tasks often do not show significant improvements over traditional methods [5, 29, 51, 79]. We argue that this is often due to the limited interactivity of previous XR systems, particularly the absence of contextual feedback typically provided by instructors. Integrating AI technology can address these gaps. AI can serve multiple educational roles, such as co-creation, mentoring, or tutoring [68], and can provide context-aware, adaptive feedback that is comparable to the interactive nature of in-person teaching.

Given its potential, AI-XR technologies have been explored to support embodied learning in domains such as STEM education [18], medical procedures [75], trade works [14, 48], emergency response [77, 108], and in rare cases, craft learning [12, 13]. Several studies have explored the use of XR in ceramic making, including VR [3, 15, 23, 32], AR [17, 38], and MR [31]. However, these works focus primarily on the technical aspects of shape manipulation of virtual ceramic pieces. Most of them, except [15], do not provide learning guidance, and none involve direct interaction with real clay. Moreover, none of these systems incorporate AI to support the making process.

Our system introduces novel contributions to AI-XR for craft learning in two aspects. First, MR is used to directly manipulate materials in the physical world. Second, the nature of wheel-throwing differentiates our system from previous work on how to use AI. It shows potential in teaching tacit knowledge by enhancing the seeing-moving-seeing process with adaptive instructions [45], mediating between learners' hands-on operation and the outcome through materiality [73], and simulating key aspects of situated social interaction [83].

3 Methods

We adopt a Research through Design (RtD) process, a research approach that "employs methods from design practice as a legitimate method of inquiry" [109]. Based on Frayling's definition of RtD [28], we value the system not only as a novel pedagogical system for real-world ceramic learning, but also as a record of our effort to generate new knowledge from the system, including design insights, user perceptions, and emerging findings beyond our initial scope of investigation with the local ceramic community and hobbyists.

We began by immersing ourselves in ceramic making to identify key steps and develop an initial prototype. This prototype was used as a design probe to iteratively refine system goals through pilot studies and design ethnography in collaboration with ceramists and learners. Guided by these goals, we implemented a two-mode system tailored for novices and experienced practitioners. Each group used the mode aligned with their skill level and watched a demonstration of the other. We then conducted semi-structured interviews and surveys to identify key insights into how the system affects embodied craft learning.

3.1 Formative Study

To identify what functions our system should provide to assist wheel-throwing, we conducted a formative study with researchers, experts, and novice learners to understand their learning needs and challenges, thereby building a foundation for our system design in an iterative manner [81].

3.1.1 Immersive Ceramic Learning. We began the study by immersing ourselves in the ceramic learning process through an auto-ethnographic approach, informally socializing into a ceramic-making group with specialized knowledge [40]. This approach positions the researcher as both an 'expert learner' [104] and a designer/developer, mediating between expert craft makers and the technical design process. We took a comprehensive ceramic course in a local studio, which included three 2-hour wheel-throwing sessions, one 2-hour trimming session, and one 2-hour painting session for firing over a month (see Fig. 4). This allowed us to document our own practice and train ourselves to become "expert learners." The auto-ethnographic approach helped us identify key steps in traditional studio practices and informed the design of the initial prototype used as a probe in the formative study. Guided by our instructor, we created schematic diagrams illustrating ceramic teaching approaches (Fig. 3). By synthesizing insights from these diagrams, we decided that the primary functions of the system should include hand and clay holograms, as well as shape guidance.

3.1.2 Iterative Inquiry. Our research process was highly participatory and iterative. We began with an initial prototype based on our understanding of the system's necessary features and conducted pilot studies using this prototype as a probe. In addition, we carried out short-term ethnographic studies in the ceramic studio to observe traditional learning processes [46, 85]. Throughout this process, we invited participants to co-design the system with us, continuously identifying new features and refining interactions. This process led to key findings and informed the design goals for the final system prototype. Through observations and participants' suggestions from these sessions, we moved beyond our initial auto-ethnographic perspective in immersive ceramic learning to reflect on teaching and learning practices as observers. This shift deepened our understanding of the wheel-throwing process during system development.

Pilot Study. We conducted pilot testing sessions with three novice learners (from PL-N-P01 to PL-N-P03) and two experienced practitioners (PL-E-P01 and PL-E-P02) to identify the essential features that support learning. During the sessions, participants were asked to experience all system functions, provide feedback, and suggest additional features through informal interviews. In addition, we consulted with our instructor for professional feedback using a demo video of the system. This iterative process allowed us to refine the system based on input from both novice and expert participants.

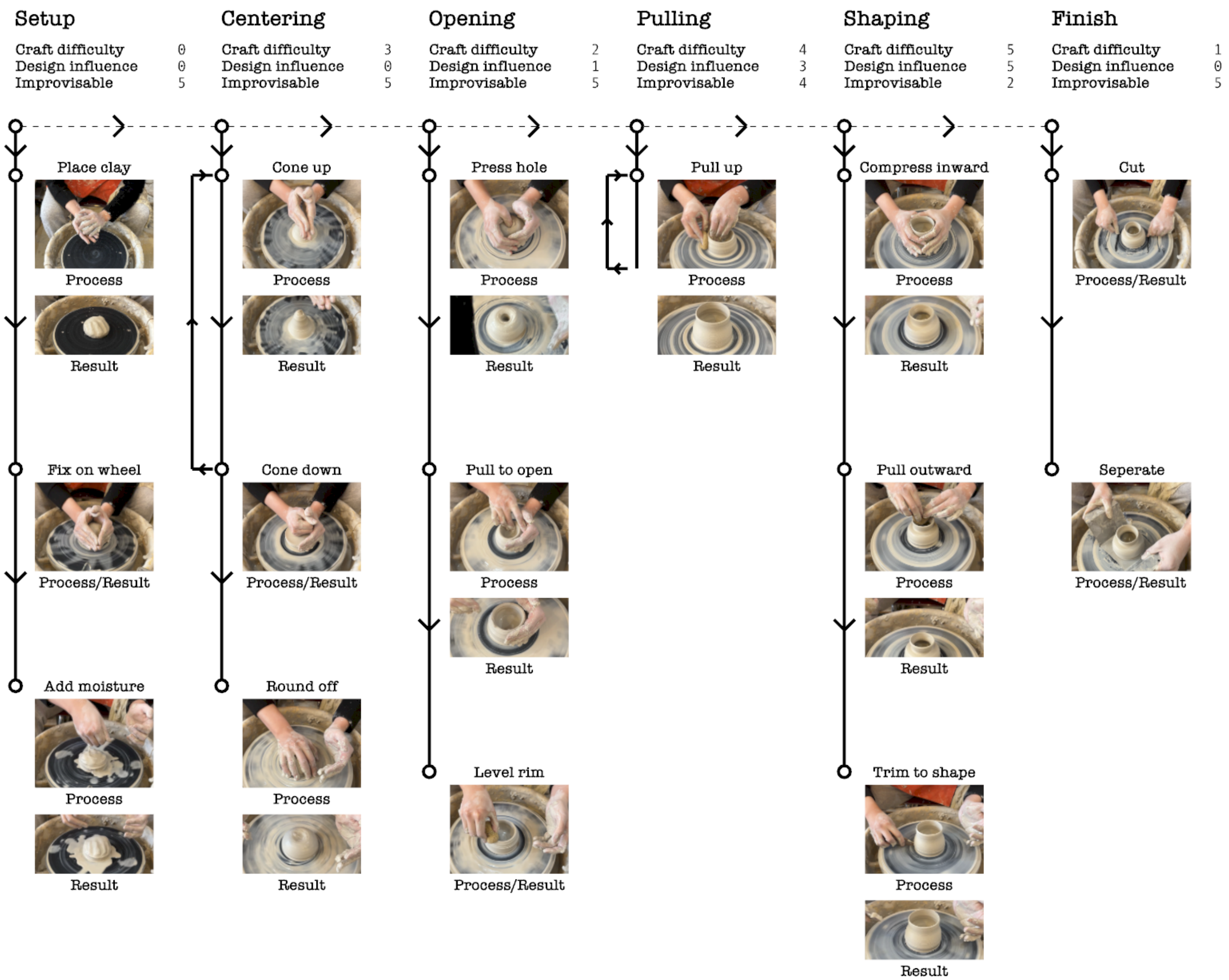

Figure 3: Schematic diagram of each step in wheel-throwing: The entire process is divided into the following steps: (1) Setup: Anchoring the clay. (2) Centering: Ensuring the clay is balanced on the wheel. (3) Opening: Creating the initial cavity. (4) Pulling Up: Raising the walls to the desired height. (5) Shaping: Creating specific shapes, such as the neck for vases. (6) Finishing: Removing the completed piece from the wheel.

Studio Ethnography. We contacted local ceramic studios and schools and conducted two short-term ethnographic study sessions with two instructors and two student participants, as Fig. 4.b shows. We brought our system into traditional ceramic studios, observed the learning session, and reflected with them on their practice and the system. Each participant was compensated with a $15 Amazon gift card for their time and effort.

During each session, participants practiced the same steps to make the same pottery pieces four times. The ethnographic study was conducted one-on-one in ceramic studios, with a researcher observing two participants at a time. The researcher sat alongside the participants and documented their operations with minimal interference to their learning process. Each session lasted approximately one hour. Following the session, both instructors and students were invited to watch a demo of our system and participate in an informal discussion. The discussion aimed to explore: (1) What they did during the session and how they reflect on it; (2) Their opinion on the system's functionality; (3) How they would use the system in their practice; and (4) The system's limitations and suggestions for improvement.

3.1.3 Findings. We documented participants' suggestions and our observations through recordings and analyzed them using thematic analysis [21]. We extracted three essential design implications that address the needs and challenges in the wheel-throwing process.

Different Perspectives on Skill and Functions: Adaptation to Various Skill Levels. From the pilot study, we found that participants in both experienced and novice groups had different opinions about

Figure 4: On-site study of the ceramic learning process: (a) Outcomes from our immersive ceramic learning in the studio; (b) Interaction between learners and instructors during an ethnographic study session.

the same wheel-throwing skills and functions in the system. For example, PL-N-P01 and PL-N-P03 considered centering to be the easiest step and pulling up the most challenging. In contrast, all experienced participants had the opposite view. PL-E-P01 explained this difference arises from different goals of two groups: For novices, mastering each step is more important. Without proper practice, performing harder ones, such as pulling up, is difficult. However, experienced practitioners prioritize the final outcome, which is directly affected by centering. In terms of function, the holograms of hands and clay were considered helpful by both groups for different reasons. Novices viewed it as a tutorial (PL-N-P02, PL-N-P03), while experienced practitioners occasionally used it to refresh their memory for specific operations (PL-E-P02). The differences and consensus between the two groups show the need for adaptive system design to accommodate users with different skill levels. This insight informed the development of two modes: a process-focused mode for novice learners and an outcome-focused mode for experienced practitioners, both supported by flexible core functions.

Instructor-Learner Dynamics: Structured Guidance Flows and Real-Time Feedback. A well-structured instructional flow and timely feedback from instructors are important for the learning process of novices. During our ethnographic study, we identified two guidance flows between instructors and novice learners: (1) Active flow: Learners initiated interactions with their instructors by describing their issues. Instructors responded by encouraging learners to reflect on the causes and attempt self-correction. If unsuccessful, instructors intervened to make the necessary corrections and provided emotional support afterward. (2) Passive flow: Instructors observed that learners' current shapes were incorrect and initiated corrections by adjusting the learners' gestures. If the adjustment failed, instructors transitioned to active flow. These two flows illustrate instructor-learner interactions in traditional settings and directly inform (1) our gesture learning process and shape-based feedback as forms of passive guidance, and (2) the use of voice commands as an active call for assistance.

Going deep into the Practice: Providing Detailed Guidance. A moderate level of detail is crucial for learners to understand what they need to do and to reduce their anxiety about the unknown. During the pilot study, we observed novice participants struggling with specific steps, such as fixing the clay on the wheel (PL-N-P01, PL-N-P02). To address this, we documented the missing details of gestures during the ethnographic study and continually refined our hologram to provide clearer guidance. In addition, we identified common rules for shape correction and the text-based guidance needed for each step to optimize system instruction from ethnography.

3.1.4 Design Goals. Based on the findings of the formative study and the gaps identified in the literature, we propose design goals to support embodied craft learning, specifically in wheel-throwing. The goals propose how the system can help craft learning and practice by emulating and augmenting the studio experience. These goals include: Embodiment, Process, Product, and Context.

Embodiment. Ceramic making, like many other crafts, is highly dependent on the interaction between the body and material. People learn the properties of material through their hands and tools with consistent practice. Thus, the system should respect the embodied nature of craft by helping learners deepen their understanding of materials and tools while encouraging them to experiment and practice. As an extension of the body, the headset can also influence the tactile experience of interacting with materials, which is another critical factor to consider in the system's design.

Process. For novice learners, acquiring explicit knowledge, such as learning a standard wheel-throwing process through teachable steps, is typically the second stage after becoming familiar with the material. For more experienced practitioners, deepening their understanding of tacit knowledge, such as sensing clay moisture, adjusting finger pressure during pulling, or intuitively responding to a wobble, forms a new dimension of learning. The system should support the transfer of both explicit and tacit knowledge by providing structured processes for practitioners at all skill levels.

Product. Regardless of skill level, ceramic practitioners often rely on the product, such as its shape and texture, as the most intuitive way to observe and reflect on their progress. Therefore, the system should provide real-time feedback by monitoring the product as it evolves, ensuring that practitioners stay on track throughout the making and learning processes.

Context. Our auto-ethnographic study confirms that interactions between ceramic instructors and learners in a classroom setting play a crucial role in the learning process. Therefore, the system should encourage the restoration of the instructor-learner dynamics and the context of in-person teaching by offering natural, intuitive, and practical instructions.

3.2 System Design

Based on design goals and insights from the formative study, we defined the functionalities of our system (Fig.6). The system includes two core features that can be customized and organized to support different skill levels. It provides structured, step-by-step guidance for novices learners and flexible, goal-oriented support for experienced practitioners.

3.2.1 System Setup. We created a ceramic-making corner in our lab with a pottery wheel (VEVOR 9.8" LCD Touchscreen Clay Wheel GCJX-008) as the main device and a webcam (Logitech C920) to

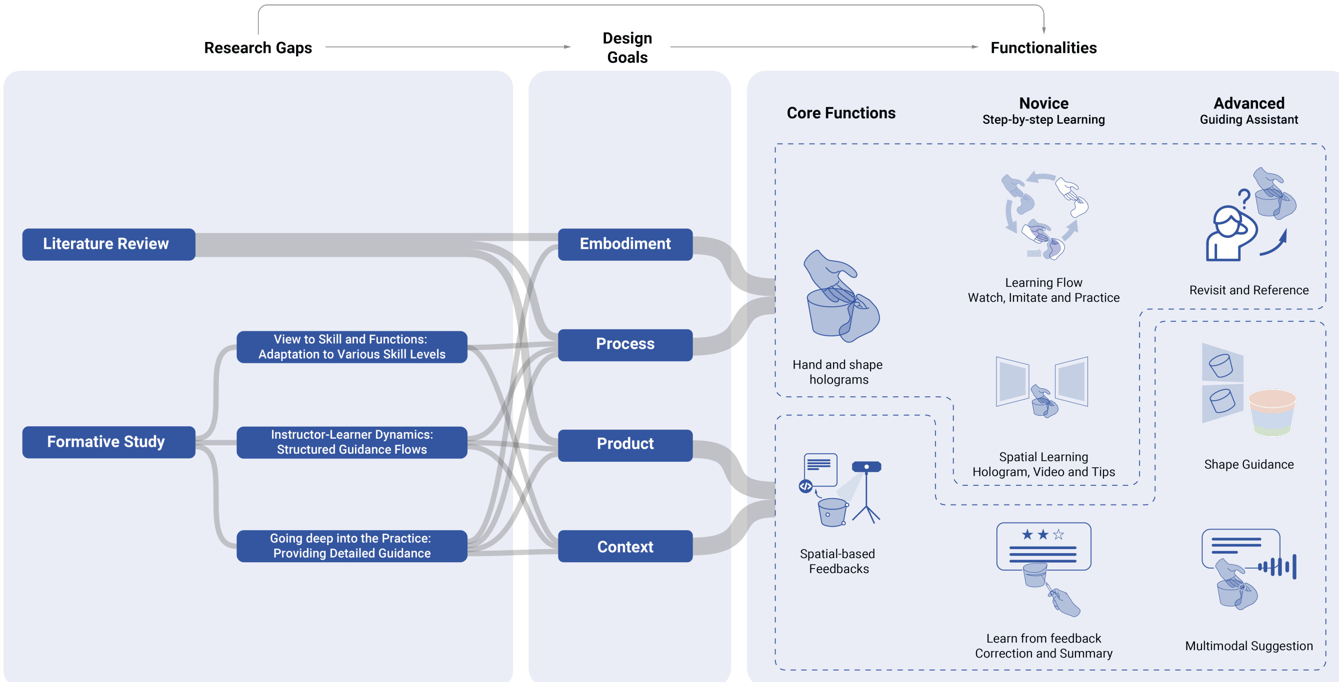

Figure 5: Overview of the system design process across three phases: identifying research gaps through a literature review and formative study, defining design goals, and developing the system.

capture the data of the shape being made (see Fig. 6). To improve the webcam's ability to capture the clay shape, we covered the corner walls with black cloth to enhance contrast against white clay and removed the pottery wheel's basin to prevent it from obstructing the camera view. Our system is built on Meta Quest 3 and uses its pass-through mode to enable real-time interaction with the physical pottery wheel and tools.

The setup process is straightforward: users wear the headset, sit in front of the pottery wheel, select the appropriate speed and mode, and initialize the selected tutorial using the controller. They then practice ceramic-making by hand while using voice commands (see Fig. 7, 8) to control the guidance progress.

3.2.2 Core Functions. We identify two core functions in our system: (1) hand and clay holograms, which serve as an immersive tutorial; and (2) shape-based feedback, including shape-based correction, guidance, and suggestions, which function as real-time feedback.

Hand and Clay Holograms. Our system offers hand and clay holograms to display the first-person view of each step. The holograms are created based on the schematic diagrams, modeled in Blender, exported as .fbx animation, and imported into Unity as prefabs. For gesture recognition, we piggybacked the XRHand package to convert the real-time gesture recognition results into text-based instructions. The language is simplified to make it easier to understand, ensuring accessibility for learners of varying skill levels.

Shape-based Feedback. Our system provides three types of feedback: correction, guidance and suggestions based on the clay shape. We developed a Python program that uses the OpenCV library to capture the outline of the object being shaped and identify critical features, such as the neck, body, and base in a vase, using Rhino.Python. The program evaluates the shaping progress by comparing the current form with a pre-stored target shape, generating similarity scores and boolean indicators based on predefined quality criteria such as symmetry. The evaluation results are further processed in two ways: (1) Based on the comparison of identified critical positions on the vase, text-based suggestions are generated using personalized prompts of different skill levels with OpenAI API. (2) Several slices at the intersection points between the current and target shapes are extracted and used to reconstruct a 3D outline of the clay shape. Both data outputs are sent to the system via servers and visualized as: (1) a real-time shape progress overlay on the anchor with three colors: red for "push inward," green for "correct shape" and blue for "pull outward" (see Fig. 6); (2) multimodal tutorial outputs that include text, audio, and hologram.

3.2.3 Elementary Mode for Novice Learners: Step-by-Step Learning. Novice learners with limited wheel-throwing experience are less familiar with each step, lack practice in wheel-throwing techniques, and need basic feedback to improve their practice. The system provides a detailed step-by-step tutorial and clear, accessible feedback during and after the learning process.

Learning Flow: Watch, Imitate, and Practice. From our ethnographic study, we observed that learners watch and imitate what their instructors do, and their gestures are occasionally corrected by the instructors. Correct and precise gestures are critical in wheel-throwing due to the high precision required in ceramic making. However, as observed in Section 3.1.2, traditional teaching methods

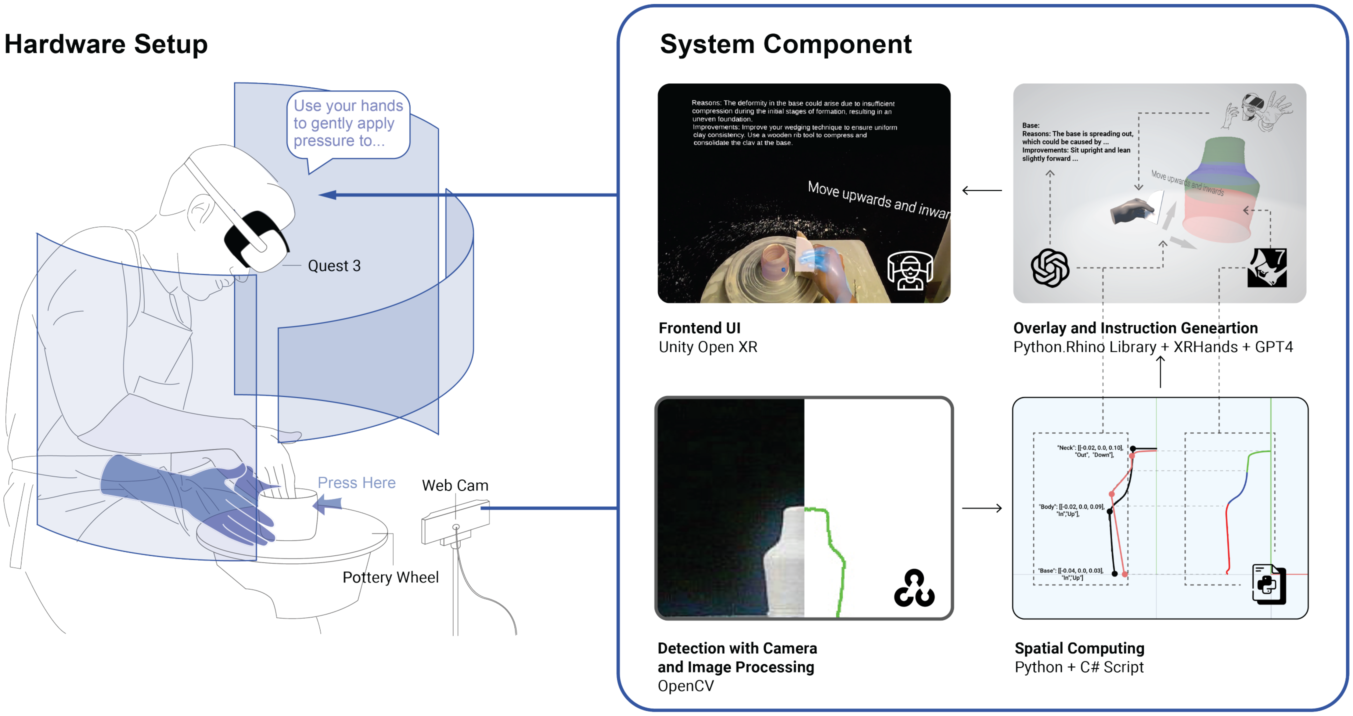

Figure 6: The ceramics guiding system comprises two main components: hardware and application. The hardware includes a pottery wheel, a webcam, and a Quest 3 headset as the display device. The software modules consist of a Python script for processing the detected shape and generating instructions via the OpenAI API, a piggybacked XRHand package for gesture recognition and guidance, and C# scripts for managing the learning process, including backend logic and the frontend user interface.

often struggle to provide real-time feedback on students' gestures while they follow the instructor. Our system adopts a similar procedure but enhances the experience: users first watch a holographic animation to observe the gestures, then imitate the starting gesture with real-time hand-part suggestions, and practice what they have learned from the hologram. (see Fig. 7.a)

Spatial Learning: Hologram, Video, and Tips. Wheel-throwing is a three-dimensional task that requires learners to shape clay in space. While gesture imitation is foundational, understanding spatial relationships in 3D is equally critical. From our observation, in traditional studio settings, observation alone is often insufficient to capture the nuanced details of hand movements and their interaction with clay; even with hands-on guidance, the learner's observation is typically limited to a third-person view of the instructor's actions. Our system leverages MR to create a spatial immersive display, providing 1) a first-person hologram overlay to illustrate the relationship between hands and clay, allowing users to closely observe and understand the intricate details of the gesture; 2) third-person demonstration videos and tips from experts to reconstruct the knowledge from traditional studio by conveying contextual factors such as moisture, pressure, and speed (see Fig. 7.b). The system enhances the learner's understanding of both explicit and tacit aspects of ceramic making, bridging the gap between traditional and immersive learning experiences.

Learn from Feedback: Correction and Summary. For novice learners, it is crucial to receive feedback during their learning process, especially when they encounter difficulties and need guidance on how to improve for future attempts. Our system fulfills these needs by providing real-time corrections during "critical incidents", restoring the hands-on instructional experience of in-person learning (see Fig. 7.c). The system also generates summaries with suggestions for the final clay shape, allowing learners to reflect on their current attempt and improve their performance in the next round (see Fig. 7.d). This iterative cycle of doing, receiving feedback, and trying again aligns with experiential learning theory [56] and reflection-in-action [89], enabling learners to make sense of their embodied actions as they engage in them.

3.2.4 Advanced Mode for Experienced Practitioners: Real-time Guidance. Experienced practitioners have acquired the core skills for ceramic making, yet are still seeking opportunities for refinement and creation. The system aims to support their independent practice while offering guidance to refine their pieces and deepen their understanding of the craft through augmented practice.

Revisit and Reference. During our ceramic study journey and pilot studies, we observed a need among experienced practitioners to refresh their skills. They can revisit gestures and shape holograms to reinforce their techniques at any time (see Fig. 8.b). The system also visualizes the real-time scanned current shape alongside the

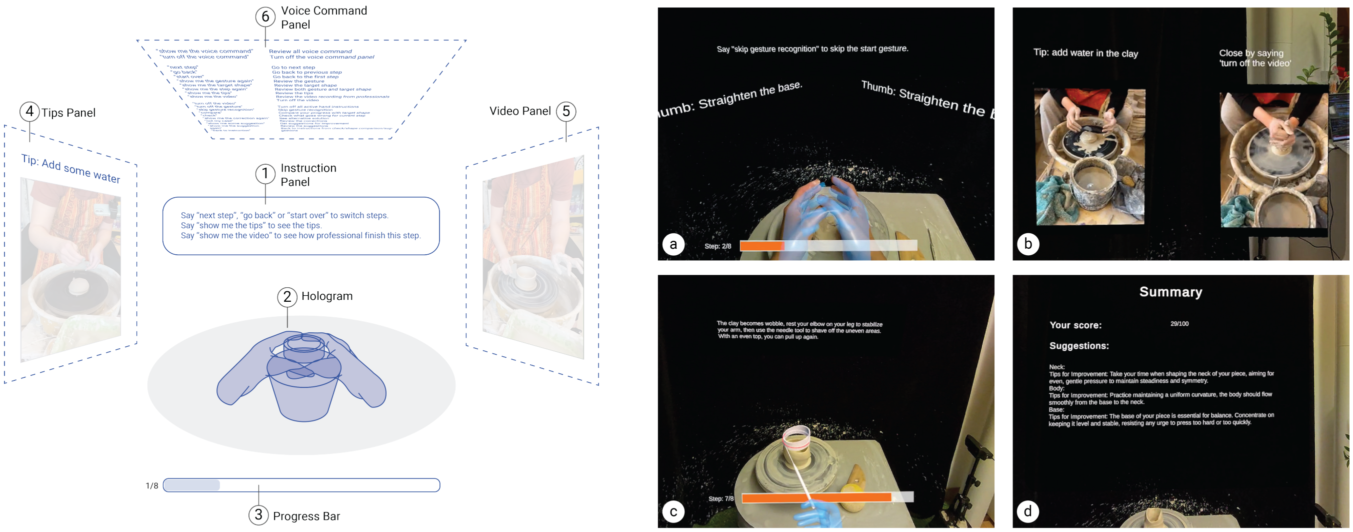

Figure 7: Novice system's UI and functionality. Left: UI diagram for novices: (1) Instruction panel displaying all text-based instructions for the current step. (2) Hand and clay holograms for reference and imitation. (3) A progress bar to track learning progress. (4-6) Optional panels for video playback, tips, and voice command listings. Right: In-situ demonstration of system functionality in headset: (a) Gesture imitation with text-based instructions. (b) Video and tips-based guidance. (c) Rule-based correction using hands and tools. (d) Summary with scores and suggestions for the next session.

pre-loaded target shape from the selected tutorial on a side panel for reference (see Fig. 8.a). Practitioners have the flexibility to make pottery at their own pace while periodically referring to visual updates as needed.

Shape Guidance. For experienced practitioners, the goal shifts from simply creating a decent ceramic shape to achieving greater precision and refinement. We provide real-time color-coded overlays to guide them in shaping the clay by comparing the current shape to the target shape during the process. They can refer to the overlay and adjust the shape accordingly (see Fig. 8.d).

Multimodal Suggestion. For experienced practitioners, their advanced knowledge of skills and tools leads to higher expectations of more detailed and precise instructional assistance. Expanding on the summary in elementary mode, our system provides multimodal suggestions based on essential pottery parts (see Appendix A), integrating text, audio, and gesture/shape hologram (see Fig. 8.c). This multimodal approach delivers more detailed information, making it easier for experienced users to deepen their understanding and extend their knowledge.

3.3 User Study

We conducted user studies as part of our investigation to answer our research questions. We evaluated the system's usability, explored how participants with different skill levels perceived its design. We also wanted to understand how the system supports their learning and practice, as well as how they envision using it in the future.

3.3.1 Recruitment and Participants. We distributed recruitment posters across our university's facilities and screened participants with different skill levels: novice learners, experienced practitioners, and instructors. After each session, we recruited additional participants through word of mouth. Cold recruitment helped mitigate bias by attracting participants from different backgrounds and ensuring they had no prior exposure to the system. Ultimately, we invited 20 participants, divided into two groups: six participants in the experienced group (two instructors, two proficient practitioners, and two experienced practitioners, see Table. 2), assigned IDs from E-P01 to E-P06; and 14 participants in the novice group, assigned IDs from N-P01 to N-P14 (see Table. 1).

Table 1: Backgrounds of novice participants: Craft practice and MR exposure

ID	Ceramic Making Experience	MR Headset Experience
P01	0	No
P02	0.5 months	Yes
P03	1 month	Yes
P04	0	Yes
P05	0	No
P06	0	Yes
P07	2 months	Yes
P08	0	No
P09	0	No
P10	0	No
P11	0	No
P12	1 month	Yes
P13	1 month	No
P14	0	No

3.3.2 Procedures. We invited both novice and experienced participants for a one-hour on-site testing session (see Fig. 9). After each

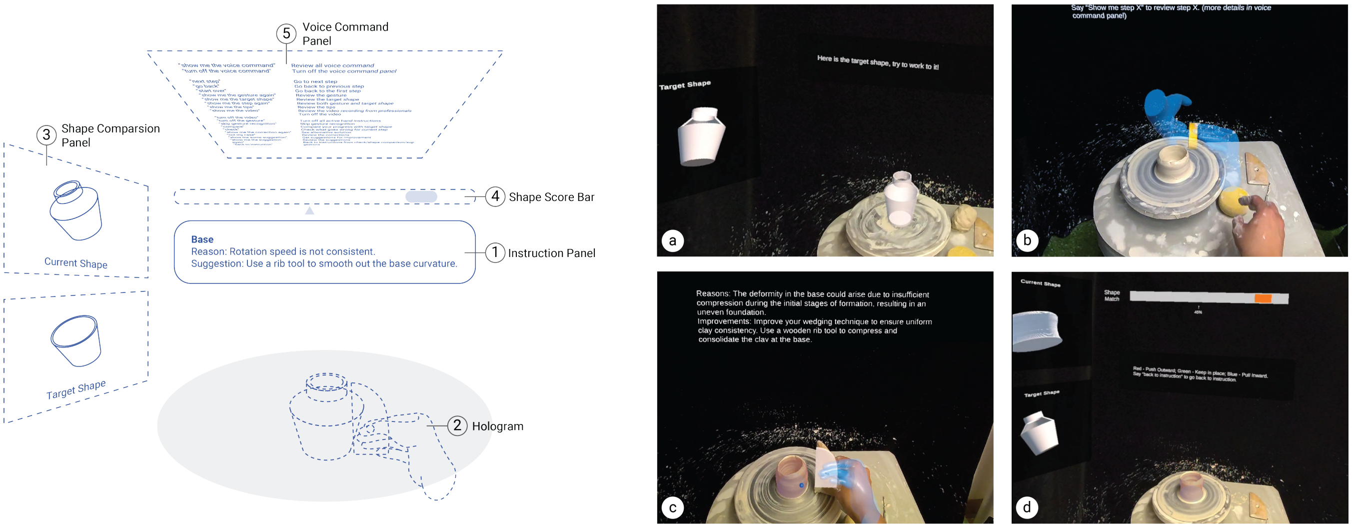

Figure 8: Experienced system's UI and functionality. Left: UI diagram for experienced users: (1) Instruction panel displaying all text-based instructions. (2) Optional hand and shape holograms for skill refreshment. (3) Optional shape comparison panel to track the current clay shape. (4) Optional shape score bar indicating progress. (5) Optional panel displaying all available voice commands. Right: In-situ demonstration of system functionality in headset: (a) Practice goal and reference panels; (b) Recalled gesture hologram for skill review; (c) Multimodal suggestions with text, audio, and holograms; (d) Color-coded shape guidance.

Table 2: Backgrounds of experienced participants: Craft practice, teaching experience, and MR exposure

ID	Ceramic Making Experience	Teaching Experience	MR Headset Experience
P01	1 year	No	No
P02	34 years	Yes	Yes
P03	10 years	Yes	Yes
P04	2 years	No	Yes
P05	4 months	No	Yes
P06	4 months	No	Yes

session, we conducted semi-structured interviews and surveys to collect data for analysis. The complete interview questions and survey are available in Appendix B, C.

Consent and Onboarding. This study was approved by the Institutional Review Board (IRB) of our university. At the beginning of the study, we provided participants with detailed explanations and obtained their consent. We then conducted an onboarding session to help them familiarize themselves with the headset, the pottery wheel, and the material (air-dry clay), which took approximately five minutes. During this period, participants were free to ask questions and seek clarifications to ensure they were comfortable using the system before beginning the study.

Wheel-throwing Task. In each session, participants from both the experienced and novice groups were given 30 minutes to complete the same task: making a vase. Participants in the novice group were assigned the elementary mode and followed the step-by-step tutorial. Those in the experienced group were assigned the advanced mode and independently worked to achieve a given target shape. During the study, participants freely explored the system's functions described in Section 3.2, using features they found useful to navigate their progress. We encouraged participants to explore as many features as possible to provide comprehensive feedback, though their use was not required. The first author sat nearby, observing participants' interactions with the system and providing assistance when needed. All participants were also invited to watch a video demonstration of the alternate mode.

Semi-structured Interview and Survey. After the session, we conducted a 20-minute semi-structured interview with each participant. The interview with novice participants focused on (1) their experience with the system and (2) potential usage scenarios. For the experienced group, the interview aimed to gather feedback on (1) their experience with the system, (2) how they would use it and how it might influence their current practices, and (3) system limitations and suggestions for improvement. In addition, participants completed a survey that included questions designed to evaluate our design goals outlined in Section 3.1.4, providing data that complemented insights from the interview.

3.3.3 Data Collection and Analysis. During the task sessions, we took handwritten notes to document the activities of participants, which informed our interviews. We recorded the semi-structured interviews and transcribed them using Otter.ai. Following the thematic analysis approach, we reviewed the transcripts and conducted interpretation sessions to extract concepts. The first and third authors collaboratively coded the transcripts. Using an inductive method, we generated initial codes through open coding and then clustered them into higher-level themes through affinity diagramming. These diagrams were refined and iterated during weekly meetings over two months to identify recurring patterns and develop final themes.

Additionally, we used a modified System Usability Scale (SUS) survey with a 5-point Likert scale to offer a quick, simple, and general evaluation of the system based on the generated design goals: Embodiment, Process, Product, and Context [7]. Since there was no baseline comparison in our study, we adopted the rule-of-thumb score of 3 out of 5 as a reference point [87]. Although the survey results provide valuable information on the system's performance, the primary purpose was to complement the themes either by supporting them or by identifying potential gaps that may require further exploration.

Figure 9: Participant engagement with the system: a) Left: Experienced user E-P02 refining the shape with system guidance. Right: Ceramic pieces created by experienced users. b) Left: Novice user N-P03 practicing gestures using the projected holograms in the headset. Right: Ceramic pieces created by novice users.

4 Findings

We present our analysis through five themes. Our findings highlight tensions between virtual instruction and the physical environment, illustrate the impact of the system's guiding flows on craft knowledge transfer, and reveal the need for real-time feedback, both in-situ and beyond the clay shape. They also suggest potential roles and use scenarios for the system in craft learning. These findings indicate the system's potential to enhance embodied craft learning, as well as opportunities and limitations of supporting improvisation in the craft process for both novice learners and experienced practitioners.

4.1 Tensions Between Virtual Instruction and Physical Environment in Embodied Craft Learning

4.1.1 Video and Hologram as a Compound View for Embodied Craft Learning in MR. Participants in both groups generally felt that holograms were effective in the following aspects: (1) Six participants (N-P01, N-P04, N-P09, N-P12, E-P02, E-P06) thought that gesture holograms helped them understand what actions to perform and where to position their hands, with survey results indicating a moderate improvement in body control (M = 3.50, SD = 1.09). For example, N-P04 found this very helpful: *"What's most helpful was the initial gesture, like where the finger should be put on, which part of the ceramic."* (2) Four participants (N-P09, N-P14, E-P01, and E-P06) felt that the projected hologram of the shape helped them identify the goal and track progress. E-P01 said: *"... you're able to put the shapes in here (the pottery wheel) so that I can see and compare them, and I think that that is very helpful in terms of practicing."*

However, three participants (N-P02, N-P09, E-P02) noted that the holograms lacked detail in the hand-clay interaction. They were uncertain about which part of the hand to use or how to apply pressure. N-P09 expressed his confusion: *"It shows you where your hand should go, but it does not say which part of your hand is supposed to be touching the clay."* Three participants (N-P03, N-P06, and E-P05) also found the instructions too mechanical, both in animation and text content. E-P05 commented on the gesture recognition text instruction: *"... I have to read a lot of sentences. I don't know how to actually listen to the thing to make changes."*

Ten participants found video instructions to be more helpful than gestures in the following aspects. Novice learners thought that videos provided richer details and helped them gain a sense of tacit knowledge. The videos allowed participants to observe the mutual effects between hand gestures and changes in the shape of the clay more intuitively (N-P02, N-P03, N-P06, N-P08, N-P12, N-P13, and N-P14). N-P08 described her experience when referring to the video: *"I saw the video and I tried to make the same thing, and I saw mine, I know it's not perfect, but okay, I think I can move on."* Through video, participants could also infer additional details such as appropriate water use, speed, and pressure (N-P02, N-P07, and N-P11). N-P02 noted: *"I can see movement and also the texture of the clay. Sometimes I can judge if I need more water or not."* For experienced practitioners, video recalled their expertise better than the gesture instructions for the same reason: E-P05 said: *"The system has the hand over the clay, and it does have instructions, but when I watched the video, I could kind of see her (the instructor in the video), feeling the clay and shaping it, so that was helpful."*

Three participants (N-P01, N-P04, and N-P14) recognized the intention behind our design choices and acknowledged the combined impact of gesture and video. Participants felt that cross-referencing between videos and holograms helped them observe the holograms from different viewpoints, thus acquiring a better understanding of their shape progress. N-P04 appreciated this feature, stating: *"Just as I feel like it did it well by seeing how it's three dimensional. It's hollow inside. So it's kind of you get what it is like in a brief structural way."* Additionally, this combination also helped participants correct errors when following the instructions (N-P01 and N-P11). N-P01 reflected on her practice: *"I think I was a little bit unsure*

Table 3: Summary of key findings from the user study on our AI-augmented Mixed Reality ceramic guiding system.

Theme	Section	Sub-theme	Description
Tensions Between Virtual Instruction and Physical Environment	4.1.1	Video and Hologram as a Compound View for Embodied Craft Learning in MR	- Gesture holograms supported the understanding of hand actions. - Shape holograms helped with goal identification and tracking progress. - Holograms lacked detail and was overly mechanical. - Videos provided richer detail and tacit knowledge cues for novice and helped experienced refresh their skills. - Cross-referencing video and holograms helped spatial understanding and error correction.
	4.1.2	MR as Both Assistance and Obstacle in Physical Environments	- MR is a better alternative to screen-based instructions because it enabled direct engagement with materials and combined visual instructions with the physical environment. - Novices feel urged to interact with the hologram, which often leads to damaging their in-progress work. - Participants struggled to perform precise actions while interpreting spatial instructions.
System Workflow's Impact on Craft Knowledge Transfer	4.2	Immersion Is Beneficial but Constrained by Skill Discrepancies	- Step-by-step workflow was immersive and beneficial to learning but easily disrupted by mismatches between instructions and real-world conditions, further exacerbated by streamlined flow. - Fixed prompts and criteria were hard to adapt to individual progress.
	4.2.2	Autonomy for Craft Knowledge Acquisition	- Autonomy allowed participants to customize progress - Autonomy brings novices the freedom to learn through trial and error without the pressure of instructor oversight, but it may also lead them to skip critical steps and overlook essential knowledge.
Need for In-Situ and Personalized Instructions Beyond Shape-Based Feedback	4.3		- Instructions lacked personalization and contextual information. - Feedback focused too narrowly on shape-based evaluation. - Participants wanted more proactive guidance.
Perception on System's Roles and Use Scenarios in Craft Learning	4.4.1	When and How to Use the System	- The system is valuable for early-stage learning and skill development. - The system is ideal for hybrid learning and post-instruction practice. - The system enables scalable, personalized instruction for instructors. - The system acts as a mediator between learners and instructors. - Alternative uses: social activities, professional training, and production assistance.
	4.4.2	Comparison Between the System and Human Instructors	- The system excels human instructors by working as knowledge repository and supporting asynchronous instruction. - The system lacks the ability to convey various forms of tacit knowledge: physically intervene in the making process, offer interactive emotional support, provide personalized experiential insight, or flexibly respond to learner-specific questions and situations.
Improvisation Is Limited by the Nature of Wheel Throwing and Skill Levels	4.5		- The system offered limited space for improvisation across skill levels. - Novices improvised unconsciously when struggling with steps. - Experienced users felt constrained by task rigidity, habits, perfectionism, and physical limits of wheel-throwing.

about that previous step (gesture animation) so I was trying to fix it before continuing, then I looked at the video and I was like oh yeah."

4.1.2 MR as Both Assistance and Obstacle in Physical Environments. Based on the survey results, the MR system significantly reduced the perceived difficulty of learning wheel-throwing (from (M = 3.57, SD = 0.85) to (M = 2.36, SD = 0.91)). Participants appreciated MR as it enables them to see both the visual instructions and the physical environment. Three participants (N-P02, N-P06, E-P02) recognized the benefit of MR in allowing them to engage directly with the material (M = 3.57, SD = 0.94). N-P02 mentioned: *"...I was able to learn how it feels to have something else beneath you and how it feels to touch the clay."* They saw MR as a natural fit for ceramics, where traditional screen-based interactions are less practical (N-P04, N-P13, E-P03). E-P03 said: *"I think mixed reality, like this medium, is uniquely suited for ceramics because your hands are dirty and you can't really control a traditional interaction modality."* N-P13 mentioned: *"I think headsets are very helpful because you don't need to look up and down to your phone screen and to the wheel."*

Despite general satisfaction with how the system allows participants to control their body movements (M = 3.5, SD = 1.09), participants expressed concerns about certain design choices for presenting instruction with MR in the physical environment. The hologram's overlay on the clay sometimes caused novices to damage their work due to their urge to practice directly on the clay (N-P07 and N-P09). *N-P09 explained: "Because you do it (ceramic making) on clay, it's very hard to correct... As soon as my hands were placed, I was already touching the clay.'* Participants also noted a conflict between virtual instruction display and the physical demands of wheel-throwing. They found it difficult to maintain precision while constantly adjusting their position to view some of the spatially organized instructions (N-P04 and E-P07). E-P05 highlighted this challenge: *"So if I came too close to my part, I cannot see instructions. So I might just stay a physical distance away from my pottery to make sure I can read all of it. But that means I cannot look very closely at the pottery, the details."*

4.2 System Workflow's Impact on Craft Knowledge Transfer

4.2.1 Immersion Is Beneficial but Constrained by Skill Discrepancies. Participants in both groups acknowledged that the step-by-step workflow in the system was immersive, providing a strong learning experience (M = 4.21, SD = 0.70). They also reported that it made wheel-throwing noticeably easier (reducing perceived difficulty from (M = 3.57, SD = 0.85) to (M = 2.36, SD = 0.93)) and helped them improve their craft skills (M = 3.64, SD = 0.84). Four participants (N-P08, N-P11, E-P01, and E-P04) compared the experience with playing a video game in a real-world context. N-P08 expressed enthusiasm for the system: *"I play video games. I was very excited to use something like that in video games. It was very nice to use it because I felt like I was playing a video game."*

However, seamless immersion is easily disrupted due to the discrepancy between the ideal condition in the instruction and reality. The immersion intensified the sense of flow, but also amplified the surprise when some functions did not work as expected (N-P04, N-P05, and N-P12). N-P04 expressed her unease: *"The step seems to be very streamlined, but if there is any chance there is an unexpected something there kind of freaked me out."* The system provides text prompts for step goals and criteria for the next step, but five participants found it challenging to adapt them to their individual progress (N-P01, N-P02, N-P04, N-P09, and N-P14). N-P09 explained a mistake due to this limitation: *"it said the base should be four to five millimeters thick. So I was aiming for the base of the wall, and it hit me later when I realized my thumb's going really far down here."*

4.2.2 Autonomy for Craft Knowledge Acquisition. Participants in both groups appreciated the autonomy offered by the system compared to other conventional learning methods, such as in-person learning or videos. This autonomy enabled participants to customize their progress while participating in physical making activities (N-P01, N-P02, N-P09, E-P02, E-P03, and E-P04). N-P09 expressed his preference for the system: *"Even if I had like a video playing, showing me how to do it, this (system) is much better than that because if I'm in the middle of doing it, I can't just pause the video and restart or look for Google tips on what I've done wrong very easily."* E-P02 and E-P03 also shared the same opinion: *"I like how much autonomy you give the user. Like you can skip certain parts. You can decide. You can basically override the system."* Novice learners valued the freedom of trial and error at their own pace without the pressure of instructors (N-P06 and N-P14). N-P06 said: *"The good thing is you can keep asking again and again, and not have to worry about teacher fatigue or patience. You just keep asking for the same instruction so that's very beneficial."* However, some experienced participants also pointed out the downsides of autonomy. The system's flexibility might cause users to bypass critical steps and lose essential knowledge. E-P04 indicated: *"... so if you cannot understand that, you cannot even go past that, and even if you just skip it, still you're missing the technique, the theory behind it, so you cannot actually learn it."*

4.3 Need for In-Situ and Personalized Instructions Beyond Shape-Based Feedback

Participants found the real-time feedback helpful during the interview, with corrections being particularly beneficial (N-P01, N-P03, N-P09, N-P10, and E-P06). However, survey results showed that all three types of instructions received scores at or below the average: shape guidance (M = 3.14, SD = 0.95), suggestions (M = 3.00, SD = 0.96) and corrections (M = 2.86, SD = 0.77). While participants found the instructions to be intuitive (M = 3.36, SD = 0.93), they reported that they lacked accuracy (M = 2.79, SD = 0.97). The interview responses on these functions provided insight into the discrepancy. Four participants felt that the instructions were not personalized and contextualized beyond shape-based feedback (N-P07, N-P13, N-P14, and E-P02). N-P13 expressed difficulty in adapting the suggestion for their progress: *"I like the correction feature, but it wasn't very situation-specific. I feel like I don't really know what we're doing wrong and how to fix it."* E-P02 felt the suggestion did not contextualize to their skill level: *"I didn't pay attention to the suggestion content, because it was all things that I know theoretically"* Four participants felt that instructions should be more proactive (N-P04, N-P13, E-P04, and E-P08). N-P04 said: *"I hope there are more proactive features to prevent me from making mistakes and suggestion changes before I ask for help."*

A common complaint among many participants was that the system lacked explicit visualization of contextual factors beyond shape, such as water, hand pressure, and wheel speed, which are also critical to the wheel-throwing process (N-P05, N-P06, N-P09, N-P11, N-P12, N-P13, E-P02, and E-P08). N-P07 mentioned this issue: *"The AI checks are all based on the visual acuity of the model. So when it was told to cut off the wobbly part above, it didn't know it had a lot of water, so it wouldn't come off by cutting it off."* E-P02 commented: *"The hardest thing with the glasses on was knowing what the texture of the clay was going to be before I touched it because you can't really see how wet it is."*

4.4 Perception on System's Roles and Use Scenarios in Craft Learning

4.4.1 When and How to Use the System. Participants recognized the system's value in providing basic guidance during the early stages of craft learning (N-P01, N-P03, N-P04, N-P05, N-P06, N-P07, and E-P05). N-P07 stated: *"In the early stages, instead of you alone practicing, you can practice with the AI."* They also saw the potential for using the system to learn different skills, such as shape creation and shaping techniques, for both novice and experienced practitioners (N-P01, N-P02, N-P12, E-P02, and E-P06). N-P02 suggested: *"Maybe I'll be able to follow different tutorials to make different shapes. That would be kind of nice."* E-P02 said: *"For somebody who has been doing it for a while, following the instructions would be a way of learning new skills, and so I could see a lot of potential in that."*

Participants reflected on the relationship between the system and human instructors. They viewed the system as a mediator between learners and instructors (E-P01, E-P03, and E-P04). E-P04 emphasized this potential: *"It could be cool to bounce back with a real professor because if a professor can give you some input but you're not that good yet you can try and improve that particular skill with the tool."* However, human presence was seen as necessary. Participants preferred to use the system in a hybrid learning context (M = 4.00, SD = 0.88) rather than learning only with the system (M = 3.43, SD = 1.28) (N-P01, N-P06, N-P07, N-P11, N-P12, and E-P03). E-P03 explained: *"I do imagine that you would need a human instructor. You need to go to the class once at least to kind of get the human instruction and maybe do it once."* They also preferred to use the system to review and practice skills after seeing instructors (M = 3.86, SD = 0.95) compared to previewing skills (M = 3.21, SD = 1.25) (N-P07, N-P09, N-P10, N-P11, E-P03, and E-P04). N-P07 highlighted its value: *"...it can be complemented with ceramic classes if I ever take them, so I can use once a week teacher and twice a week this, because it's no use seeing the teacher again and again if you don't practice."*

Participants saw potential for the system to shift the paradigm of craft learning. Both groups noticed different approaches to passing on knowledge compared to traditional craft learning methods (N-P07 and E-P02). E-P02 noted: *"This all felt very much like I was groping my way towards finding where the instruction was valuable rather than having it handed to me."* N-P07 said: *"It (system)'s more of imitation-based learning, that (teacher) is more of correction-based learning."* Experienced participants saw the potential for the system to provide scalable and personalized learning, helping to establish fundamental skills while allowing instructors to focus on more tailored guidance. E-P06 explained: *"Maybe if it's in a class setting, everyone uses the VR headset at the same time to establish the same understanding. And then for parts that they're struggling with, the human can come in. Instead of the human having to teach everything, it's more personalized and nuanced, more contextual of what the student is lacking."*

Participants also imagined the system being used in diverse contexts beyond amateur learning. Using it as a creative activity for socializing, such as dating, was mentioned by two participants in our pilot study. The system was considered ideal for amateurs who want to learn professionally (E-P01 and E-P02). E-P01 described the system: *"I think it's a hobbyist's aid, it's more for the amateurs who want to learn something, to be able to learn it relatively professionally, and learn it to a very good status."* Additionally, participants saw potential for the system to assist with specific steps in professional production (E-P01, E-P02, and E-P04). E-P01 noted: *"a production aid needs to be very specialized, it's a very complicated thing to make, and it (the system) may be an aid to some of the steps."*

4.4.2 Comparison Between the System and Human Instructors. The system's functionality shaped participants' perceptions of intended usage scenarios. Considering how the system shifts the learning context from human instructors to collaborative systems, we encouraged participants to reflect on its functionality and make comparisons. Participants identified several benefits of learning from human instructors.

Nine participants from both the novice and experienced groups mentioned that the system lacks a human instructor's ability to fix mistakes in the clay for them on the spot (N-P01, N-P02, N-P03, N-P04, N-P06, N-P07, N-P09, E-P02, and E-P03). As N-P04 stated: *"The teacher will be able to directly do it for me, correct it so that I can use a relatively perfect shape. I can have it done before I move on to the next step, but here I have to go with whatever I have."* Human instructors can provide interactive emotional support (N-P02, N-P04, E-P08), N-P02 expressed her wish for the interactive support: *"I wish it was asking me 'Are you ready?' And I'd be like, 'oh yeah, I'm ready."* E-P06 commented on the final summary: *"A score is nice, but also saying, hey, you did it."*

In terms of instructional depth, human instructors can provide customized experiential insight (N-P02, N-P09, E-P02, E-P03, and E-P04). N-P09 shared: *"They would have had experience like, I remember I screwed this up before. And this is how I didn't do that anymore."*, *"They could see if it's too wet or not wet enough, or you need to slow it down, and that helped a lot."* They are more mobile and sensitive in clarifying specific doubts (N-P02, N-P03, N-P04, N-P05, N-P07, N-P09, N-P13, E-P03, and E-P08). N-P03 reflected on the system's limitations: *"It gives you certain instructions, but it can't really elaborate on certain things, or you can't ask it any questions."*

Participants, especially experienced ones, also acknowledged the system's unique benefits in teaching wheel-throwing skills compared to traditional approaches. The system can be used as a knowledge repository for different practices and use scenarios (E-P01 and E-P04). E-P01 suggested: *"I think we can give them more choices, for example, for beginners, which is the easiest way to pull higher and more stable without destroying the center."* It can also work as a recording tool to provide remote asynchronous instruction (E-P01 and E-P03). E-P03 proposed: *"... it could be interesting to use as a recording tool. Just kind of record either the shape of the vessel or just a video where they are seeing and they can... If they screw up, they can tell the system to save the last five minutes or save this entire session."*

4.5 Improvisation Is Limited by the Nature of Wheel Throwing and Skill Levels

Ceramic making is not only about achieving technical proficiency or making perfect forms; it is also a creative process involving improvisation, a responsive and situational departure from preformed plans or expectations [50], in the shape being made and how it is made. The study showed that improvisation in the system is limited by the nature of wheel-throwing and the skill level of the user.

During the study, participants from both groups felt that they were following instructions without an opportunity for experimentation and improvisation (N-P01, N-P03, N-P05, N-P06, and E-P08). This was supported by survey results, which indicated that the current system does not fully facilitate new ideas (M = 2.50, SD = 1.02) or enable participants to achieve them (M = 2.93, SD = 1.07). Two experienced participants attributed this to the nature of wheel-throwing (E-P03 and E-P04). On the one hand, wheel-throwing is a craft that often pursues perfection. E-P04 said: *"Sometimes precision doesn't let you be creative."* On the other hand, wheel-throwing brings innate physical limitations. E-P03 explained: *"Because everything has to be circular. And you only have creativity in this one dimension."*

Skill level also affects improvisation. Survey results showed moderate motivation to improvise (M = 3.21, SD = 1.48) and only limited perceived restrictions when doing so (M = 2.93, SD = 1.21). Novices tended to follow the tutorials closely, but when their practice did not work as expected, or they forget the step due to skill proficiency, they unconsciously improvise a solution (N-P06, N-P08, N-P09, E-P05, and E-P06). E-P06 described her improvisation: *'Because I tried to cut it, but I think it was not so good, so I tried to shape it a little* *more'* As participants become more skilled, they mastered the skills needed to improvise, but the pursuit of perfect shape and reliance on past experience often confined improvisation, despite the system providing high-level freedom in advanced mode (E-P01, E-P04, and E-P06). E-P01 reflected on this: *"but if I'm an experienced person, and my goal is clear: make this shape, then I don't have this creative process, I only have the process of following the steps to finish it."*

5 Discussion and Implications

In Section 4, we examined how AI-MR technology and the embodied nature of craft learning influence one another through the perceptions of novice and experienced practitioners. We also observed emerging behavioral patterns and participants' future visions for the system. In this section, we discuss these results from three perspectives: insights derived from our system design, insights emerging from user behaviors beyond our initial expectations, and insights that extend beyond learning contexts. We also discuss the limitations of our work. Together, these findings address our three research questions regarding the design of the instructions, practitioners' perceptions, and broader applications of the system.

5.1 Insights from System Design: Effective Strategies and Opportunities for Refinement

5.1.1 Designing for Craft Learning with Immersion in MR: Restoration, Reconstruction, and Augmentation. While the headset provides a medium for immersive experience in physical space, the design implementation determines how successfully immersion can enhance the learning experience. Our findings identify three key design strategies that significantly contribute to immersive craft learning, with wheel-throwing serving as our primary case.

First, combining video and holograms provides learners with first- and third-person perspectives, enabling them to better understand the three-dimensional shape being made, develop hands-on skills, and identify errors. The compound view encourages learners to engage more deeply with hands-on tasks through reflection. This enhanced embodiment contributes to a stronger sense of immersion [8, 86]. Second, the step-by-step workflow, which emulates real-world practices, enhances learners' sense of presence, an element closely related to immersion according to [90]. In addition, gamification features such as the progress bar, emotional support cues for successful practice, and shape scores motivate learners to proceed (see 4.2.1). Third, the system leverages autonomy to immerse learners in the experience of controlling the process. This autonomy includes revisiting past instructions, a task that is more difficult for instructors to backtrack and reproduce in one physical piece. In addition, autonomy enables learners to experiment more freely without the pressure of instructors, thus encouraging more focused and sustained practice.

Together, these three design strategies demonstrate how MR systems can meaningfully interact with real-world craft learning environments through restoration, reconstruction, and augmentation, as shown in Fig. 10. The system restores real-world ceramic studio workflows by distilling and organizing instructions from traditional ceramics teaching. It reconstructs the learning process through user-controlled workflows, allowing learners to replay and refine specific learning sequences, an approach that resonates with Cho et al.'s concept of "replaying reality" [16]. Finally, it augments the restored experience with a compound view that combines video and holograms, along with gamified features, to enhance engagement and spatial understanding in embodied craft learning.

Our findings suggest that features such as compound visual perspectives (e.g., first- and third-person views), gamification, and user autonomy hold promise for enhancing craft learning. However, more research is needed to evaluate the effectiveness of these immersive features and understand how and why they contribute to learning outcomes in craft practice. For instance, while repetition from reconstruction is crucial for practice, we observed that many participants became stuck on specific steps, replaying instructions repeatedly, and potentially risking short-term progress at the expense of overall skill development. Thus, it is important to examine how autonomy shapes users' practice patterns in immersive environments and how this, in turn, influences learning outcomes [52]. Existing research has shown that gamification enhances learning experiences on XR platforms [44, 71, 101, 105]. However, significant gaps remain in the evaluation of gamification features for craft learning in MR, suggesting clear opportunities for future exploration.

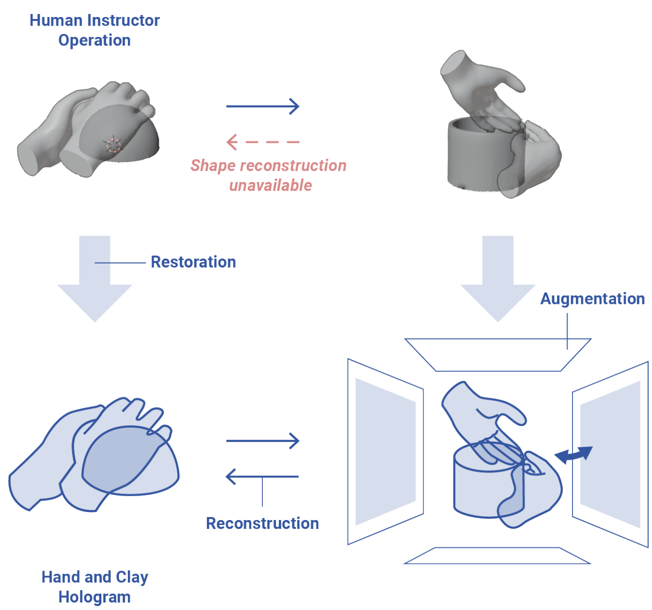

Figure 10: Diagram of how the system supports restoring, reconstructing, and augmenting reality: The system restores real-world instruction, allowing users to reconstruct it without the concern of irreversible physical changes when applying guidance to the clay. Besides, gamification features augment reality with unseen details during practice, enhancing the immersive learning experience.

5.1.2 Designing Instructions in MR: Detail and Hierarchy. The findings of our user study highlight opportunities to enhance the designed instructions of our system by incorporating more detailed and hierarchically organized guidance to better support embodied craft learning.

Table 4: An overview of the discussion and implications of AI-MR for embodied craft learning and practice.

Theme	Section	Sub-theme	Description
Insights from System Design: Effective Strategies and Opportunities for Refinement	5.1.1	Designing for Craft Learning with Immersion in MR: Restoration, Reconstruction, and Augmentation	- Restoration: interprets and organizes real-world instructions. - Reconstruction: user-controlled replay. - Augmentation: compound view + gamification.
	5.1.2	Designing Instructions in MR: Detail and Hierarchy	- Design insight 1: Provide detailed, context-aware instructions. - Design insight 2: Organize instructions hierarchically, drawing on active and passive flows observed in studio practice. - Opportunities: Provide real-time feedback at critical moments, metric visualizations, collaborative learner input, and intent-based adaptive AI support.
	5.1.3	Designing More Effective Communication Features in AI-MR: Modalities and Emotion Support	- Design insights: Use metaphor-based language, coherent multimodal guidance, and emotional feedback. - Opportunities: Use AI to generate context-specific instructions and diverse gesture datasets; assess emotional feedback in AI-MR interactions.
Insights Beyond Design Expectations: Emerging Patterns and Implications for Future Design	5.2.1	Designing Spatial and Motor Experience in MR: Instruction Distribution and Body Engagement	- Challenge: Hologram placement interfered with practice, while the narrow field of view and physical constraints hindered instruction. - Proposal: Integrate haptic feedback and structured spatial design to support crafts involving full-body movement.
	5.2.2	Designing for Personalized Craft Learning in AI-MR: Bridging Skill Differences and Growth	- Challenge: Balance adaptive personalization with standardized process. - Proposal: Leverage AI to address horizontal knowledge gaps among practitioners and support vertical development in tacit knowledge and design judgment.
AI-MR Systems Beyond Learning: Creation and Collaboration in Craft Making	5.3.1	Towards a Creative Craft Support System	- Opportunity: Support the shift from unconscious to conscious improvisation to foster practitioner growth. - Proposal: Use AI to detect and encourage meaningful deviations as guided experimentation for creation.
	5.3.2	Evolving Roles and Speculative Applications of AI-MR in Craft Practice	- Opportunity: Shift from human-human instruction to human-agent collaboration when AI empowers MR systems with greater agency. - Proposal: Position the system as a collaborator with variable agency, extending its use across educational, professional, and leisure contexts.

Implications for Detailed Instructions. During the formative study, we observed the importance of detailed instructions and contextual factors beyond shape, such as hand movement directions and material characteristics. To address these, we developed hand and clay holograms that effectively captured each step. However, user feedback reveals the need for more explicit and fine-grained instructions. Participants preferred to break down smooth animations into key snippets that emphasize critical points (see Fig. 12) and desired more dynamic, context-aware guidance beyond static recognition of starter gestures (see 4.2.1). To further support contextual understanding, our system provides video demonstrations, which participants found particularly valuable for observing and emulating subtle but essential factors such as speed, pressure, and clay texture (see 4.1.1 and 4.3). Analysis of the outcomes revealed that failures often resulted from insufficient control of these elements (Fig. 13.d, e), underscoring the importance of contextual guidance.

We suggest that AI-MR systems for craft learning should include detailed illustrations [80], real-time animated feedback [103], and visualization of contextual metrics [14]. All of these approaches have been shown to be effective in improving learning outcomes in XR environments. However, implementing these features presents several challenges. Contextual metrics are heavily influenced by material properties, target shape, and individual skill levels. These factors are rarely explicitly addressed during in-person instruction [58], making them a challenge for system design. One participant suggested that, rather than relying solely on system analysis, learners could actively report their progress to help build a robust dataset. By collecting various real-world scenarios, the system could better model tacit expertise and provide more effective guidance. Although improved system design may bridge some of these gaps, determining the appropriate level of instructional detail and evaluating its effectiveness in helping learners internalize craft knowledge remain critical challenges in advancing AI-MR systems in this domain.

Implications for Hierarchical Instructions. From our pilot study, we anticipated the risk of overwhelming learners with excessive information. To mitigate this, we presented only the necessary voice commands at each step and added a review panel displaying all available functions. Despite these efforts, participants still found the system cognitively demanding (see 4.1.2). To understand the underlying cause, we compared this with how information is conveyed in traditional studio settings.

Instructors in passive-flow scenarios monitor learners' progress and provide suggestions or clarifications as needed, creating a hierarchical learning experience. In active-flow scenario, learners initiate questions and instructors elaborate with explanations and tailored feedback (see 3.1.3). In contrast, our system requires users to call specific solutions through voice commands, exposes all features at once, and places the burden of identifying errors and selecting appropriate system responses on the learner. For novices with limited craft knowledge, this self-directed approach can be overwhelming and may disrupt the sense of progression typically supported by human-centered teaching in both active and passive scenarios.

To address this issue, we suggest using AI, such as large language models (LLM), to interpret learners' intentions and skill levels and provide customized guidance [49, 54]. Since expecting participants to predict errors is challenging, as mentioned in 4.3, the system should identify potential problems proactively and intervene through real-time monitoring of shape and contextual factors.

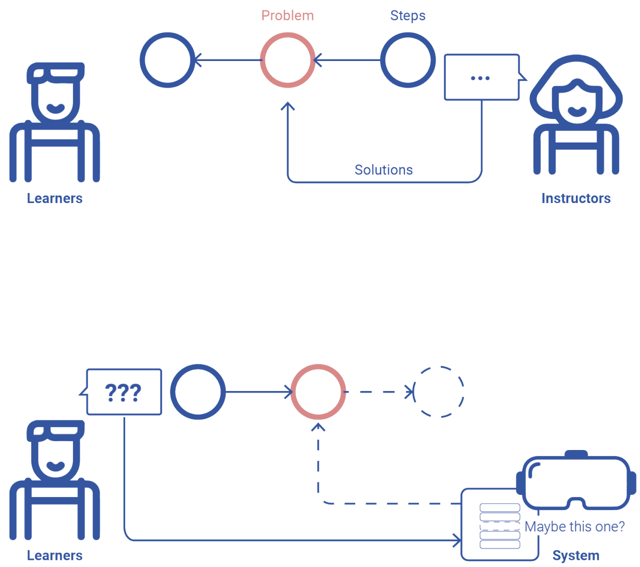

Figure 11: Diagram of how the system changes the interaction flow in the wheel-throwing process: In traditional settings, instructors guide the process and provide solutions based on their expertise. In the system, knowledge is embedded in its functions. Learners are required to determine the process themselves and select appropriate functions to address their challenges. However, this shift often leads to confusion due to their varying levels of skill proficiency.

5.1.3 Designing More Effective Communication Features in AI-MR: Modalities and Emotional Support.

5.1.3 Designing More Effective Communication Features in AI-MR: Modalities and Emotional Support. During the user study, five participants expressed the desire to ask questions to reduce confusion (N-P03, N-P04, N-P05, N-P11, and N-P15; see 4.3). This highlights opportunities to further improve the system's ability to communicate effectively with users about the challenges they encounter.

Implications for Creating Multimodal Communication Features. In traditional studios, instructors often use metaphors such as "curve your hand like a volcano" to simplify complex hand movements and reduce cognitive burden. In contrast, participants in our system struggled with technical phrasing in gesture recognition, such as "curve the tip of your index finger" (see 4.1.1), indicating the need for intuitive metaphors to facilitate clearer instruction. While there is increasing research on AI reasoning, limited attention has been paid to generating intuitive, metaphor-based instructions for embodied tasks. This gap presents a promising avenue for future research, particularly for investigating AI's potential to capture and convey the relational and tacit expertise developed by human instructors.

Beyond textual instruction, multimodal communication is essential in craft learning. Although our system integrates text, audio, and gesture holograms for suggestions, it struggles to synchronize these modalities. Participants primarily relied on interpreting text and often found gesture instructions confusing due to modal mismatches, largely stemming from the absence of a comprehensive gesture database. This challenge presents an opportunity to leverage AI to generate dynamic, integrated multimodal instructions. First, we propose building a robust database of gesture variations for specific scenarios, leveraging AI's capability to learn from multimodal resources such as instructional videos in other domains [6]. Second, we suggest exploring AI's ability to generate animated gestures aligned with corresponding text instructions, using multimodal reasoning to ensure consistency and coherence [41].

Implications for Creating Emotional Support Communication Features. Emotional support plays a critical role in maintaining learner motivation during craft learning. In our ethnographic study, we observed that the instructors naturally offered encouragement during the learning process. While our system currently provides limited text-based encouragement when gestures are perfectly matched or when no errors occur when calling the correction function, participants expressed a strong desire for more interactive and engaging emotional feedback.

Thus, we suggest providing richer emotional responses for craft learning in the AI-MR environment, such as confirmations ("Let's start," N-P02) or celebratory encouragement ("Hey, you did it," E-P06), as shown in Fig. 12. While emotionally supportive feedback has been explored in MR contexts [62, 105] and in domains such as conversational agents [92, 106], there remains a gap in understanding how to design emotionally engaging features for MR-based learning systems. This opens opportunities for future research on how interactive emotional support can enhance both user experience and learning outcomes in embodied AI-MR environments.

5.2 Insights Beyond Design Expectations: Emerging Patterns and Implications for Future Design

5.2.1 Designing Spatial and Motor Experience in MR: Instruction Distribution and Body Engagement. Our findings revealed mixed participant feedback about the positioning of the hologram. Some participants wanted to practice gestures but were concerned about damaging their piece (see 4.1.2). When asked about moving the hologram aside, several participants (N-P04, N-P09, and E-P05) found the practice "on air" ineffective due to the lack of tactile feedback, which is essential for interacting with clay. Additionally, integrating instructional content within the limited visual scope posed challenges, especially under the physical constraints of wheel operation (see 4.1.2). These findings raise two key challenges: how to design the spatial distribution of instructions, and how to leverage motor memory, the ability to sense, store, and recall body movements, to support skill development [55].

For spatial experience, we suggest applying strategies informed by successful instructional design practices [60] to establish clear guidelines for situated visualization, the placement of instructions in physical space [102], and improving instruction delivery in constrained embodied settings. For motor experience, we suggest integrating haptic-based practice into MR, inspired by prior research

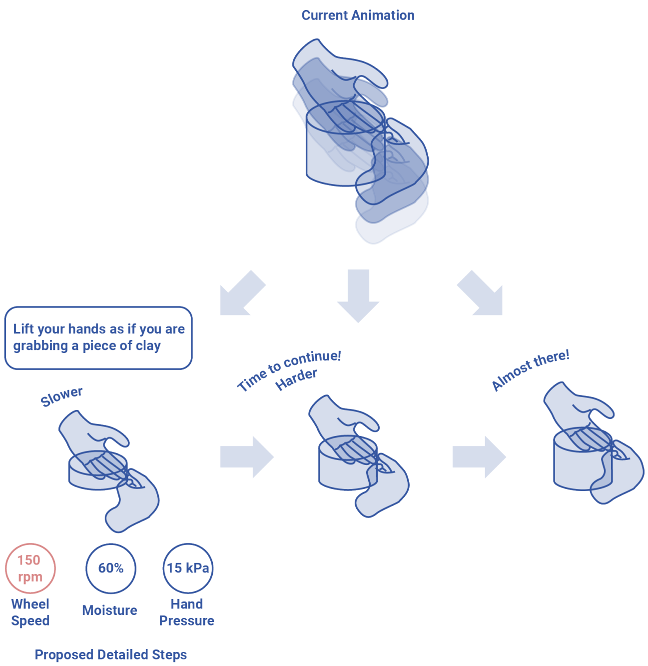

Figure 12: Envisioning detailed instruction: The animation is divided into several key frames, each accompanied by intuitive instructions and explanations using metaphors. Contextual factors are monitored in real time, providing feedback based on learners' current progress.

using VR with controllers for ceramic-making [32] and incorporating pressure feedback [3]. Doing so could enhance embodiment and maximize impact for hands-on craft learning.

Although our study has design limitations, it opens opportunities to apply spatial and motor guidance to other embodied craft practices. For example, N-P02 and PL-N-P03 referenced knitting, noting that it requires constant flipping and spatial awareness, highlighting the broader potential of adapting AI-MR systems to other domains when key design challenges are addressed.

5.2.2 Designing for Personalized Craft Learning in AI-MR: Bridging Skill Differences and Growth. Varying skill levels among learners influence both the instructional process and the outcomes in two distinct ways. First, the same instructional steps can lead to different outcomes. In traditional teaching, instructors rely on implicit judgment to decide when learners are ready to move on. In contrast, our system uses predefined goals, criteria for the next step, and target shapes. However, participants frequently reported being uncertain about when to proceed, as shape-based judgments often do not accommodate the flexible and unpredictable nature of wheel-throwing, especially when steps do not have specific shape requirements or when novice learners' output cannot meet standards (see 4.2.1 and 4.3).

Second, different approaches can yield the same outcome. While wheel-throwing follows standardized procedures, instructors often accept diverse methods for achieving similar results (see 4.4.2). This raises an important design question: should the system prioritize a standardized path for its replicability or adapt to learners' varied skills, styles, and objectives? This question is especially important for novices, who are already challenged by the complexity of spatial craft learning [57], and who may feel disoriented when their progress deviates from the expected sequence (6.2.1).

We see that AI has the potential to address this challenge. If it can interpret participants' needs and progress, it could organize predefined and real-time contextual instructions in a personalized, adaptive way. Rather than eliminating variation, the system could offer guidance that adapts to context and embraces the diversity of learner approaches, helping manage the inherent ambiguity of craft practices such as imperfection, variation, and signs of handwork [78]. For instance, contextual cues like clay moisture could be used to guide step transitions more effectively.

While the above reflects a horizontal learning process, focused on gaining knowledge for specific pieces, it is equally important to support vertical perceptual growth, in which learners develop tacit knowledge and design judgment over time [70]. Our formative study revealed that novices and experienced practitioners often perceive the same step differently, such as centering (see 3.1.3). This emphasizes the importance of designing for perceptual growth, suggesting that the system should adaptively support learners to observe and understand the same actions in deeper ways over time. In addition, the system can serve instructors by recording teaching practices and analyzing learner progress (see 4.4.2), helping them better empathize with novices and refine their pedagogical strategies by revisiting earlier stages on the "skill ladder". This bidirectional exchange: empowering learners with progressive knowledge and enabling instructors to better understand novices' challenges, positions the system as more than an instructional tool. It becomes a mediator between learners and instructors, fostering reciprocal learning and adaptation within embodied craft practice.

5.3 AI-MR Systems Beyond Learning: Creation and Collaboration in Craft Making

5.3.1 Towards a Creative Craft Support System. During the user study, we observed how practitioners with different skill levels interacted with our system. To interpret these interactions, we draw on the "power" concepts for creative support tools [61], analyzing them through the lens of "power-to," which refers to tools granting users the ability to perform a task, and "power-over," which refers to tools that structure and bound users' ideas, goals, and intentions" [88]. Both novice and experienced users generally followed the system instructions to complete their pieces, exercising "power-to." We also observed frequent "power-over" moments, where users improvised either unconsciously or deliberately. This reveals a current limitation of the system: While it provides instruction, it does not address the motivations behind improvisation and its implications.

During the study, novice participants often improvised unconsciously to compensate for difficulties in following the instructions precisely (see 4.5), while two experienced practitioners (E-P05 and E-P06), who had been away from practice for an extended period, consciously improvised based on their regained kinesthetic memory. These cases reflect different levels of "power-over": novices were constrained by the system, while experienced individuals actively resisted or reinterpreted it. This pattern is closely related to skill level and challenges the assumption that empowering users is simply about aligning tools with their goals [61]. This raises an important design question: How might we create systems that help shift unconscious improvisation into more conscious practice, thus addressing power imbalances between system designers and practitioners while fostering practitioners' skill development?

This challenge presents a promising role for AI. While our system currently uses gesture recognition and LLMs to detect deviations from instructions, AI could also assess the viability of these deviations, recognize successful improvisations, and encourage those that lead to meaningful outcomes. By framing unconscious improvisation as a form of design material, the system could transform deviation into guided experimentation, helping practitioners move from unconscious to conscious improvisation and gain greater agency over the system and their craft.

We also observed an inherent tension between wheel-throwing as a technical skill and as a creative practice. Ceramics serves both as a hobby and as a livelihood, with the instructors in our study also selling their handmade pieces. In production contexts, wheel-throwing often emphasizes precision, but the charm of handmade pottery often lies in its creative qualities, some of which emerged during our sessions (see 4.5). Participants improvised alternative shapes when they were unable to achieve the intended vase form (Fig. 13.c), and an instructor (E-P03) described intentionally creating a wave pattern as a creative choice. Participants offered valuable suggestions, such as introducing gamified challenges or optional advanced steps to encourage creativity while maintaining the rigor of craft practice. These insights point to expanding the system's role beyond a structured learning tool to a platform that also supports creative aspirations.

5.3.2 Evolving Roles and Speculative Applications of AI-MR in Craft Practice. Our findings revealed that participants envisioned various applications for the system, including remote craft learning, a knowledge repository of different practices, support for specific steps in handmade production, and even companionship in leisure contexts such as dating (see 4.4.1).

In these varied scenarios, interaction expands from traditional human-human engagement to include human-agent collaboration within the AI-MR system [19]. The system acts as an agent that senses user actions and environmental context, collects data, and communicates with the user [20]. The headset functions as a body extension, integrating with the user's physical actions, while AI features introduce a sense of alterity, guiding and collaborating with users in practice [39]. In this new setting, the traditional learner-instructor relationship is redefined: For novice learners, the system can serve as a mediator between them and their instructors, enhancing learning while relieving instructors from continuous direct instruction. For experienced practitioners, it becomes a creative collaborator and a living archive of diverse practices, forming a digital community of shared apprenticeship [83] that "connects" practitioners with different skills and techniques. In social or leisure contexts, such as dating or co-making, it may offer emotional support or facilitate human interaction.

These envisioned roles position AI-MR systems as collaborative tools in craft practice, capable of adapting to various levels of agency [66]. While our current design focuses on optimizing the system as an "effective and pleasant" learning agent [19], further research is needed to explore its broader applications across educational, professional, and social domains.

5.4 Limitation

The above section discusses design implications and future directions based on current system limitations and user feedback. However, we also recognize broader limitations that extend beyond system design, particularly those rooted in the nature of craft, XR as a medium, and our user study methodology.

5.4.1 Essential Human Dimensions in Craft Learning: Human Presence and Sustained Practice. While our AI-MR system offers promising support for ceramics learning, it cannot replace two aspects of the process, which may apply to other craft genres.

First, ceramic making is an irreversible and time-intensive process. Novice learners often require physical intervention during "critical incidents," moments when embodied actions go wrong in ways that they cannot self-correct. Second, ceramics learning depends on consistent and iterative practice, through which learners gradually develop intuitive control, error recognition, and correction strategies.

Survey results reflect this gap: while participants acknowledged that system instructions were applicable to future practice (M = 4.00, SD = 0.39), they expressed lower confidence in executing those practices independently (M = 3.14, SD = 0.95). Achieving the "aha" moment described by E-P06, when learners internalize the rhythm and respond to uncertainty with confidence, signals the acquisition of tacit knowledge.

These aspects indicate two indispensable human elements in craft learning: the presence of a human instructor and the value of consistent practice. While our focus was on wheel-throwing, future research should explore how these limitations manifest in other crafts, where the making process and learning rhythm may differ.

5.4.2 Limitations of XR as a Medium. Several limitations stem from the XR platform used to present our system: Meta Quest 3 headset, including narrow field of view, and physical discomfort during extended use. We also observed that some participants had a preconceived preference for traditional learning methods and were skeptical about the value of XR in craft learning. Both affected participants' behaviors and feedback.

5.4.3 Limitations of User Study. Our study offers insights into the design of AI-MR systems for embodied craft learning. However, several limitations of user study constrain the scope of our findings and outline important directions for future work.

The user study was conducted primarily in a controlled lab environment with a limited number of participants. While it is appropriate for generating qualitative insights in the early design phase, this setting may not fully reflect the complexities of real-world craft learning. Future work should involve long-term, in-the-wild deployments with more participants to understand how such systems perform over time in authentic studio settings, including extensive

Figure 13: Overview of observed outcomes when participants followed the system to create a vase: (a) Experienced practitioners produced well-formed vases with variations in height and details. (b) Experienced practitioners crafted well-shaped pottery but did not achieve a vase shape. (c) Novice learners improvised when they felt they could not salvage the shape. (d) Novices struggled with opening and pulling up, resulting in excessively thick walls. (e) Novices had difficulties in shaping the neck due to insufficient moisture control, leading to neck collapse.

observations, learning assessments, and co-design workshops with instructors and learners.

The system was used as a design probe and evaluated through thematic analysis and SUS. While these methods revealed rich perceptions and interactions, they do not capture the effectiveness of system features or learning outcomes. In future work, we will include more qualitative and quantitative measures to better assess the system's impact and offer a more comprehensive evaluation.

In this study, we did not include participants with impairments as part of the screening criteria. However, we see the potential of the system to support accessibility, for example, by benefiting individuals with hearing impairments through visual guidance in the MR environment. Designing for inclusive use offers promising directions for future research.

6 Conclusion

This paper presents an AI-augmented Mixed Reality ceramic guiding system as a design probe to explore the shift from traditional instructor-guided instruction to self-directed amateur craft learning. Using a Research-through-Design approach, including immersive learning, iterative inquiry, and interviews with ceramic practitioners of varying skill levels, we answer our three research questions:

(RQ 1) The combination of holograms, videos, and personalized feedback creates an authentic, immersive, self-directed, and context-rich craft learning experience. Participants emphasized the need for more structured and detailed instructions, more effective communication features, and richer spatial and motor experiences.

(RQ 2) Novices learners view the system as a complementary tool to human instructors, particularly useful for early-stage practice free from social pressure. Experienced practitioners see it as a skill-extending repository and a means of reshaping studio pedagogy through scalable and asynchronous support. Both groups noted its limitations in conveying tacit knowledge and providing interactive support.

(RQ 3) Both groups view the system not only as an instructional tool, but also as a creative support tool and collaborative agent. It opens new possibilities for hybrid learning, improvisational creation, and social crafting scenarios, suggesting an evolving role for such systems in contemporary craft practice.

While our study was conducted primarily in a controlled setting, future research should involve long-term real-world engagement to evaluate how AI-MR systems integrate into everyday craft learning, support diverse users, and evolve through consistent use and co-development. Ultimately, we hope this work will inspire further exploration of how AI-augmented MR technologies can support and enhance embodied craft learning and serves as a reference for investigating the evolving relationship between craft learners, makers, and intelligent systems.

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A Prompt for suggestion

Elementary Mode: You are a tutor teaching novice artists how to make ceramics. Based on the provided differences between the current and target ceramic shape and the novices' elementary skill level, the authors give short and specific reasons for the issues and suggest specific, actionable advice on how to fix them. Your suggestion may include hand stability, pressure, posture and body alignment, water use, time and rhythm, tool use, etc.

Advanced Mode: You are helping experienced artists to make ceramics. Based on the differences provided in the ceramic shape and their advanced skill level, give short and specific reasons why there are issues and suggest specific, actionable advice on how to fix them with skills and/or tools.

Rules:

- Do not suggest adding more clay as a solution
- Avoid coordinate references or shape state descriptions
- Exclude consequence mentions in reasons
- Use dialogue-style paragraphs for each analysis

Please organize your response in the following format:

- Neck:
  - Reasons: ...
  - Improvements: ...
- Body:
  - Reasons: ...
  - Improvements: ...
- Base:
  - Reasons: ...
  - Improvements: ...

B Interview Questions

B.1 Ethnographic study interview questions

B.1.1 *Questions for instructors.*

Questions for ethnographic session (5 mins each).

(1) Based on your experience, what step or technique do you find most crucial for successful ceramic learning/outcome, and why?
(2) From your experience, which step or technique is the hardest for novice learners to master and why?

Demo video presentation (5 mins).

Questions for comparison and reflection (5 mins each).

(1) Do you have any prior knowledge or experience using MR headsets (such as Quest, HoloLens, HTC Vive, etc.) for ceramic learning (or related art creation/craft field)? If so, how does the system we demonstrate compare to the one you are familiar with? Think about how you worked with the clay/medium, how you interact with the instruction, what technologies are used, and what is the role of the system.
(2) Compared to your teaching methods, like what you just did, what are your thoughts on the system we proposed? What aspects of the system do you think will work well? What do you anticipate might be challenging, frustrating, or distracting? Think about how you worked with the clay/medium, how you interact with the instruction, and what the role of the system is.
(3) What are your thoughts on the technology used during the process? What were your expectations? Are there surprises?
(4) The purpose of the system is to enhance student learning experiences rather than replacing instructors. How would you envision using the system as an assistive teaching tool?

Questions for system improvement (5 mins). Do you have suggestions for us to improve the system? Consider its role, current teaching/learning flow, user interface, interaction details, etc.

B.1.2 Questions for learners.

Questions for ethnographic session (5 mins each).

(1) During the class, what step do you think you performed well and poorly and why? How did the instructor help you with these steps? Do you feel confident during the process?
(2) What will you do in your next class to improve your ceramic-making skills?

Demo video presentation (5 mins).

Questions for comparison and reflection (5 mins each).

(1) Do you have any prior knowledge or experience using MR headsets (such as Quest, HoloLens, HTC Vive, etc.) for ceramic learning (or related art creation/craft field)? If so, how does the system we demonstrate compare to the one you are familiar with? Think about how you worked with the clay/medium, how you interact with the instruction, what technologies are used, and what is the role of the system.
(2) Compared to what you just learned in the class, what are your thoughts on the system we proposed? What aspects of the system do you think will work well? What do you anticipate might be challenging, frustrating, or distracting? Think about how you worked with the clay/medium, how you interact with the instruction, and what the role of the system is.
(3) What are your thoughts on the technology used during the process? How does it compare with your expectations? Were there any surprises?
(4) If you could use this system, how would you envision it in your ceramic learning process?

B.2 In-situ study interview questions

B.2.1 Questions for experienced practitioners.

Question revisit after in-person experience:

(1) What do you think about the system now compared to your first impression after seeing the video demonstration? What specific parts changed your opinion? Think about features, technology, and teaching method.
(2) Looking at the ceramic piece you just made, how satisfied are you with the final result? How do you think the system influenced the quality of the piece you made?
(3) How do you think this system could fit into your practice now? What improvements would you recommend? (two modes, learning and creation)

New questions for creative support: Ceramic making is a creative process. Did you add your own ideas to your piece while following the tutorial? How did the system affect your creativity? Creativity could be a broader concept, such as how you worked with the clay (using materials creatively), your wheel-throwing techniques (trying new gestures), and the final shape (creative outcome). How do you think the system could help the creative process in the future?

New questions for interaction dynamics:

(1) After using the system, how do you imagine that your interaction with the students will change? Why?
(2) After using the system, how has your perception of the instructors changed? Consider both the necessity of having an instructor and their functions in the learning process.
(3) After using the system, how do you feel about the role of technology in traditional craft education? While this tool isn't meant to replace craftspeople, are there any aspects that excite you or any concerns you would like to share?

B.2.2 Questions for novice learners.

(1) What was your learning experience during this session? What parts of your work went well and what did you find challenging?
(2) Consider how you worked with the clay, your wheel-throwing skills, and the final result. How do you think the instructions you received affected your work?
(3) What aspects of the system do you think work well? What do you find challenging, frustrating, or distracting? And how does this experience compare with your expectations? Were there any surprises? Think about both the system itself and the environment setup in which you used it.
(4) Looking at the ceramic piece you just made, how satisfied are you with the final result? How do you think the system influenced the quality of the piece you made?

(5) Have you ever learned something similar, like art or craft, using both in-person teaching and digital learning tools (like virtual reality, videos, etc.)? If so:
  (a) How does our system compare to those other tools?
  (b) How is learning with those tools different from learning with a real teacher?"
(6) What are your thoughts on the technology used during the process? How does it compare with your expectations? Were there any surprises?
(7) Imagine that you are planning to continue learning ceramics in the future. How do you think you would use this system to support your learning?
(8) What could be added or improved in the system to make the learning experience better?
(9) Optional (based on the progress of the session):
  (a) Ceramics is a creative process. Did you add your own ideas to your piece while following the tutorial? How did the system affect your creativity? Think about how you worked with the clay (using materials creatively), your wheel-throwing techniques (trying new gestures), and the final shape (creative outcome).
  (b) How do you think the system could help the creative process in the future?

C Survey Questions

C.1 Embodiment

(1) I improved my understanding of the material's characteristics.
(2) I improved my control over my body movements.

C.2 Learning Process

(1) My overall learning experience with the Mixed Reality (MR) system is:
(2) I improve my wheel-throwing skill after using the system.
(3) I feel it is difficult to learn wheel throwing.
(4) I feel it is difficult to use MR Headset to learn wheel throwing.
(5) I feel it is difficult to use the system to learn wheel throwing.
(6) I find it is easy to translate the feedback into my practice.
(7) I trust in the accuracy of the information learned from the system.
(8) I feel confident if I need to make the same ceramic piece again.

C.3 Instruction

(1) I find the system gives intuitive feedback.
(2) I find the system gives accurate feedback.
(3) I improved my ability to create the designated pottery shape through error correction.
(4) I improved my ability to create the designated pottery shape using real-time shape guidance.
(5) I improved my ability to create the designated pottery shape based on suggestions.

C.4 Use Scenarios

(1) I will use the system to learn ceramics from scratch.
(2) I will use the system to learn in a hybrid learning environment.
(3) I will use the system before learning from an instructor.
(4) I will use the system to continue to practice ceramic skills.

C.5 Improvisation

(1) I generated new ideas to create ceramic pieces while using the system.
(2) I applied new ideas while using the system.
(3) I felt motivated to play with the clay beyond the system's constraints.
(4) I restricted my creativity to align with the system's capabilities.