Title	EmbodyCraft : designing haptic embodied experience system as a tool for reflection in pottery skill transmission
Sub Title	
Author	朱, 宇凡(Zhu, Yufan) 南澤, 孝太(Minamizawa, Kouta)
Publisher	慶應義塾大学大学院メディアデザイン研究科
Publication year	2024
Jtitle	
JaLC DOI	
Abstract	
Notes	修士学位論文. 2024年度メディアデザイン学 第1147号
Genre	Thesis or Dissertation
URL	https://koara.lib.keio.ac.jp/xoonips/modules/xoonips/detail.php?koara_id=KO40001001-00002024-1147

Master's Thesis
Academic Year 2024

EmbodyCraft: Designing Haptic Embodied Experience System as a Tool for Reflection in Pottery Skill Transmission

Keio University
Graduate School of Media Design

YUFAN ZHU

A Master's Thesis
submitted to Keio University Graduate School of Media Design
in partial fulfillment of the requirements for the degree of
Master of Media Design

YUFAN ZHU

Master's Thesis Advisory Committee:

Professor Kouta Minamizawa	(Main Research Supervisor)
Professor Akira Kato	(Sub Research Supervisor)

Master's Thesis Review Committee:

Professor Kouta Minamizawa	(Chair)
Professor Akira Kato	(Co-Reviewer)
Professor Nanako Ishido	(Co-Reviewer)

Abstract of Master's Thesis of Academic Year 2024

EmbodyCraft: Designing Haptic Embodied Experience System as a Tool for Reflection in Pottery Skill Transmission

Category: Design

Summary

As Richard Sennett highlights in The Craftsman, craft skills are tacit knowledge, with observation, imitation, and reflection recognized as essential to mastering them. However, the lack of media to convey bodily knowledge through physical sensations makes post-action reflection particularly challenging. Previous studies have explored technologies like visualization and sonification to support reflection on tacit knowledge, yet tools leveraging tactile feedback for this purpose remain undeveloped despite its recognized importance in craft skill learning.

In collaboration with Ikutouen Co., Ltd., this study designed and developed a reflection support system to enhance understanding of both one's own and others' skills through tactile feedback. Craftsmen from Ikutouen participated actively in a participatory design process, enabling iterative improvements with haptic technology. The system was evaluated with Ikutouen craftsmen and general users to assess its impact on understanding embodied knowledge and its potential for skill transmission.

Keywords:

haptic, embodiment, pottery skill, reflection, experience sharing

Keio University Graduate School of Media Design

YUFAN ZHU

Contents

Acknowledgements **vii**

1 Introduction **1**

1.1. Current Status and Challenges of Japan's Traditional Crafts . . . 1
1.2. The Significance and Challenges of Skill Transmission 2
1.3. Opportunities Provided by Digital Media 3
1.4. Pottery as a Paradigm for Technology-Supported Skill Transmission 3
1.5. Research Objectives and Contributions 5
1.6. Structure of This Thesis 6

2 Related Works **7**

2.1. Reflective Practice Theory in Skill Learning 7
2.1.1 Schön's Reflective Practice Theory 7
2.1.2 Reflective Observation in Kolb's Experiential Learning Theory 8
2.2. Craft Form An Embodied Perspective 10
2.2.1 Role of Haptics in Craft Skill Learning 10
2.2.2 Material Engagemnet Theory 12
2.3. Quantitative Analysis of Skills and Learning Support 13
2.3.1 Quantitative Analysis of Movement and Muscle Activity in Craft Skills 13
2.3.2 Support Systems for Learning and Transmitting Craft Skills 15
2.4. Applications of Haptic Technology 18
2.4.1 Sharing Kinesthetic Sensations and Intersubjectivity . . . 18
2.4.2 Skill Learning Support through Haptic Feedback 19
2.5. Summary 20

3 Design Process **21**
3.1. Design Approach 21
3.2. Project: CrafTouch 22
3.2.1 Project Overview 22
3.2.2 Roles of the Collaborative Partners 22
3.3. Field Work 23
3.3.1 Contextual Inquiry 23
3.3.2 Preliminary Findings and Analysis 26
3.3.3 Summary 28
3.4. Concept Design 29
3.4.1 Design Goals and Requirements 29
3.4.2 Conceptual Framework: EmbodyCraft 30
3.4.3 Use Cases and Rationale 31
3.4.4 Summary 32
3.5. Prototype Development 33
3.5.1 Objectives of the Prototype 33
3.5.2 Hardware Implementation 33
3.5.3 Software Implementation 36
3.5.4 Recording Test 37
3.5.5 Data Processing Workflow 39
3.5.6 User Feedback 42
3.6. First Iteration 44
3.6.1 Hardware Implementation 44
3.6.2 Software 48
3.6.3 Recording 48
3.6.4 Data Processing 49
3.6.5 Visualization 50
3.6.6 User Feedback 50
3.7. Second Iteration 51
3.7.1 Recording 52
3.7.2 User Feedback 52
3.8. Summary 53

4 Proof of Concept **55**
4.1. User Test 55
4.1.1 Use Cases 55
4.1.2 Research Objectives 56
4.1.3 Hypotheses 56
4.1.4 Experimental Method 57
4.2. Session 1 : Post-action Self-Reflection of Skills 60
4.3. Session 2 : Reflective observation to understanding Others' Skills . 65
4.4. Thematic Analysis of the Result of Semi-structured Interview . . 71
4.4.1 Verification of Hypothesis 1: Enhanced Awareness of Fine Movement Details and Force Dynamics 72
4.4.2 Verification of Hypothesis 2: Deepened Reflective Engagement and active evaluation and improvement of their skills in Post-Action Self-Reflection 73
4.4.3 Verification of Hypothesis 3: Supporting Meaningful Interaction and Shared Understanding in Reflective Observation 75
4.5. Discussions 77
4.5.1 Reflection on the Study Boundaries and Limitations 77
4.5.2 Future Directions 79
4.6. Summary of the Proof of Concept Study 80

5 Conclusion **82**

References **84**

Appendices **89**
A. Semi-Structured Interview Questions for User Test 89
A.1 Session 1: Post-Action Self-Reflection of Skills 89
A.2 Session 2: Reflective Observation of Others' Skills 90

List of Figures

1.1 Production value of the traditional crafts industry, e.g. 1
1.2 Throwing the clay 4

2.1 Kolb ' s description of the learning cycle 9
2.2 The major postulates of MET. Diagram by Lambros Malafouris. 12
2.3 Annotation tool for Myo signals synced with video signal 14
2.4 A system using EMS(electric muscle stimulator) to share kinesthetic between individuals 18

3.1 (A)The environment of Ikutouen (B)Carver of Ikutouen (C)Potter of Ikutouen 23
3.2 Experience session design memo by Mr.Haraoka from Japan Craft Industry Association 24
3.3 Demonstration and practice for pottery 25
3.4 Demo session held in ikutouen 27
3.5 Session design memo 30
3.6 System paradigm of the wearable force myography and skin-stretch feedback device 34
3.7 (A) Components of the hardware (B)Wearing image 35
3.8 (A)Accelerometer (B)Vibration actuators 36
3.9 Function network in Touchdesigner 37
3.10 Record environment 38
3.11 (A)Sensors wearing image (B)Recording accelerometer data (C)Recording FMG data 39
3.12 Using video editing software to synchronize data 40
3.13 Limiter and low-pass filter 41
3.14 An example of processed FMG data 42

3.15 (A)8 channel FMG device (B)The left forearm perimeter of user (C)The right forearm perimeter of user 44
3.16 A haptic device integrated 2 channel fingertip vibro-tactile feedback and 4 channel rotary skin-stretch feedback 46
3.17 (A)Vision Pro (B)Spatial video 47
3.18 (A)Potter wearing a Vision Pro (B)Monitoring on a tablet 49

4.1 Skill recorder S reflecting on his own skill 60
4.2 Illustration of the discrepancy between perceived (blue) and actual (red) force application during clay manipulation by S 63
4.3 Skill observer M reflecting on other's skill 66
4.4 Illustration of the discrepancy between perceived (blue) and actual (red) force application during clay manipulation by T 68
4.5 Code scheme for thematic analysis 71
4.6 Theme percentage under tow conditions(n=6) 73
4.7 Theme percentage under two conditions(n=1) 74
4.8 Theme percentage under two conditions(n=5) 76

Acknowledgements

Embarking on this research was not just an academic pursuit but also a personal journey. Transitioning from materials science to human-computer interaction was both exciting and challenging, and I am deeply grateful for the support I have received in this multidisciplinary environment. It has given me the freedom to explore, the guidance to navigate unfamiliar territories, and the encouragement to push forward even when things felt uncertain.

First and foremost, my deepest gratitude goes to Professor Kouta Minamizawa, my supervisor. Your guidance has been invaluable throughout this journey. From the very beginning, your encouragement gave me the confidence to pursue this path, and your insights have continuously challenged me to think deeper and refine my work. This research would not have been possible without your unwavering support.

I am also sincerely grateful to Professor Akira Kato for the thoughtful feedback and guidance. Your keen observations and constructive criticism encouraged me to approach my work with greater clarity and rigor. The patience and insight you provided have been instrumental in helping me reflect on the limitations of my research and refine my arguments.

My heartfelt appreciation goes to Professor Arata Horie, who has been a constant source of support throughout this project. Your invaluable advice at crucial moments, coupled with the opportunity to be part of this research, has shaped my academic growth. The freedom you granted me to explore my ideas and the thoughtful feedback you provided have strengthened my work significantly. I deeply appreciate the patience, insights, and countless discussions that have made this research more meaningful.

To my collaborators at Ikutoen, I cannot thank you enough. Your openness in sharing your knowledge, skills, and experiences in pottery-making provided me with perspectives I could never have gained on my own. Our discussions and your engagement with this research have been essential in bridging traditional craft with technology.

In particular, I am deeply grateful to Mr. Satoru Tamaki, whose exceptional craftsmanship and enthusiasm for this research have greatly enriched my understanding of pottery. Throughout the research process, you generously shared your years of expertise, offering patient guidance on every experimental detail. Especially during the intensive multi-day experimental sessions, your tireless participation, professional insights, and hands-on adjustments helped us gain a deeper understanding of muscle dynamics, hand control, and material interaction in pottery-making. Your dedication has been truly inspiring, and I am deeply moved by your commitment. Learning from you and exploring the transmission and innovation of pottery techniques together has been a great privilege.

My sincere appreciation also goes to Mr. Takahiro Tsuruta, whose deep reflections on craft education and innovative spirit have been profoundly inspiring. Your commitment to evolving traditional techniques and your invaluable feedback have significantly shaped my perspective on the intersection of craft and technology. Through our discussions, I have come to understand that traditional craftsmanship is not merely about skill transmission but also a way of thinking and a means of cultural continuity.

Additionally, I extend my thanks to Mr. Tomohiro Haraoka and the Japan Craft Industry Association. Your support in facilitating communication and coordination between us and Ikutoen was invaluable, ensuring the success of our collaboration. Your efforts have played a crucial role in making this project possible, and I deeply appreciate your generosity and dedication.

I am also grateful to Kenta Kan from Dalifilms, whose work in filming the teaser for this project beautifully captured its essence. Your dedication and artistic vision helped convey the significance of this research in a compelling and visually engaging way.

To my friends and colleagues at KMD—Elizabeth Shen, Songchen Zhou, Mark Armstrong, and all the members of the Embodied Media Lab—your support, conversations, and collaboration have made this journey not only meaningful but also enjoyable. Being part of such an inspiring and supportive community has helped me navigate both the highs and lows of research, and I could not have

asked for better companions along the way.

This research was conducted with the support of the JST Moonshot Research and Development Program, “Development of Cybernetic Avatar Technology and Social Infrastructure for Creating Shared Physical Experiences” (Grant number JPMJMS2013).

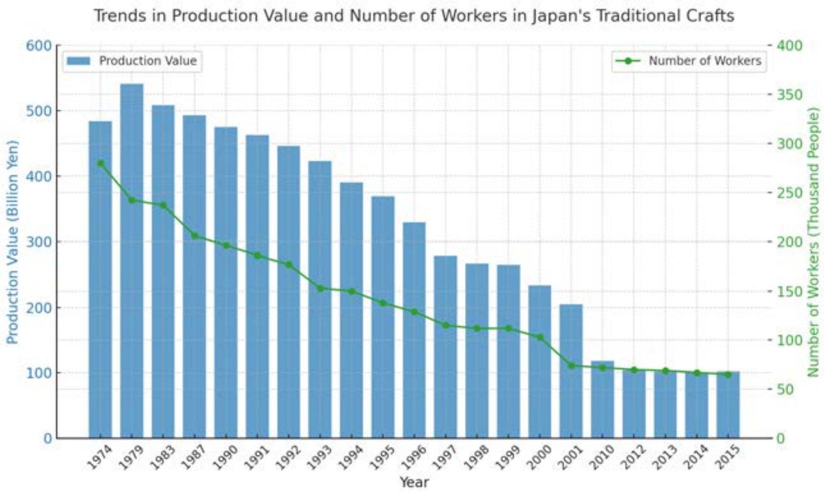
Lastly, my deepest gratitude goes to my parents. Your unwavering belief in me, even when my path was unconventional, has been my greatest source of strength. Your support has carried me through every challenge and made this journey all the more meaningful.

Thank you all.

Chapter 1
Introduction

1.1. Current Status and Challenges of Japan's Traditional Crafts

Traditional crafts in Japan represent a valuable cultural heritage, embodying skills developed over centuries and reflecting the unique characteristics of specific regions. These crafts encompass a wide range of handmade items such as ceramics, lacquerware, textiles, woodworking, and bamboo crafts. Rooted in artisanal processes, they often rely on local materials and techniques, serving not only functional purposes in daily life and rituals but also acting as symbols of regional and cultural continuity [1] [2].



(Source:The Association for the Promotion of Traditional Craft Industries [2])

Figure 1.1 Production value of the traditional crafts industry, e.g.

However, the traditional craft industry in Japan has been facing significant challenges in recent years. Both the total production value and the number of craftspeople have been in steady decline. In 1983, the industry's production value peaked at ￥523.7 billion but had decreased to below ￥200 billion by 2004.

Similarly, the number of craftspeople dropped from approximately 290,000 in 1979 to just 67,000 in 2014. These challenges stem from several factors, including Japan's aging population, the high cost and scarcity of raw materials, and shifting consumer preferences toward mass-produced goods. Additionally, the declining interest in traditional crafts among younger generations has intensified the challenges of skill transmission [2].

1.2. The Significance and Challenges of Skill Transmission

The reduced interest among younger generations has not only decreased the number of new artisans but also heightened the difficulties in skill transmission. Historically, the apprenticeship system was the cornerstone for passing down traditional craft skills. Rooted in both Eastern and Western cultures, this system relied on observation, imitation, and repetitive practice to transmit expertise, particularly tacit knowledge [3] [4]. Tacit knowledge, as Polanyi famously described, is knowledge that "we know more than we can tell" [5]. This form of knowledge resides in the body and is deeply tied to action, making it difficult to verbalize or document. In crafts like pottery, essential adjustments—such as sensing the elasticity of clay or fine-tuning the hand's pressure during throwing—cannot be effectively conveyed through instructions alone. Instead, they require the learner to engage in practice and develop a sensory understanding through embodied interaction.

While the apprenticeship model was once effective in transmitting such knowledge, its decline has revealed significant limitations. Younger generations are increasingly deterred by the substantial time and financial investment required for traditional training. Moreover, the demand for handmade crafts is diminishing in favor of cheaper, mass-produced alternatives, further threatening the sustainability of traditional crafts [2]. These challenges necessitate the exploration of innovative and sustainable methods to support and enhance the transmission of craft skills. Modern technologies, with their potential to systematically capture and represent tacit knowledge, offer promising solutions to bridge the gap left by the decline of traditional apprenticeships.

1.3. Opportunities Provided by Digital Media

In the context of these challenges, digital media technologies offer transformative possibilities for addressing the difficulties of skill transmission. Tools such as motion capture, haptic feedback, and immersive environments like Virtual Reality (VR) and Extended Reality (XR) enable the systematic capture, replication, and presentation of tacit knowledge that is otherwise challenging to document. Motion capture records precise movements, providing detailed visualizations of expert techniques and generating quantitative data on trajectories, speed, and coordination. Haptic feedback systems recreate tactile sensations, allowing learners to experience subtle material interactions, such as the elasticity of clay or the pressure required during a task. VR and XR environments further enhance these capabilities by immersing learners in realistic, interactive scenarios where they can observe, practice, and refine their skills. These technologies bridge the gap between implicit, ineffable knowledge and explicit, measurable representations, offering new ways to analyze and understand traditional crafts. By combining these capabilities, digital media not only supports more effective and accessible skill transmission but also deepens the understanding of the nuanced dimensions of craft expertise, contributing to the preservation and evolution of traditional practices.

1.4. Pottery as a Paradigm for Technology-Supported Skill Transmission

Craft practices are often described as a "dialogue" between the practitioner and the material [6] [7]. This description is particularly relevant to pottery, as Ingold explains, in pottery making, the "mindful" or "attentive" movements of the practitioner respond to the material's flows and resistances, creating a reciprocal exchange [8].

Figure 1.2 Throwing the clay

Compared to other crafts such as metalwork, woodworking, or glass replication, pottery demands a heightened sensitivity to the material's responses, making it a powerful example of this dynamic interaction. Among the various stages of pottery, throwing—where the practitioner shapes the clay on a spinning wheel—stands out as a moment of profound engagement. This stage has been described as "an almost poetic moment of tacit knowledge at work" [14], where the potter intuitively adjusts their movements based on subtle tactile feedback, exemplifying how body and material coalesce in the act of creation.

Given its reliance on tacit knowledge, pottery, and particularly the process of throwing, can serve as a valuable model for exploring how technology might support skill transmission in crafts. By leveraging technology to investigate the sensory and embodied dimensions of this interaction, we can uncover new ways to document, express, and transfer tacit knowledge. This approach has the potential to not only deepen our understanding of pottery practices but also provide insights and tools for the transmission of skills in other crafts.

1.5. Research Objectives and Contributions

This study aims to design an intuitive and flexible system that enhances reflective practice in pottery skill transmission. Focusing on the wheel-throwing process and employing a participatory design approach in collaboration with Ikutoen Co., Ltd., a renowned pottery workshop, the system facilitates the understanding and transmission of tacit knowledge in pottery making. By capturing and presenting the sensory and bodily interactions inherent in craft practices, the system not only enhances skill transmission within traditional apprenticeship models but also provides valuable insights for technology-supported skill transmission in other crafts.

In summary, the main contributions of this study are threefold:

1. **Proposing a Framework for Craft Skill Transmission:**
   - Integrates sensory and bodily interaction dimensions to enhance traditional methods of skill transfer.
2. **Designing and Evaluating a Bridging System:**
   - Develops a system that closes the gap between tacit knowledge and explicit understanding, facilitating better knowledge transfer.
3. **Exploring Sustainable Technological Solutions:**
   - Utilizes technology to protect and develop traditional craft practices in a sustainable and efficient manner.
   - Assesses the practical application potential of the system through collaboration with pottery experts, providing a fresh perspective on skill transmission.

Additionally, this research explores how the system can enhance the observation and reflection processes, thereby deepening the understanding of the tacit knowledge embedded in pottery skills. By collaborating with pottery experts, the study not only validates the system's effectiveness but also ensures its practical applicability in real-world educational settings. This approach offers a novel method for the observation and reflection process in pottery skill transmission, paving the way for broader applications in various craft disciplines.

In summary, this study contributes a comprehensive framework and a technologically advanced system that together enhance the preservation and transmission of traditional pottery skills. By leveraging participatory design, the research provides innovative solutions to sustain and develop traditional craft practices in the modern era.

1.6. Structure of This Thesis

This thesis is structured into five chapters:

Chapter 1 provides an introduction to the background, objectives, and structure of the research. Chapter 2 explores the topic from the perspective of embodied cognition theory, discussing theories of reflective practice, support systems in the learning process of craft skills, the sharing of motor sensations and intersubjectivity, and the application of haptic feedback in skill acquisition. Chapter 3 details the design process of the study. Chapter 4 presents the evaluation of the system proposed in Chapter 3, assessing whether it achieves the anticipated outcomes. Chapter 5 concludes the dissertation by summarizing the key findings and discussing the implications for future research.

Chapter 2
Related Works

2.1. Reflective Practice Theory in Skill Learning

2.1.1 Schön's Reflective Practice Theory

When exploring appropriate points of intervention in skill transmission, it is crucial to identify which phases are most amenable to improvement. Traditional apprenticeship models emphasize demonstration and hands-on practice, while reflection runs through both of these processes, enabling practitioners to analyze their actions, extract insights, and transform experiences into knowledge [9]. Integrating reflection-focused theories of reflective practice into skill transmission may serve as an effective approach to fostering deeper skill acquisition and transfer.

Donald Schön's theory of Reflective Practice provides a foundational framework for understanding how reflection occurs, offering a key contribution by classifying reflection based on its timing:

- **Reflection-in-Action:**
  - Occurs during the practice or action.
  - Practitioners reflect and make real-time adjustments to their actions in response to challenges or immediate feedback.
  - For example, a potter might adjust the pressure of their hands on the clay while shaping it on the wheel to prevent collapse.
- **Reflection-on-Action:**
  - Takes place after the practice or action has been completed.

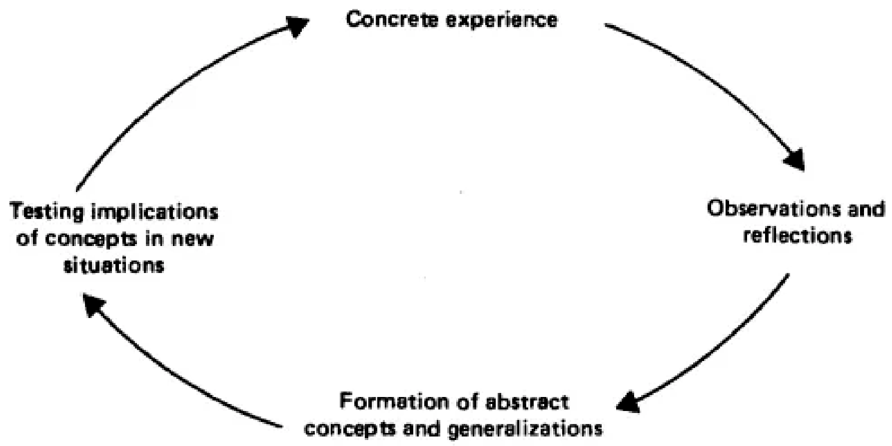
  - Practitioners review and analyze their past actions to gain insights and improve future performance.
  - For example, reviewing a video recording of the pottery-making process to identify strengths and areas for improvement.

Schön's theory of reflective practice provides valuable insights into the reflection process, particularly through the classification of reflection timing, which helps practitioners engage in effective reflection at different stages.

However, Schön's theory also has certain limitations. Charlene Tan critiques Donald Schön's *Reflective Practice* by describing it as embodying "self-protective individualism" [10]. This framework prioritizes self-reflection and assumes that practitioners rely predominantly on their own tacit knowledge and experiences, thereby underemphasizing the social and collaborative dimensions of learning. This focus restricts opportunities for engaging with external perspectives and benefiting from collective processes. Moreover, Schön's theory provides limited guidance on how practitioners can learn from others' actions or collaborate in team environments, where skill learning often involves cooperation and knowledge sharing among multiple individuals. Consequently, relying solely on personal reflection may be insufficient to foster comprehensive skill development. In the context of using digital media to enhance the understanding of one's own or others' skills, incorporating external perspectives becomes indispensable. However, Kolb's concept of reflective observation, with its flexibility, not only supports skill acquisition and reflection but also hints at ways to address challenges in integrating collective learning and external feedback.

2.1.2 Reflective Observation in Kolb's Experiential Learning Theory

David Kolb developed a four-stage reflective model known as the Experiential Learning Cycle, which emphasizes the process of learning through experience [11]. The cycle highlights reflective practice as a tool for deriving conclusions and generating ideas that can inform future actions, completing the learning loop. It consists of four interconnected stages: Concrete Experience, Reflective Observation, Abstract Conceptualization, and Active Experimentation. Practitioners begin with a Concrete Experience, where they engage in a new activity or task. This is followed by Reflective Observation, where they critically analyze the experience to identify its strengths and areas for improvement. Next, in the Abstract Conceptualization stage, they draw on theoretical knowledge and past experiences to develop generalizable insights. Finally, during Active Experimentation, these insights are applied to new situations, creating opportunities for further learning.



(Source: Kolb and Fry,1975 [11])

Figure 2.1 Kolb ' s description of the learning cycle

Reflective Observation plays a particularly significant role among these stages, as it bridges experience and understanding. By stepping back from direct experience, practitioners critically analyze their actions and outcomes, thereby fostering deeper learning and skill development. Although Kolb's theory does not explicitly propose "observing others," its framework is flexible enough to be extended to contexts that include external observation. For example, by observing the techniques of skilled professionals or analyzing the operations of complex systems, practitioners can also gain valuable insights from others' experiences.

This extended application of Reflective Observation has demonstrated broad applicability and flexibility across various fields. In education, peer observation enables practitioners to critically evaluate teaching methods, providing new perspectives and promoting self-awareness [12]. In social work, observation exercises involving older adults encourage students to identify implicit biases, challenge assumptions, and develop reflective skills [13]. These examples illustrate that by integrating external practices into observation and reflection, practitioners can consolidate diverse learning resources and deepen their understanding.

Moreover, this focus on external observation addresses certain limitations in Schön ' s Reflective Practice theory, which primarily centers on self-reflection through Reflection-in-Action and Reflection-on-Action. While Schön's framework provides valuable tools for analyzing personal actions, it offers limited guidance on how to learn from others' experiences. Instead, Kolb's Reflective Observation allows for theoretical extensions to incorporate external insights into the learning process, offering a structured approach for integrating these external perspectives. This makes it particularly relevant in skill-based fields, where understanding others' expertise through visual observation or tactile exploration can provide richer, more diverse learning opportunities.

Although Schön's reflective practice theory and Kolb's experiential learning cycle provide significant insights into the cognitive processes involved in skill acquisition and improvement, the interaction between bodily perception and materials is equally crucial in the practice of crafts. The following section will explore craft skill learning from the perspective of embodied cognition, with a focus on the importance of touch and theories of material engagement.

2.2. Craft Form An Embodied Perspective

2.2.1 Role of Haptics in Craft Skill Learning

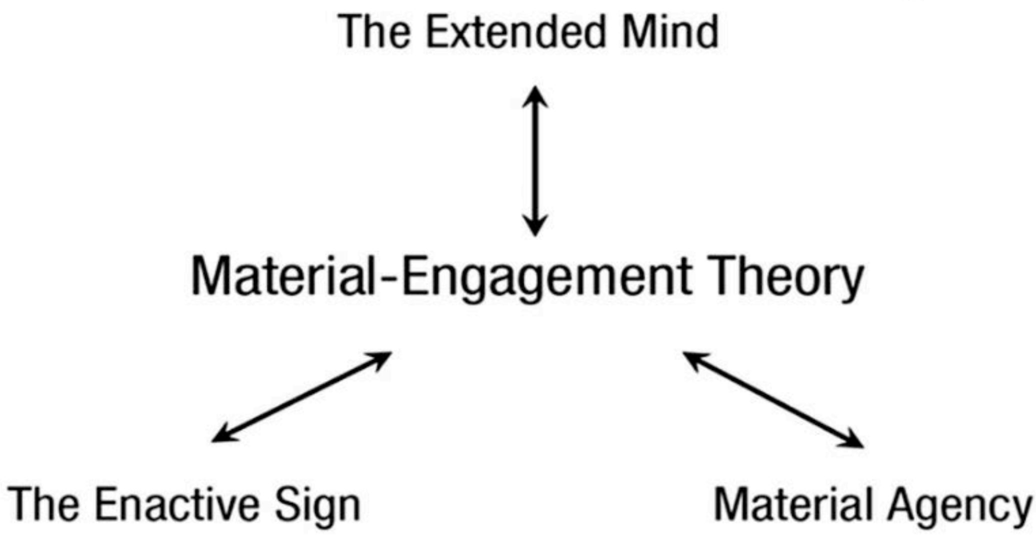
Touch is a fundamental aspect of craft practices, providing essential sensory feedback that bridges the maker and the material. Richard Sennett, in The Craftsman, emphasizes that "all skills, even the most abstract, begin with physical practice," underscoring the role of bodily sensations—particularly touch—in developing and refining craft skills [9]. He highlights how the hand, wrist, and forearm work together to apply minimal force, allowing the maker to respond dynamically to the material ' s properties. This coordination transforms craft into an ongoing dialogue mediated by sensations and movements .

In the practice of pottery, touch plays a central role as potters rely on tactile feedback to sense the clay's texture, elasticity, and thickness. These tactile sensations allow potters to make immediate adjustments to their movements, ensuring the material behaves as intended. For example, sensing the clay's moisture content through touch helps potters decide when to increase pressure or ease their grip. Such interactions showcase the integral relationship between the maker and the material, where touch not only guides the hands but also fosters an intuitive understanding of the material's behavior.

This perspective aligns with the findings of Brinck et al. [14], who argue that tactile integration and sensory feedback from materials are pivotal in developing and mastering craft skills. They emphasize that touch not only provides real-time feedback but also supports the cognitive processes that underpin skill acquisition. Through tactile engagement, makers develop an embodied understanding of their craft that visual observation alone cannot achieve.

Tactile sensations also facilitate skill transmission in craft learning. By engaging directly with materials, learners develop an embodied understanding that cannot be acquired through visual observation alone. The iterative process of sensing and adjusting deepens their connection to the material and refines their techniques over time. As Sennett points out, touch is not merely a sensory input; it is an active participant in shaping the craftsperson's skills and enabling the continuous development of craft knowledge.

2.2.2 Material Engagemnet Theory



(Source: Malafouris,022,p.268) [15])

Figure 2.2 The major postulates of MET. Diagram by Lambros Malafouris.

As shown in Figure 2.3, Material Engagement Theory (MET) integrates three major postulates: The Extended Mind, Material Agency, and The Enactive Sign. These interconnected concepts provide a theoretical foundation for understanding the dynamic relationship between the maker and the material.

MET emphasizes that craft is not a one-sided process where the maker imposes their will on inert materials. Instead, it is a co-creative interaction, where the material actively participates in shaping the outcome. For example, the concept of Material Agency highlights the material's ability to "speak back" to the maker during the creative process, influencing their decisions. Similarly, The Enactive Sign reflects how meaning emerges through engagement with the material, while The Extended Mind captures the idea that cognition is distributed between the maker and the material.

In the context of pottery, the clay itself illustrates these principles. Wet clay may sag under excessive force, signaling the potter to adjust their technique. The material's elasticity or resistance further informs the potter's shaping and molding decisions. Through this dialogic process, the potter learns to respect and collaborate with the material's natural tendencies rather than imposing their will upon it. This interaction exemplifies the central tenet of MET: the maker and the material are equal participants in the act of creation.

Touch is integral to this co-creative process. It serves as the primary channel through which the material communicates its properties to the maker. The feedback loop created by tactile sensations enables makers to continuously adapt their actions in response to the material ' s behavior. This iterative interaction fosters a deeper understanding of the material ' s affordances and limitations, enriching the craftsperson ' s practice over time.

2.3. Quantitative Analysis of Skills and Learning Support

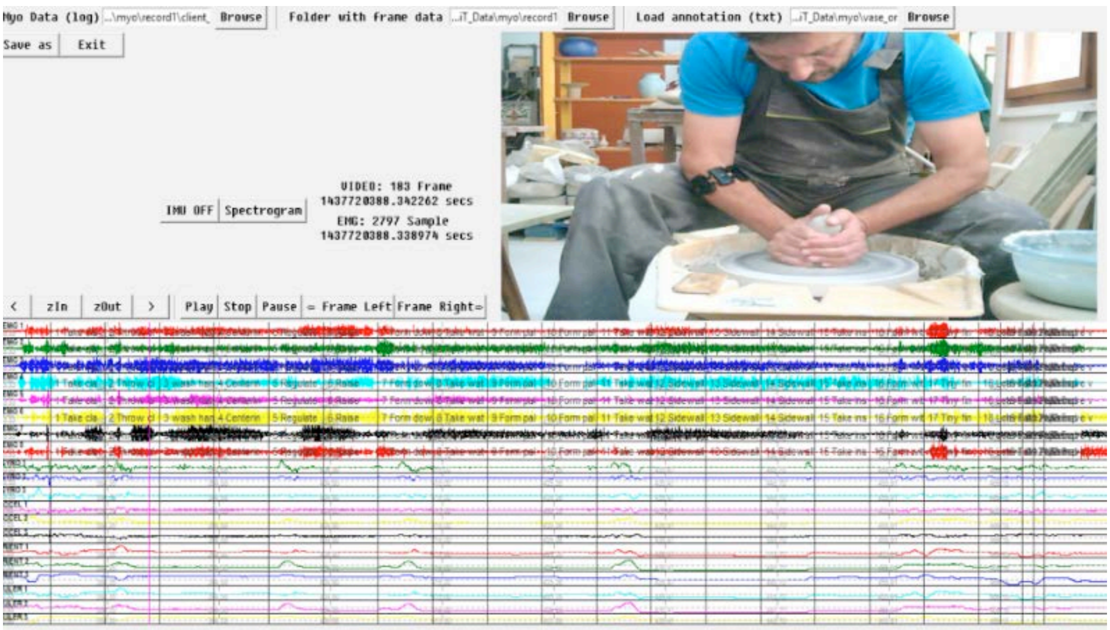
2.3.1 Quantitative Analysis of Movement and Muscle Activity in Craft Skills

Before the advent of tools such as motion capture technology and electromyography (EMG), our understanding of pottery-making skills relied heavily on subjective observation and the tacit knowledge passed down through apprenticeship and practice. However, this experience-based approach often struggled to capture the intricate details of these skills comprehensively and precisely. Quantitative analysis has emerged as a scientific method to bridge the gap between traditional craftsmanship and scientific understanding. It not only makes the pottery-making process more scientific and objective but also plays a vital role in preserving intangible cultural heritage and facilitating the transmission of skills.

In recent years, researchers have utilized various advanced technologies to establish a solid foundation for the quantitative analysis of pottery skills. For example, motion capture technology has been used to record the movement characteristics of pottery-making. Studies have shown that during the process of kneading clay, experts demonstrate a high level of coordination between the torso and arms, highlighting a strong correlation between skill proficiency and overall body coordination [16].

Furthermore, EMG technology has captured the dynamic changes in muscle activity, revealing the specific roles of different muscle groups in pottery-making, such as the distribution of pressure between flexor and extensor muscles. By measuring deviations in the symmetry of wheel-thrown pottery, researchers have been able to assess the degree of craftsmanship and quantify the precision of the production process [17].

Building on these advancements, Ververidis proposed an analytical framework combining EMG data and forearm anatomy, focusing on capturing stylistic differences in pottery gestures [18]. Using Myo sensors, they recorded the muscle activity of master potters while creating bowls, cylindrical vases, and spherical vases, extracting key features such as total muscle pressure and gesture stiffness. Their findings revealed that even seemingly identical gestures, such as "Raise clay" or "Centering clay," exhibit significant differences when applied to various types of pottery. These quantitative data provide a scientific basis for comparing skill styles and offer new insights for designing personalized teaching methods in skill transmission.



(Source: Ververidis. 2016 [18])

Figure 2.3 Annotation tool for Myo signals synced with video signal

The importance of these technologies and research methods lies in their ability to transform traditionally experience-based pottery skills into measurable and analyzable numerical data, making skill learning and transmission more scientific. To some extent, these quantitative processes can be regarded as a partial externalization of tacit knowledge. By converting hard-to-describe techniques and intuitions into quantifiable, comparable, and transferable forms, researchers have opened up new possibilities for the dissemination and preservation of skills. However, the practical application of this data remains underexplored. For example, through physicalization or other approaches, these data could be transformed into intuitive and embodied sensory experiences, providing more accessible tools and methods for skill learning and transmission in practice.

2.3.2 Support Systems for Learning and Transmitting Craft Skills

With technological advancements, the learning and transmission of craft skills have gradually shifted from traditional master-apprentice models to technology-assisted systems. This transformation aims to enhance the efficiency of skill dissemination and broaden its scope. Traditional craft skill learning relies on face-to-face observation and imitation, where hands-on practice accumulates expertise. However, this model faces various limitations in modern society, such as a lack of skilled mentors, geographical distances, and time constraints. The introduction of digital technology thus opens up new possibilities for the learning and transmission of craft skills.

In recent years, numerous studies have focused on capturing and externalizing the tacit knowledge inherent in traditional crafts through technology. For example, Liu et al. developed an electromyography (EMG)-based system to record muscle activity during the pottery throwing process. By visualizing this data, learners can reflect on their practices, gain a deeper understanding of subtle differences in their movements, and utilize this information to improve their skills [19]. Similarly, Smith et al. investigated gesture sonification technologies, which convert motion data into sound, helping craft practitioners reflect on their techniques while promoting communication. This sonification technology provides a unique perceptual dimension, enabling learners to perceive the rhythm and quality of their actions and improve their skills through discussion [20].

The integration of advanced technologies such as virtual reality (VR) and gesture recognition further enriches the learning experience of craft skills. For instance, systems like PotteryGo simulate the pottery-making process within a virtual environment, offering learners real-time corrective feedback and interactive tutorials. These systems effectively reduce reliance on mentor resources and provide structured learning pathways for beginners [21] [22]. Gesture recognition technologies, which incorporate machine learning methods such as Hidden Markov Models (HMM) and Dynamic Time Warping (DTW), can accurately track and model expert movements. This allows learners to compare their own performance against expert benchmarks and achieve autonomous learning through real-time feedback [23].

In addition, visual and auditory modalities are the core sensory channels of traditional multimedia, and recent studies have further expanded their applications in skill learning through innovative approaches. For instance, visual feedback is no longer confined to static demonstrations but can now highlight deviations in hand movements through real-time optical annotations, providing learners with immediate corrective guidance [21] [23]. Similarly, auditory feedback, such as sonification techniques, converts motion data into rhythmic sounds, emphasizing continuity and rhythm, thereby enabling learners to identify instabilities in their movements and make adjustments [20]. These dynamic feedback methods leveraging visual and auditory modalities significantly enhance the efficiency of skill learning while offering learners a richer sensory experience.

However, as previously mentioned, tactile perception plays a critical role in craft practice, particularly in processes where nuanced physical interactions with materials are essential [9]. Despite the advancements in digital systems for skill learning and transmission, there is a notable underutilization of tactile feedback in these technologies. This limitation arises primarily from the challenges of accurately replicating the fine-grained, dynamic tactile sensations that are central to craft-making. Consequently, current systems may fail to fully capture and convey the embodied nature of craft skills, potentially limiting the depth of learning and the ability to internalize these skills in a manner comparable to traditional hands-on methods. This highlights the need for further research to integrate advanced haptic feedback mechanisms into digital systems, ensuring a more comprehensive and authentic representation of the tactile dimension of craft practices.

According to Material Engagement Theory (MET), the dynamic interaction between the maker and the material is central to craft practices, characterized by co-creation and reciprocal influence [15]. MET integrates three key concepts—The Extended Mind, Material Agency, and The Enactive Sign—to explain how cognition, material properties, and meaning-making are interwoven during the creative process. For instance, in pottery, clay actively "responds" to the potter's actions through its elasticity, resistance, or sagging tendencies under excessive force, guiding the potter ' s decisions and shaping the outcome. This dialogic process underscores that the maker and the material are co-participants in the act of creation.

However, current digital systems for craft skill transmission largely overlook these principles, particularly the role of tactile interaction in facilitating this co-creative relationship. While visual and auditory feedback may support reflection and correction, they fail to replicate the embodied experience enabled through touch—the primary channel through which materials communicate their properties and affordances. This omission not only diminishes the embodied engagement central to skill acquisition but also neglects the iterative and reciprocal nature of maker-material interaction emphasized by MET.

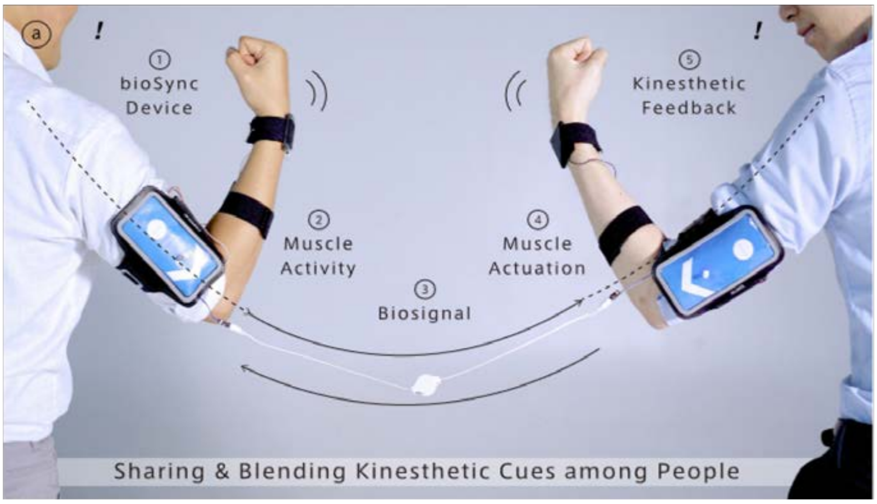
Addressing this limitation requires the integration of haptic feedback mechanisms that authentically simulate the material's tactile responses. Such systems should enable learners to experience the material's agency and dynamically adapt their actions based on the tactile feedback received, mirroring traditional craft practices. By embedding MET's principles into the design of digital tools, future systems can better support the embodied understanding and transmission of craft skills, preserving the integral maker-material relationship fundamental to craft practices.

2.4. Applications of Haptic Technology

2.4.1 Sharing Kinesthetic Sensations and Intersubjectivity

The body serves as the foundation of all experiences, housing embodied knowledge while simultaneously generating emotions and affect [24] [25]. Achieving intersubjectivity, such as mutual understanding and primary empathy, requires examining the extent to which individuals can share bodily and kinesthetic experiences. From the perspective of embodied cognition in social interaction, intersubjectivity, connection, and interaffectivity are considered to emerge when bodily states are harmonized [26]. When bodily states and movements synchronize with those of others, the distinction between self and other diminishes, allowing individuals to internalize and feel what they observe in others [27].

The concept of intersubjectivity has inspired various design approaches that focus on perceiving others' movements through different sensory channels. For example, Françoise et al. explored the use of continuous auditory feedback to enhance kinesthetic awareness, enabling second-person exploration [28] to better understand others' experiences [29].



(Source:Nishida (2017), Biosync [30])

Figure 2.4 A system using EMS(electric muscle stimulator) to share kinesthetic between individuals

Similarly, Nishida et al., through the bioSync project, developed a method to deepen empathy for the physical challenges faced by individuals with Parkinson ' s disease by using paired wearable devices to explore the integration of muscle contractions and joint rigidity [30]. Other systems aim to facilitate shared kinesthetic sensations by fostering synchronization in participants ' movements or breathing [31, 32].

Research suggests that kinesthetic sharing can also occur internally through observing others ' movements, even without direct physical interaction. Visual observation of others' actions [33, 34]or auditory observation [35] of their movements has been shown to activate mirror neurons in the premotor cortex, initiating processes related to empathy [36].

Another technological approach to fostering embodied empathy involves recreating similar physical experiences. For instance, placing participants in comparable postures [37] or replicating similar physical sensations [38] enables them to relate more closely to the conditions of others. These methods, which facilitate intersubjectivity through shared kinesthetic sensations, often conceptualize intersubjectivity as the mirroring of bodily states, creating scenarios where individuals can approximate others' lived experiences.

2.4.2 Skill Learning Support through Haptic Feedback

Craftsmanship skills are motor skills, and numerous studies have explored the use of haptic feedback to support motor skill learning, demonstrating its effectiveness. This provides a rationale for incorporating haptic feedback into this system.

The acquisition of pottery skills is a complex process involving the development of multifaceted abilities. Pottery creation can be seen as a fusion of artistic expression and motor skills [9]. Therefore, when considering the transmission and teaching of pottery skills, the learning of force control skills should also be taken into account.

In the context of learning force control and motor skills, researchers have utilized various methods to support users' learning processes. Morris et al. [39] demonstrated through experiments that haptic feedback significantly enhances the learning effects of force control skills. Their research shows that, compared to visual feedback alone, the addition of haptic feedback allows learners to acquire targeted force control skills more quickly and accurately.

Furthermore, Horie et al. [40] proposed a wearable device combining Force Myography and rotational skin shear stimulation. This device detects muscle activity while stretching the user ' s skin through the rotation of servo motors, providing intuitive real-time feedback. The wearable and modular design of this system, coupled with the integration of muscle activity measurement and haptic feedback, offers advantages over traditional grounded haptic devices used for motor skill learning. It is portable, does not interfere with the user ' s hand movements, and can be applied to specific tasks such as measuring muscle activity during pottery-making.

2.5. Summary

By reviewing reflective practice theories, embodied cognition theories, and quantitative analysis methods for skill learning, this chapter identifies key issues that may exist in the transmission of craft skills. These include the challenges beginners face in post-action reflection, the central role of tactile feedback in craft learning, and the limitations of current systems in applying tactile feedback.

Additionally, based on a review of Schön's Reflective Practice Theory and Kolb's Experiential Learning Cycle, this study proposes the following hypothesis: In the Reflection-on-Action phase, recording muscle activity and transforming it into haptic feedback may enable learners to more intuitively revisit their actions, thereby deepening their understanding of their own skills. Furthermore, by applying Kolb's extended concept of Reflective Observation, sharing such haptic feedback or muscle activity data in visual or perceptible forms with others may further enhance learners' understanding of others' skills.

However, these hypotheses require further validation in practical contexts to ensure alignment with real user experiences and needs. To this end, subsequent research will involve fieldwork, engaging with users in the craft domain to explore how the issues identified in the literature manifest in real-world practices and to develop solutions better suited to user needs. This process will not only help verify the conclusions drawn from the literature review but also provide a practical foundation for designing more effective skill-learning support systems.

Chapter 3
Design Process

3.1. Design Approach

This study employs an Iterative Participatory Design methodology to develop a system that enhances reflective practice in pottery skill transmission. This approach emphasizes iterative refinement and active user involvement, ensuring that the system evolves to meet users' needs effectively. By integrating continuous feedback loops, the design process remains flexible and responsive to insights gathered throughout the project.

The methodology consists of four key phases:

- **Understanding User Needs**: Initial workshops and interviews with stakeholders are conducted to identify challenges in pottery skill transmission and to define the system requirements.
- **Prototyping**: Iterative prototyping is used to explore potential solutions, moving from low-fidelity prototypes for conceptual testing to high-fidelity prototypes for functionality evaluation.
- **Testing and Feedback**: Prototypes are tested in real-world scenarios, where feedback on usability and effectiveness is gathered from users.
- **Refinement**: Based on the feedback, the system is refined through multiple iterations to ensure it aligns with user needs and supports reflective practices effectively.

This iterative process ensures that the system is not only functional but also meaningful and impactful for its users, fostering a seamless integration of traditional craftsmanship with modern technology.

3.2. Project: CrafTouch

3.2.1 Project Overview

CrafTouch is a collaborative research project supported by the moonshot project. The core research theme explores how technology can transform traditional craftsmanship. This collaboration combines cutting-edge academic research with the rich heritage and expertise of Japan's craft industry to investigate innovative ways of preserving and evolving traditional skills in the digital age.

3.2.2 Roles of the Collaborative Partners

The success of CrafTouch relies on the expertise and collaboration of several key partners. Each partner brings unique skills and knowledge to the project, ensuring a comprehensive and multidisciplinary approach.

- **Embodied Media Project**: Leads the design, development, and user testing of the system, focusing on creating a user-centered solution through expertise in embodied interaction and haptic technology.
- **Japan Craft Industry Association**: Coordinates the project, facilitating collaboration among partners and ensuring alignment with traditional craft practices. Their insights into the industry provide essential guidance for the project's direction.
- **commissure**: Offers technical consulting to refine the haptic feedback mechanisms, ensuring realistic and responsive tactile interfaces for effective skill transmission.
- **Haptics Laboratory at Nagoya Institute of Technology**: Conducts parallel research and supports the integration of innovative haptic technologies to enhance the system's functionality.
- **Ikutouen Pottery Studio**: A member of the Japan Craft Industry Association, Ikutouen serves as a field partner, providing testing environments, user feedback, and practical insights into pottery-making practices.

Ikutouen Pottery Studio as a Field Partner

Ikutouen Pottery Studio, based in Okinawa's Tsuboya district, is renowned for its innovative integration of advanced technology with traditional craftsmanship. In the 1970s, when the use of traditional climbing kilns was discontinued, Ikutouen swiftly adapted by introducing kerosene and gas kilns, positioning itself as a pioneer in modernizing pottery practices in the Tsuboya area [41].

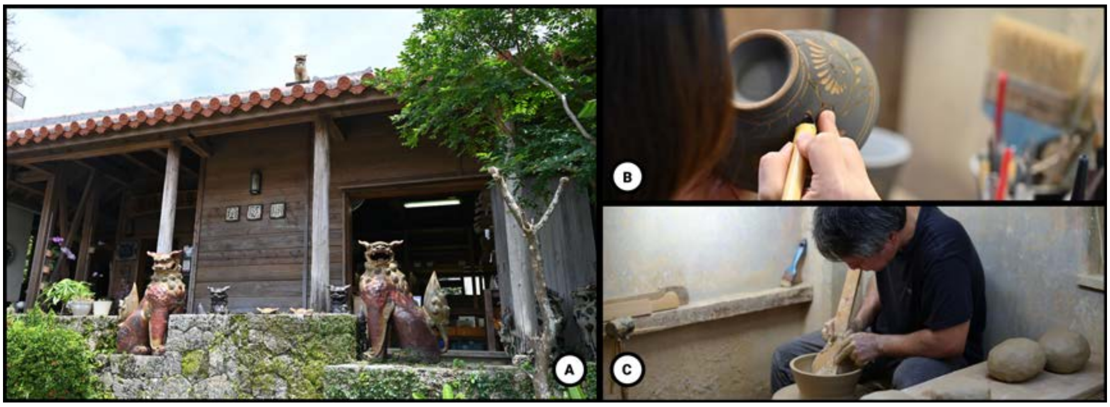


Figure 3.1 (A)The environment of Ikutouen (B)Carver of Ikutouen (C)Potter of Ikutouen

Their participation in this project includes offering hands-on expertise in pottery-making, providing practical testing scenarios, and facilitating user feedback to refine the system.

As a field partner, Ikutouen ensures that the research respects traditional methods while addressing modern practices. Their active involvement bridges the gap between technology and craftsmanship, fostering a seamless integration of innovation and heritage.

3.3. Field Work

3.3.1 Contextual Inquiry

To explore and validate the challenges highlighted in the literature, specifically the difficulty of tacit knowledge transmission in skill learning and the limitations of digital media technologies in supporting post-action reflection in craft practices, the research team conducted a pottery experience session organized by the project partner, Ikutouen.

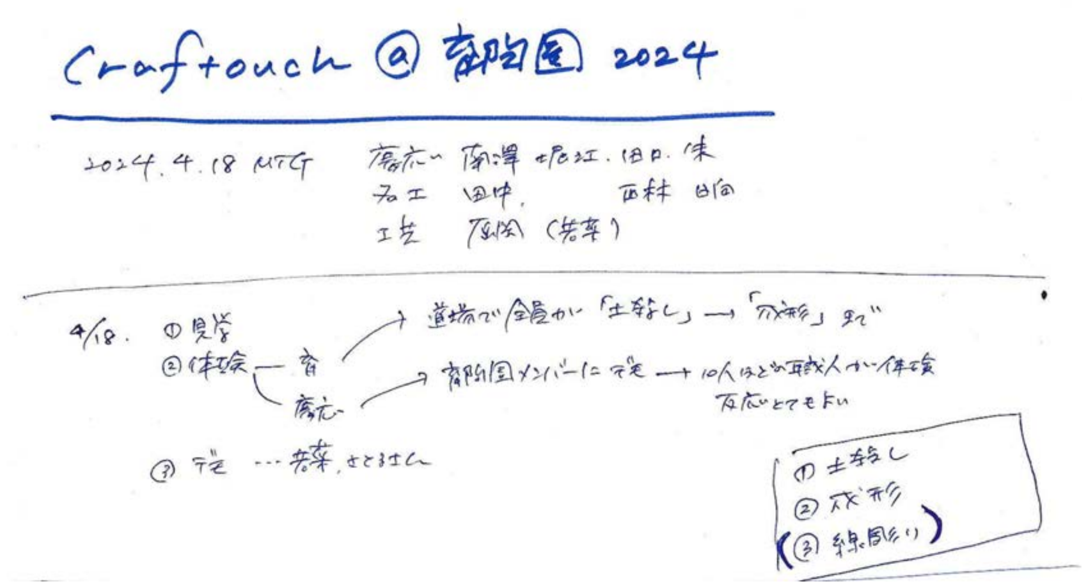


Figure 3.2 Experience session design memo by Mr.Haraoka from Japan Craft Industry Association

All participants were research team members with no prior experience in pottery. The session aimed to investigate key difficulties in pottery skill learning from the perspective of novices and to gather direct user experience data to inform the research.

The session consisted of three phases: Demonstration, Practice, and Discussion, as outlined below:

- **Demonstration:** The pottery master demonstrated the fundamental actions, including preparing clay and wheel-throwing, explaining key points and precautions for each step.

- **Practice:** The research team members attempted to perform these tasks independently, observing and experiencing the characteristics of the clay during the process.

Figure 3.3 Demonstration and practice for pottery

- **Discussion:** An open-ended discussion was held with the pottery master after the practice phase. The discussion focused on the following key aspects:
  - **Challenges in tacit knowledge transmission:** Exploring how tactile information, such as the appropriate pressure or ideal clay texture, is conveyed during demonstrations and identifying any communication challenges.
  - **Challenges in Post-Action Reflection:** Investigating how learners reflect on their actions after practice, particularly in recalling tactile sensations and applied forces.
  - **Potential for Technological Interventions:** The research team introduced conceptual ideas for technological solutions, such as VR simulations, haptic feedback systems, and data visualization tools. Participants were invited to share their perspectives on these interventions,

with the following points of focus:

* **Relevance to Existing Challenges:** Evaluating whether these technologies address the specific challenges identified in skill learning and transmission, such as difficulties in recalling tactile sensations or visualizing material responses.
* **Practical Integration:** Discussing the feasibility of incorporating these technologies into current teaching and learning workflows. Participants considered factors such as ease of use, training requirements, and compatibility with traditional teaching methods.
* **User Preferences:** Collecting feedback on the perceived usefulness and desirability of different modalities. For example, participants were asked to compare the potential value of VR-based visual feedback versus haptic feedback for improving skill acquisition.

3.3.2 Preliminary Findings and Analysis

Based on the observations and discussions, the research team identified key issues and their theoretical implications:

- **Challenges in Tacit Knowledge Transmission:** The pottery master highlighted the difficulties of conveying tacit tactile knowledge, such as the "appropriate pressure" or "ideal clay softness," through verbal explanations alone. These aspects often required multiple demonstrations to partially convey the information. However, even with repeated demonstrations, beginners still struggled to fully understand these tactile details. One participant noted, "Even though I watched the master's actions, I had no idea how much force to apply, and the clay kept collapsing every time." This observation confirms the issues highlighted in the literature regarding the challenges of externalizing tacit knowledge. It suggests that relying solely on verbal explanations and demonstrations may not be sufficient, and additional supportive tools may be necessary.

- **Limitations in Post-Action Reflection:** After completing the practice session, participants were asked whether they could reflect on their actions.

Most reported difficulties in reflecting on aspects related to tactile perception, particularly in recalling the variation in applied force, the continuity of movements, and how their actions aligned with the feedback from the clay. While some participants recorded videos of their actions, they could only use the recordings to recall the general sequence of movements visually. Subtle tactile changes or the rhythm of their actions could not be captured through video. One participant commented, “I can see my hands moving in the video, but I have no idea how the force changed or if it matched the clay’s condition. I’m not even sure if my rhythm was correct.” This lack of Force-tactile sensation based reflection significantly hindered the learners’ ability to deeply understand and improve their skills. It not only made it difficult for them to evaluate whether their actions matched the material’s feedback but also limited their ability to identify precise areas for improvement. These findings highlight the limitations of existing reflection tools, which do not adequately support learners in revisiting or understanding tactile feedback. There is a clear need for tools that can recreate tactile sensations to better support reflection and skill refinement.

- **Acceptance of Technological Interventions:** In the discussion, the research team presented potential technological solutions to the pottery masters, including vibration-based haptic feedback tools, virtual reality (VR), and data visualization tools, and gathered their feedback.

Figure 3.4 Demo session held in ikutouen

The pottery masters expressed strong interest in the vibration-based haptic feedback tools, believing that these tools could help learners recreate and better understand tactile sensations, such as the texture of the clay's surface, which fingers were in contact with the clay, and whether the touch was deep or light. However, some masters mentioned that vibration feedback alone might not be sufficient to fully support learners ' reflection. One master remarked, "The vibration is useful, but students might still ask, 'How much force did I use?' Just vibration alone might not fully answer that question."

When trying VR, some pottery masters found it potentially helpful for observing and reflecting on complex actions. However, several masters reported experiencing discomfort or dizziness while using the system, which limited their willingness to engage with the virtual environment. Additionally, they noted that the lack of tactile feedback in VR was a significant limitation. Without a tactile interface, the experience could not replicate the sensation of working with real clay. One master remarked, "It looks impressive, but without the feeling of the clay, students might still struggle to reflect on the actual pressure they applied." This feedback underscores that, in addition to addressing issues like 3D motion sickness, a complementary tactile interface would be essential for fully supporting reflection in VR-based systems.

Data visualization tools also garnered the attention of the pottery masters, particularly those with features for real-time display of muscle activity and applied force. They believed these tools could provide learners with more intuitive feedback, helping them understand operational issues.

3.3.3 Summary

The fieldwork at Ikutouen Pottery Studio confirmed that beginners struggle with post-action reflection—particularly in recalling and understanding the tactile aspects of their pottery-making process. Instructors, on the other hand, find it challenging to communicate the subtleties of touch and pressure through verbal guidance alone. While participants expressed interest in potential technological interventions—such as haptic feedback and data visualization tools—they noted that these solutions must better convey tactile nuances to be truly effective. The insights from this session will guide the next steps in concept development, aiming to create tools that address both the learners ' need for more tangible post-action feedback and the instructors ' difficulties in conveying tactile knowledge.

3.4. Concept Design

In this chapter, the insights derived from prior literature reviews and fieldwork are synthesized to propose and articulate the system's design concept. The primary goal is to address the challenges faced by novice learners in post-action reflection and the transmission of tacit tactile knowledge. This design aims to integrate forearm muscle activity sensing and fingertip vibration capture into a multimodal feedback system, allowing learners to better perceive, understand, and internalize their skills, while respecting the traditional teaching context of pottery craftsmanship.

3.4.1 Design Goals and Requirements

The findings from the preliminary research and contextual inquiries highlighted the following challenges:

- **Difficulties in Post-Action Reflection:** Novices struggle to recall tactile sensations and the dynamics of force application after practice, which hinders deep reflection and improvement.
- **Challenges in Tacit Knowledge Transmission:** Instructors find it difficult to effectively convey tactile details, such as proper pressure and clay texture, through language or demonstrations alone.
- **Integration with Traditional Practice:** Any technical solution must seamlessly integrate into traditional workflows, complementing rather than disrupting the cultural rhythm and teaching practices of pottery craftsmanship.

To address these challenges, the system is designed with the following objectives:

- **Support Post-Action Reflection:** Enable learners to revisit their tactile and muscular interactions through multimodal feedback, even after leaving the practice environment.

- **Facilitate Tacit Knowledge Externalization:** Provide instructors with tools to externalize subtle tactile and muscular knowledge, making them visible and tangible for learners.
- **Respect and Extend Traditional Practices:** Ensure the system naturally integrates into existing teaching workflows, enriching rather than disrupting the traditional approach.

3.4.2 Conceptual Framework: EmbodyCraft

Building upon these goals, we propose the conceptual framework *EmbodyCraft* as shown in 3.5, which integrates three key data streams—forearm muscle activity, fingertip vibrations, and video recordings—into a unified, time-synchronized dataset. This framework aims to capture and reproduce the nuanced interplay between the potter ’ s body, the material, and the craft process, thereby offering a richer medium for post-action reflection and skill transmission.

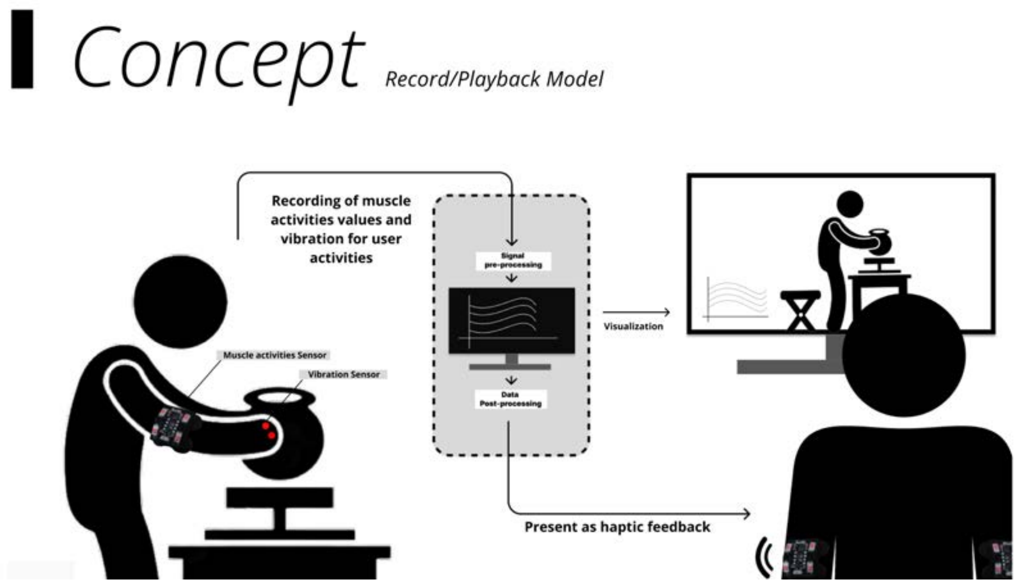


Figure 3.5 Session design memo

Forearm Muscle Activity: The forearm muscles are the primary source of power for the precise hand and finger movements required in pottery-making, such as shaping, centering, and applying pressure to the clay [18]. Compared to placing sensors directly on the fingers or palms, which are prone to interference from clay, moisture, and material adhesion, measuring forearm muscle activity offers a robust and environmentally adaptable solution. This approach reliably captures muscle contractions associated with hand and finger movements, reflecting the user ' s applied force and motor control during pottery-making. It ensures high-quality data collection while maintaining the natural workflow of the craft and adapting to the practical environmental conditions of a pottery studio without disrupting the process.

Fingertip Vibration: Fingertips are the primary interface for sensing the properties of clay, such as elasticity, moisture, and resistance. By recording subtle vibration patterns during the shaping process, EmbodyCraft incorporates the perspective of Material Engagement Theory (MET) [15], emphasizing the importance of material feedback in the maker ' s perception and actions. This approach preserves tactile details that are often overlooked once the process is complete, capturing the feedback generated during the interaction between the hand and the clay. Replaying these fingertip feedbacks allows learners to "re-touch" their past actions, transforming fleeting tactile experiences into stable references for reflection and comparison.

Video Recordings: Simultaneously, high-quality video footage documents the visible aspects of the pottery-making process, including hand position, clay deformation, and overall form evolution. Synchronized with muscle and vibration data, the video serves as a visual anchor, linking quantitative signals of force and tactile interactions to observable outcomes in the final artifact ' s shape and consistency.

3.4.3 Use Cases and Rationale

By aligning this multimodal dataset—muscle activity, fingertip vibrations, and video—on a common timeline, EmbodyCraft supports two fundamental use cases:

- **Use Case 1: Post-Action Self-Reflection**

  After completing a training session, learners can revisit their recorded data. Visualized muscle activity curves highlight moments of excessive force or in-stability, while fingertip vibration playback reintroduces tactile sensations. Coupled with video references, novices gain a deeper understanding of how their actions influenced the behavior of the clay. By providing tangible sensory evidence, this approach aims to enhance the Reflection-on-Action process as defined in Schön ' s theory of Reflective Practice, helping learners more intuitively evaluate their performance and extract strategies for improvement.

- **Use Case 2:Reflective Observation and Verbal Interaction Based on Others ' Experience**

  Building upon the expanded concept of Reflective Observation in Kolb ' s experiential learning model which is mentioned in literature reviw, Use Case 2 enables users to learn not only from their own experiences but also by observing and reflecting on others' skilled performances. Users can record their skilled performances and share them with others, enabling not only the observation and auditory experience of demonstrations but also the tactile sensation of these performances through haptic playback. Guided by verbal interactions—such as discussing when to apply force or how to perceive subtle transitions in the material—users are supported by multi-sensory cues to enhance their understanding of embodied skills.

3.4.4 Summary

In sum, the EmbodyCraft framework weaves together multimodal data streams—forearm muscle activity, fingertip vibrations, and synchronized video—to enable deeper, more embodied forms of reflection and learning. It enriches traditional apprenticeship models with concrete, sensory-rich feedback mechanisms that illuminate the tacit dimensions of craft knowledge. Through this conceptual design, we set the stage for subsequent prototype development and iterative refinement, paving the way for a more nuanced understanding and transmission of pottery skills.

3.5. Prototype Development

The prototype development phase focused on creating the foundational system for the *EmbodyCraft* platform. This included determining the appropriate haptic feedback modalities and sensor types, and building a functional system capable of capturing and replaying user data for post-action reflection. The prototype represents the first operational iteration, laying the groundwork for subsequent refinements.

3.5.1 Objectives of the Prototype

The first prototype aimed to achieve three main objectives:

- **Evaluate Haptic Feedback Modalities:** Determine the types of haptic feedback most effective for conveying muscle activity and tactile details, including the use of vibration to represent dynamic tactile changes.
- **Validate Sensor Selection:** Test FMG sensors for capturing forearm muscle activity and vibration sensors for detecting tactile interactions at the fingertips, ensuring their accuracy and reliability in a pottery-making context.
- **Build a Functional System:** Develop a system that integrates hardware and software components to enable data recording, visualization, and tactile feedback replay, providing a basis for reflective practice.

3.5.2 Hardware Implementation

The hardware for the prototype comprised two primary components:

- **Forearm Muscle Activity Sensor and Skin-stretch actuator:**

  As noted in the literature, pottery making is fundamentally an activity highly reliant on motor skills. In designing our verification system, we sought to draw on tactile cue methods that have been proven effective in the domain of motor skill learning [40]. By integrating muscle activity sensing (FMG) and skin stretch stimulation into the system, we not only aim to provide users with immediate feedback during real-time operation but also establish a practical approach to validating the feasibility of the EmbodyCraft concept.

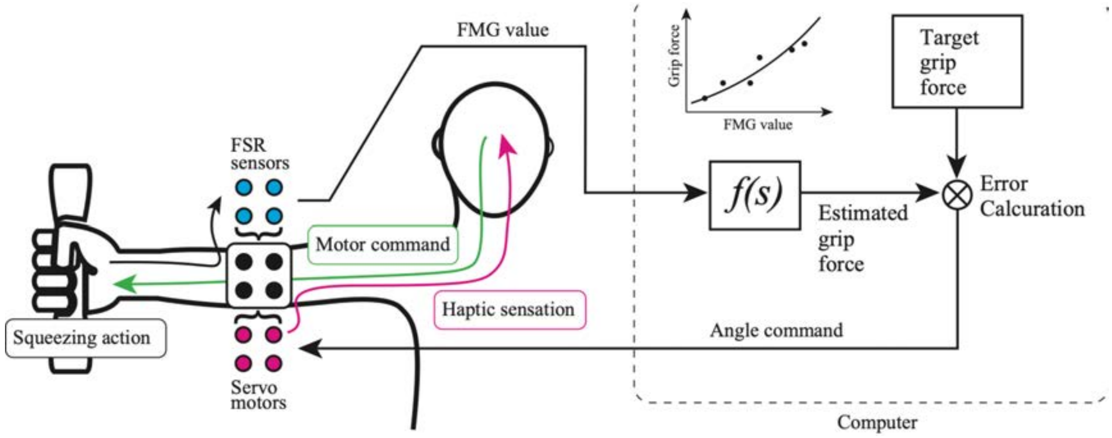


Figure 3.6 System paradigm of the wearable force myography and skin-stretch feedback device

Specifically, we installed FSR (Force Sensitive Resistor) sensors on the user’
s wrist to capture muscle activity and applied grip force data, transmitting these data in real-time to a computer for processing. The computer calculates the error between the target force and the applied force, mapping this error to motor rotation angle commands. Through the skin shear stimulation induced by motor rotation, users can perceive tactile feedback of varying intensity, enabling them to recognize the deviation between their applied force and the target force. Gradually, they can reduce this deviation by adjusting their muscle control. In other words, users can infer the trend of relative force changes from variations in tactile stimulation intensity, thereby achieving more precise force control.

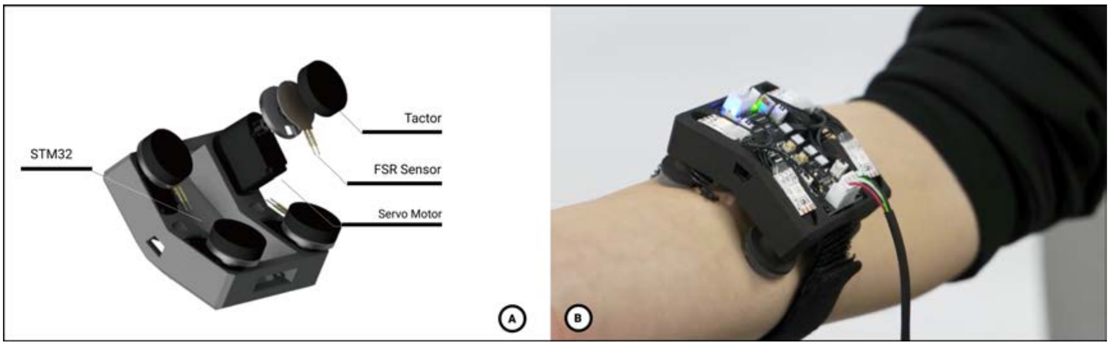


Figure 3.7 (A) Components of the hardware (B)Wearing image

This feedback mechanism based on skin stretch stimulation is not limited to real-time training scenarios. During subsequent reflective practice, where users ’ muscle activity data are recorded as time series and replayed, this tactile feedback can help users reconstruct the dynamic process of force application. This is crucial for deeply understanding their action characteristics and force habits in pottery making.

From the perspective of environmental adaptability, FMG sensors do not require direct skin contact, making them more stable and reliable than traditional EMG sensors in humid, high-temperature, and sweat-prone environments. For scenarios like summer pottery workshops in Okinawa, where humidity and muddy water can be disruptive, FMG sensors are undoubtedly a more suitable sensing method. Additionally, the sensors' flexible installation accommodates various operating postures and crafting conditions, offering users a more natural experience.

- **Fingertip Vibration Sensor and Actuator:** To capture the subtle interactions between the fingers and clay, such as contact intensity and surface texture, we selected accelerometer-based vibration sensors. These sensors offer high sensitivity and multi-axis measurement capabilities, allowing them to detect fine tactile vibration characteristics. Their compact design and low power consumption enable seamless integration into the system without interfering with the user ’ s natural hand movements.

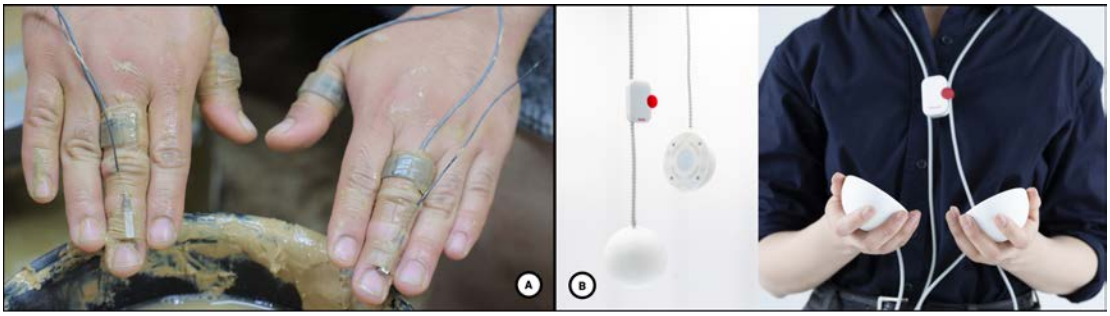


Figure 3.8 (A)Accelerometer (B)Vibration actuators

During the reflection phase, we employed vibration actuators developed by Taguchi et al. to replay the recorded tactile feedback [42].

These actuators are finely engineered to provide clear and localized tactile stimulation with high fidelity, making them ideal for reproducing complex tactile experiences. The system also emphasizes real-time responsiveness, ensuring that tactile feedback is synchronized with other modalities, such as video and muscle activity data. This design supports users in reconstructing and reflecting on their tactile interactions with the clay, thereby deepening their understanding of the pottery-making process.

3.5.3 Software Implementation

The software development focused on creating a platform capable of processing, storing, and visualizing data. Key features included:

- **Data Recording and Synchronization:** A recording module was implemented to capture synchronized data from the FMG sensor and fingertip vibration sensors. This module ensured the accurate alignment of muscle activity and tactile interaction data.
- **Visualization Interface:** Muscle activity data was visualized as time-series curves, highlighting key moments such as force peaks or irregular fluctuations. This interface provided users with a clear representation of their performance.

- **Tactile Feedback Replay:** The system allowed users to replay recorded tactile sensations using fingertip actuators, providing an immersive "re-experience" of their interactions with the clay

All features were developed using Touchdesigner[1], leveraging its powerful interactive design capabilities. Touchdesigner provided a flexible platform for integrating multi-modal data streams, designing dynamic visualizations, and implementing tactile feedback mechanisms, ensuring seamless synchronization and real-time interaction.

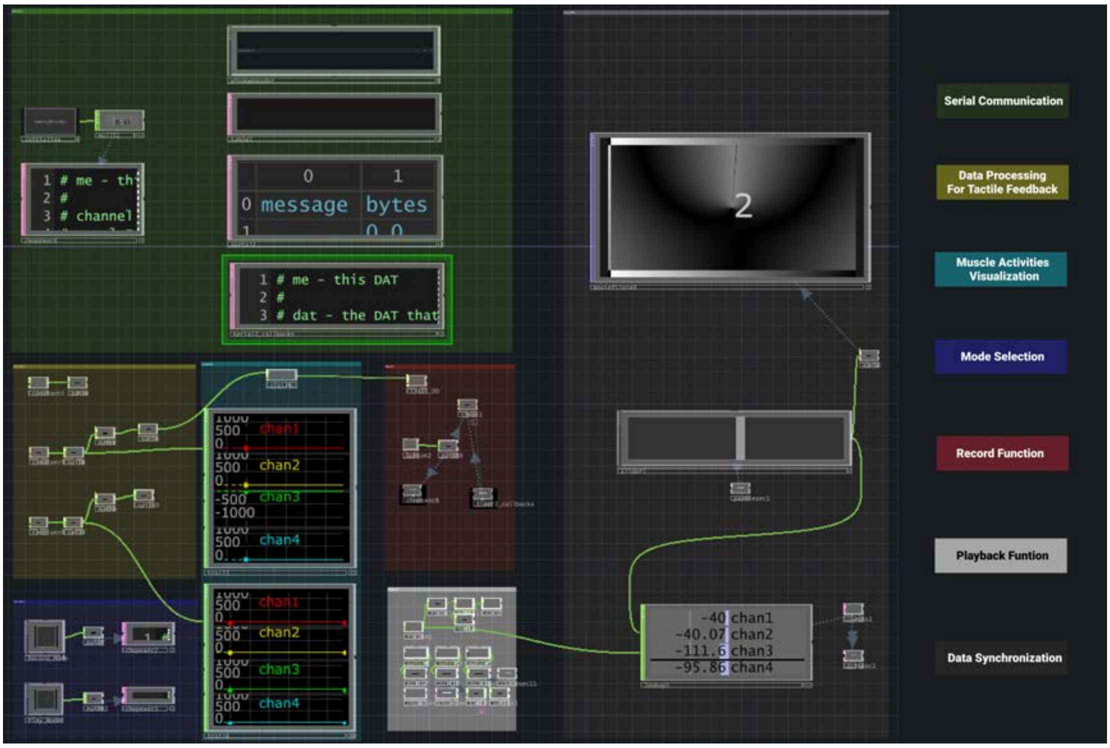


Figure 3.9 Function network in Touchdesigner

3.5.4 Recording Test

After integrating the system, we conducted an initial test in Okinawa to validate its fundamental recording and playback functions. The test focused on capturing

1 Touchdesigner. Developed by Derrative.inc https://derivative.ca/

key tactile and motion data during the pottery-making process, specifically wheel throwing. The primary modalities recorded were fingertip vibrations, forearm muscle activity, and second-person video.

Figure 3.10 Record environment

Fingertip vibrations were recorded using accelerometers mounted on the fingertips. These sensors provided high-precision measurements of vibration dynamics during the interaction with the clay, including variations in contact intensity and surface texture. With their high sensitivity and multi-axis capability, the accelerometers ensured reliable data capture without interfering with natural hand movements due to their compact design. Forearm muscle activity was captured using FMG sensors. These sensors were positioned on the forearm to monitor real-time muscle contractions and relaxations, reflecting the force dynamics involved in the pottery process. This data was crucial for understanding the distribution of force and its relationship with tactile feedback at the fingertips.

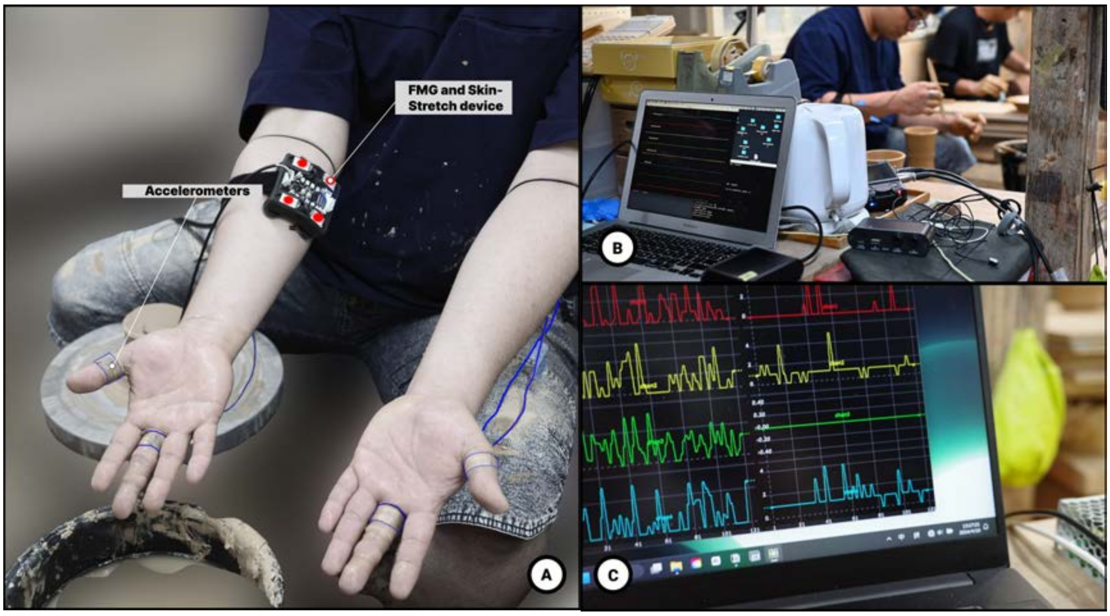


Figure 3.11 (A)Sensors wearing image (B)Recording accelerometer data (C)Recording FMG data

The second-person video was recorded from an observer ' s perspective, positioned directly opposite the pottery maker. The camera was aligned at the same height as the hands to clearly capture hand movements and clay deformation. Using a tripod ensured the stability of the footage, which was detailed enough for subsequent analysis.

During the test, all data streams were recorded synchronously to ensure temporal alignment across modalities. The recording covered the core stages of wheel throwing, including centering, raising, and shaping the clay. The results confirmed the system's ability to function effectively under real-world conditions, providing high-quality multimodal data for further analysis and system refinement.

3.5.5 Data Processing Workflow

In this stage, our main goal was to align the video, accelerometer data, and muscle activity data collected from the FMG (Force Myography) sensor and process them as needed for generating haptic feedback.

Data Synchronization:

First, we achieved data synchronization by identifying a common time reference point. Specifically, we used the "clap" sound, which could be detected in both the video audio track, the accelerometer signal and the FMG signal, as a synchronization marker. This ensured that each video frame, accelerometer sample, and FMG measurement could be aligned to the same time base for further comparison or analysis.

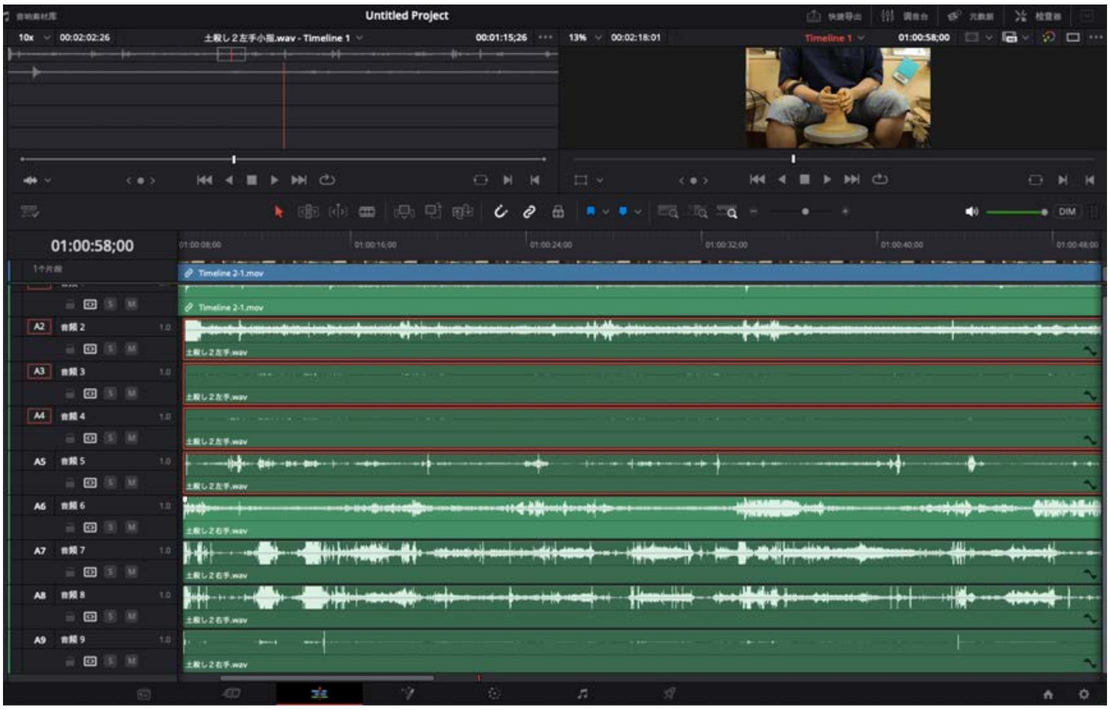


Figure 3.12 Using video editing software to synchronize data

Accelerometer Data Processing:

The accelerometer data, recorded in an audio-compatible format, were processed using techniques similar to those applied to audio signals. A low-pass filter was first applied to eliminate high-frequency noise, preserving the low-frequency motion components that are more suitable for vibration feedback. To further refine the signal, a limiter was used to cap sudden high-amplitude peaks, minimizing excessive variations caused by abrupt movements or noise as shown in 3.13.

Figure 3.13 Limiter and low-pass filter

FMG Data Processing:

The FMG data often contain noise and random fluctuations. To process the data effectively and ensure synchronization with video playback at the same frame rate, we first performed downsampling. The data, originally collected at a variable sampling rate, were resampled to a fixed rate of 60 Hz to match the video frame rate. Following this, the data were normalized to ensure they could be mapped appropriately to the servo motor angles used for providing rotary skin-stretch feedback on the haptic device as shown in 3.14. Finally, Gaussian smoothing was applied to remove remaining noise and random fluctuations, yielding a more stable and refined signal for generating tactile feedback.

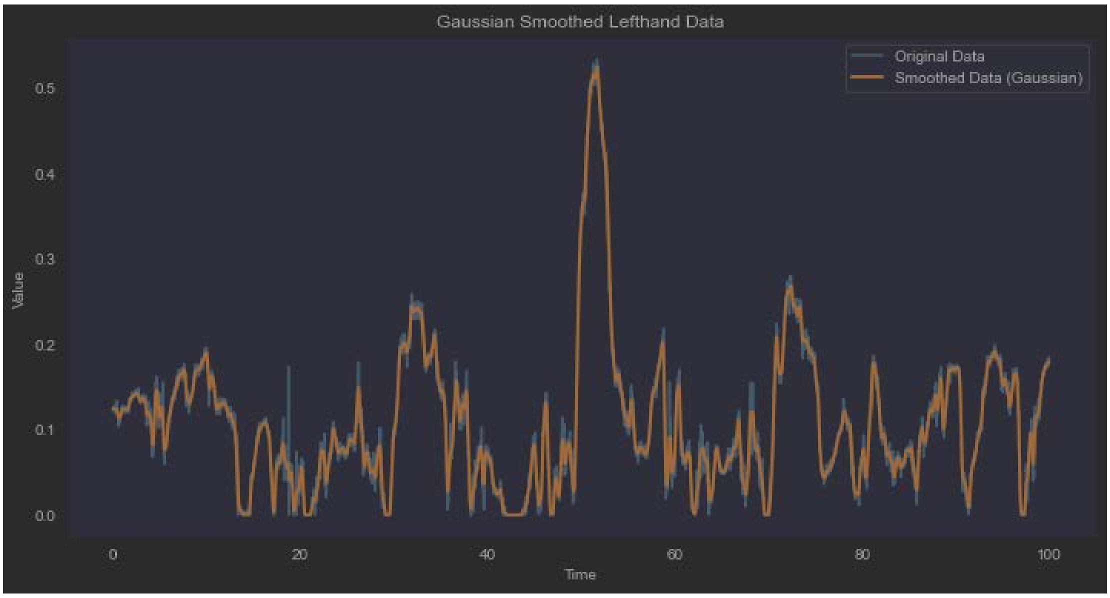


Figure 3.14 An example of processed FMG data

Integration into TouchDesigner:

After processing, we imported the video, accelerometer data, and FMG data into TouchDesigner. By using its " Lock on Timeline " feature, we ensured that all the data streams were synchronized during playback. This time-locking approach allowed the video frames, accelerometer signals, and muscle activity data to be presented simultaneously, enabling us to design corresponding haptic feedback based on the synchronized data.

3.5.6 User Feedback

- The muscle activity sensing device was reported to be uncomfortable to wear. Users also noted that the sensor's indicator light often failed to flash during exertion, possibly because all four FMG channels were placed on one side of the forearm, making it difficult to detect muscle activity from the opposite side.

- Users highly appreciated the fingertip tactile feedback, stating that the synchronization between the tactile sensations and video during fingertip-clay contact was very intuitive, helping them better understand subtle changes in the interaction.

- The use of multiple devices in the system led to feedback that the modules lacked seamless integration, resulting in a less cohesive overall experience and impacting immersion.

- Regarding visualization, users mentioned that during reflective practice, most of their attention was focused on the clay ’ s shape changes and their own hand movements. Visualizing forearm muscle activity on the screen added excessive visual elements, making it hard for them to decide where to focus, especially when a large number of sensor channels were involved. This overload reduced the effectiveness of the reflection process, suggesting that simplifying the visualization or aligning it with user priorities could enhance the overall experience.

- The second-person video created confusion for users due to the reversed perspective of left and right hands. Users reported difficulty mapping their own actions onto the video, as the mirrored view required additional cognitive effort to align what they saw with their physical movements. This misalignment disrupted the reflection process, suggesting the need for alternative video representations, such as first-person or over-the-shoulder perspectives, to provide a more intuitive and relatable view of their actions.

Users positively acknowledged the system's core functionalities, particularly the synchronization of fingertip tactile feedback and video. However, they also highlighted several areas for improvement, such as the comfort and comprehensiveness of the muscle activity sensing device, the noise in the muscle activity data, and the lack of integration among different modules, which affected the continuity of the experience. Additionally, the visualization of muscle activity data was perceived as overwhelming, indicating the need to simplify visual elements to better align with users ’ reflective focus. These insights provide clear directions for further system refinement.

3.6. First Iteration

Based on user feedback during reflective practice with the prototype, the first iteration focused on improving the wearability and usability of the FMG device, integrating different tactile actuators, optimizing the processing of muscle activity data, and addressing issues with visualization.

3.6.1 Hardware Implementation

FMG Sensor

To address issues with device wearability and comprehensive muscle data collection, several improvements were made to the design. The forearm circumference of users was measured to create a customizable wristband that can accommodate users with varying forearm sizes. The BOA® Fit System was integrated into the wristband design, allowing users to easily adjust the fit for secure and comfortable wear.

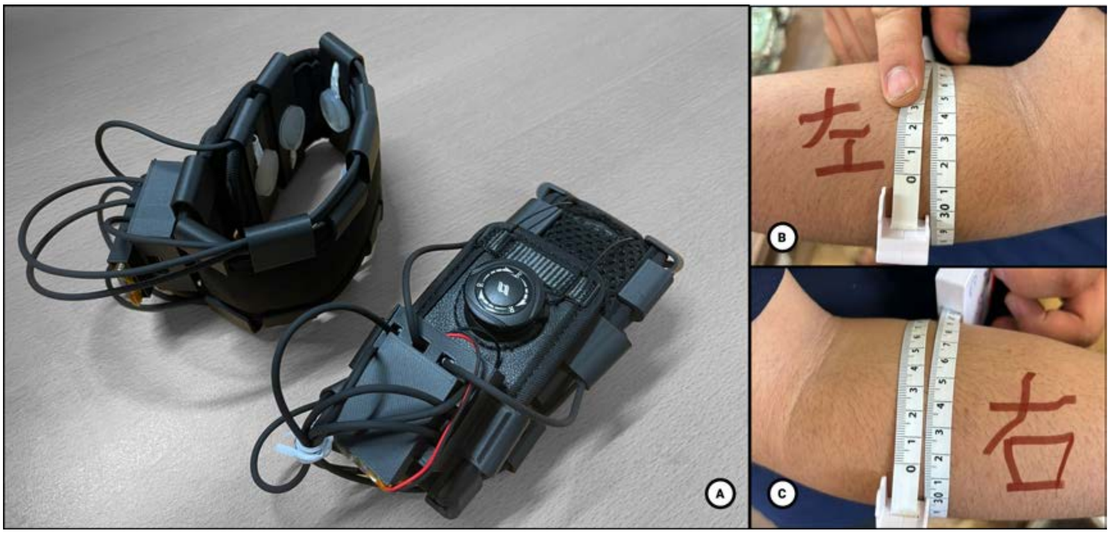


Figure 3.15 (A)8 channel FMG device (B)The left forearm perimeter of user (C)The right forearm perimeter of user

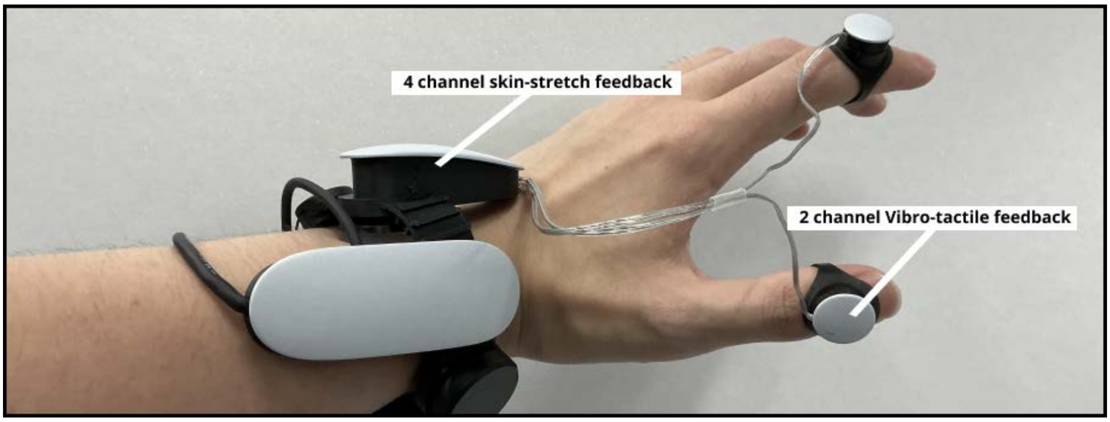
The wristband features 8 FSR sensors evenly distributed around its circumference to comprehensively capture muscle activity from all sides of the forearm. The sensors are connected to the micro controller in a star topology, with sufficient cable length provided to allow for positional adjustments. The cables are routed along the wristband to prevent interference during user operations.

The wristband features 8 FSR sensors evenly distributed around its circumference to comprehensively capture muscle activity from all sides of the forearm. The sensors are connected to the microcontroller in a star topology, with sufficient cable length provided to allow for positional adjustments. The cables are routed along the wristband to prevent interference during user operations.

To enhance connectivity, the device core was upgraded from an STM32 microcontroller to an ESP32-S3 module with an integrated wireless Wi-Fi module. Wireless data transmission via UDP eliminates the need for wired connections, reducing physical constraints on user movement. Combined with a built-in battery, these upgrades aim to improve the device's overall usability and flexibility.

Haptic Device Combining Fingertip Vibrio-Tactile Stimulation and Skin-Stretch Stimulation

In the previous system, different devices were used to provide vibro-tactile feedback and skin-stretch stimulation, leading to certain inconveniences during use. The need to manage multiple devices and their associated cables not only reduced wearability but also impacted the consistency of the user experience. To address these issues, we used a device that integrates different types of haptic feedback, combining fingertip vibro-tactile stimulation and skin-stretch stimulation into a single system.



(Source:FEELTECH Wear [43])

Figure 3.16 A haptic device integrated 2 channel fingertip vibro-tactile feedback and 4 channel rotary skin-stretch feedback

This device includes a single-hand, dual-channel fingertip vibro-tactile feedback mechanism and a 4-channel rotational skin-stretch stimulation system [43]. Compared to the previous setup, which integrated FMG sensing with a rotational skin-stretch feedback device, this new design features four servo motors evenly distributed around the wrist to deliver tactile feedback. Using a 2-to-1 mapping of the FMG device's FSR sensors, the device provides localized haptic feedback based on muscle activity at different positions of the forearm. This design improves upon the previous device, which was limited to providing feedback only on one side of the wrist, allowing for a more comprehensive representation of forearm muscle activity.

By integrating both vibro-tactile and skin-stretch stimulation into a single device, this device not only enhances the continuity of the user experience but also reduces the physical and operational burden associated with wearing and managing multiple devices. These improvements aim to provide a more intuitive and seamless haptic interaction for reflective practice.

POV Video Recording Device

To enhance the quality and perspective of the video recordings, the Vision Pro[2] was utilized for capturing spatial video. This device offers an immersive recording capability that integrates depth information with high-resolution visuals, making it an ideal choice for documenting the nuanced interactions between the user ' s hands and the clay during the pottery-making process.

The Vision Pro ' s spatial video captures not only the hand movements but also the surrounding environment, creating a three-dimensional representation of the workspace. This perspective allows for a more comprehensive understanding of the user ' s actions and the clay ' s shape transformations, providing rich visual data for subsequent reflective practices.

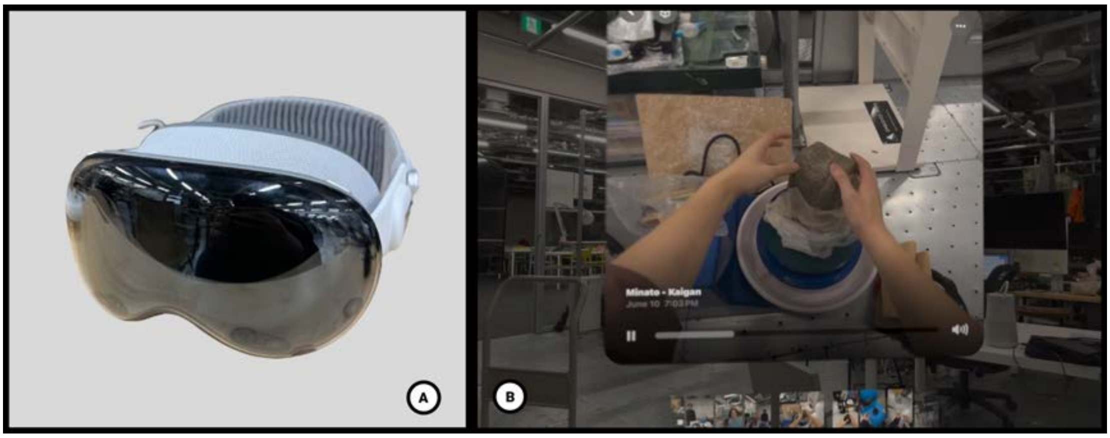


Figure 3.17 (A)Vision Pro (B)Spatial video

The recording setup used the first-person perspective, aligning with the user ' s natural field of view. This setup minimizes the cognitive dissonance that can arise from reversed or misaligned perspectives, as commonly experienced with second-person videos. Additionally, the spatial video format supports precise synchronization with other modalities, such as muscle activity and tactile feedback data, enabling seamless integration into the reflective system.

By leveraging the Vision Pro ' s advanced capabilities, the recording device

2 Vision Pro. Develpoed by Apple.inc https://www.apple.com/jp/apple-vision-pro/

enhances both the clarity and relatability of the visual data, offering users an intuitive way to revisit and analyze their actions during the reflective process.

3.6.2 Software

The TouchDesigner program was updated to accommodate the changes in the hardware configuration. Specifically, functionality was added to control the movement of designated motors in the haptic device. This new feature allows for precise targeting of specific motors to deliver localized tactile feedback based on muscle activity data.

The updated software integrates seamlessly with the 8-channel FMG sensor array, enabling real-time mapping of muscle activity to corresponding servo motor movements. By allowing targeted motor activation, the program helps users experience tactile feedback in specific areas of the forearm, aiming to enhance their ability to associate haptic cues with particular muscle activities.

These modifications ensure that the software fully supports the improved hardware setup, providing a more intuitive and responsive user experience during reflective practice.

3.6.3 Recording

In this iteration, the primary objective of the recording process was to capture high-quality, first-person perspective data on muscle activity and fingertip vibrations during pottery-making, along with synchronized video information for subsequent reflection and analysis. The recording process followed these steps:

- **Device Setup and Calibration:** Before starting the experiment, users wore the improved FMG (Forearm Muscle Activity) wristband and accelerometer-based sensors for capturing fingertip vibrations. The wristband ' s tightness and sensor positions were quickly calibrated before recording to ensure reliable data collection without interfering with the user ' s natural pottery-making movements. Baseline calibration of the devices was also performed prior to recording.

- **Video Recording Setup:** Vision Pro was used to record spatial video from a first-person perspective. The device was aligned with the user's line of action to document the entire pottery-making process. This perspective was chosen to closely match the user's natural viewing angle, making it easier to revisit action details during subsequent reflection.

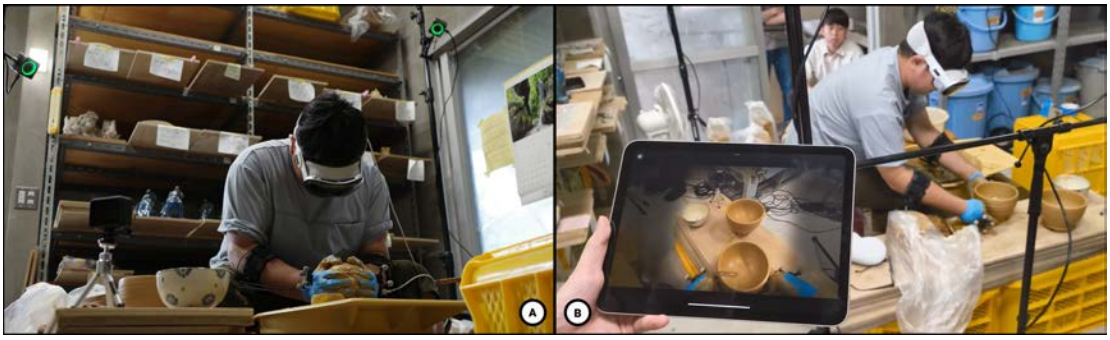


Figure 3.18 (A)Potter wearing a Vision Pro (B)Monitoring on a tablet

- **Data Synchronization and Recording:** During the recording, data from the FMG sensors and fingertip accelerometers were wirelessly transmitted to a computer, where timestamps were added to the data streams in real-time. This ensured synchronization with the video frames. The recording continued until the user completed specific foundational pottery-making steps, such as centering, pulling, and shaping.

- **Preliminary Data Check:** After recording, researchers performed a basic quality check of the video clarity, sensor data completeness, and synchronization accuracy. Once the data quality was confirmed to meet the required standards, it was prepared for subsequent offline processing and integration into the reflection tools.

3.6.4 Data Processing

- **Data Standardization:** The raw data collected from the FMG sensors and fingertip accelerometers was standardized to eliminate variations caused by device differences and environmental factors. This step aimed to ensure consistency across different sessions and users.

- **Noise Reduction with Gaussian Filtering:** Gaussian filtering was applied to smooth the data and reduce noise interference. This step was designed to address challenges from the first test, where excessive noise made it difficult for users to interpret muscle activity. The goal was to make signals clearer and easier to understand.

- **Value Mapping and Normalization:** After filtering, the sensor data was normalized to a 0–1 range for compatibility with subsequent processing. The normalized values were then linearly mapped to servo motor rotation angles, ranging from 0 to 60 degrees. This mapping aimed to provide precise tactile feedback corresponding to muscle activity.

- **Data Synchronization and Integration:** Processed data was aligned with the spatial video timeline to ensure complete synchronization between muscle activity, fingertip vibrations, and visual information. This integration aimed to enhance the continuity of the user ' s reflective experience.

3.6.5 Visualization

To prevent cognitive overload for users during reflective practice, muscle activity visualization was removed in this iteration. Feedback indicated that users found it challenging to focus on both the clay ' s shape changes and additional visual elements, especially when multiple FMG channels were involved. The decision to omit visualization aimed to streamline the reflection process and allow users to concentrate on tactile and visual feedback from the video.

3.6.6 User Feedback

Users reported that the updated device was more comfortable to wear, and the reduction in cables significantly minimized interference during operation. They no longer needed to worry about cables getting caught on the pottery wheel, which made the overall experience smoother and less restrictive.

The noise in the muscle activity data was reduced after preprocessing, and the servo motor movements became more stable, eliminating sudden jumps in rotation angles. This made the tactile feedback more intuitive and easier to interpret.

The integration of different tactile feedback mechanisms into a single device was also well-received, as it provided a more cohesive and unified experience. Users noted that the consistency in haptic feedback enhanced their ability to reflect on their actions during the pottery-making process.

However, users highlighted an issue with the Vision Pro's spatial video. The head-tracking perspective caused discomfort when their head remained stationary while the video view moved. This mismatch between head motion and the visual perspective led to dizziness for some users, suggesting a need for adjustments in video stabilization or perspective handling to improve comfort.

3.7. Second Iteration

The primary objective of this iteration was to improve the user experience with first-person perspective videos. In the first iteration, users reported motion sickness (commonly referred to as "3D dizziness") due to the need to move their heads to match the video perspective. However, since the Vision Pro's video playback window is fixed, even when users turned their heads, the video did not align with their movements, exacerbating the discomfort.

To address this issue, we proposed and tested two solutions:

- **Side-by-Side Stereo Video with an Eye-Tracking 3D Display:** The first solution involved using a stereo camera to capture side-by-side videos. These videos were played back on a 3D display equipped with eye-tracking capabilities. This approach aimed to provide a more natural viewing experience by adapting the 3D video perspective to the user ' s eye movements, reducing the mismatch between head motion and the displayed video.

- **Horizontal Mirroring of the Video:** The second solution was to horizontally mirror the video during playback. This method aimed to provide a more intuitive correspondence between the video and the user's physical movements. By mirroring the video, users could view actions as if they were looking into a mirror, potentially reducing the cognitive effort required to align the video perspective with their own.

Both solutions were tested to evaluate their effectiveness in mitigating motion sickness and improving the overall user experience with first-person perspective video playback.

3.7.1 Recording

A stereo camera was mounted on a stable rig positioned slightly below the user ' s head level. This setup ensured that the camera's perspective closely matched the user ' s natural field of view, while avoiding interference with their line of sight during pottery-making.

The stereo camera was calibrated before recording to ensure accurate depth perception and alignment between the left and right video feeds. The setup captured side-by-side stereo video, which was later processed and synchronized with other data streams, including muscle activity and fingertip vibration data. This configuration enabled us to create high-quality, immersive 3D content for playback on the eye-tracking 3D display.

For the second solution, the same camera setup was used to capture regular video, which was then horizontally mirrored during post-processing. This ensured consistency between recording methods and allowed a direct comparison of the two playback strategies.

3.7.2 User Feedback

- **Side-by-Side Stereo Video with Eye-Tracking 3D Display:** Users noted that the stereo video provided a clear sense of depth, which made the visual experience richer and more immersive. However, many participants reported discomfort after prolonged viewing, including dizziness and eye strain. The combination of depth perception and the need for slight head adjustments to align with the display created visual fatigue, making this solution less practical for extended use.

- **Horizontal Mirroring of the Video:** The mirrored video playback was simpler and more comfortable for users. It provided an intuitive experience, as the mirrored perspective resembled looking into a mirror, allowing users to easily correlate their movements with the video. This solution did not cause motion sickness or visual discomfort, and most participants found it preferable for reflection tasks.

Overall, while the 3D display offered enhanced depth perception, its drawbacks in terms of comfort and usability highlighted the practical advantages of the mirrored video solution. The feedback suggests that simplicity and comfort are key factors in designing effective reflective tools.

3.8. Summary

This chapter provides a comprehensive account of the iterative design process undertaken to address the challenges in transmitting and reflecting upon the tactile and embodied aspects of pottery-making skills. Building on an Iterative Participatory Design methodology, the project involved close collaboration with multiple partners—including the Japan Craft Industry Association, haptics researchers, and the Ikutouen Pottery Studio—to ensure the solution met the needs of both novices and expert artisans.

Initial fieldwork and workshops at Ikutouen revealed the limitations of traditional methods in conveying the tacit, tactile knowledge integral to pottery. Beginners struggled to recall subtle details of hand pressure and clay texture changes after practice sessions, while instructors found it difficult to communicate nuanced tactile concepts through demonstrations and verbal explanations alone.

To address these issues, the EmbodyCraft framework was proposed. It integrates forearm muscle activity data (FMG), fingertip vibration feedback, and video recordings into a synchronized dataset. This multimodal approach aims to enhance post-action reflection, allowing learners to “re-feel” their past experiences and better understand the relationship between their actions and the clay’s behavior.

Over several iterations, the prototype underwent significant refinements:

- **Wearability and Data Quality:** Early versions used FMG sensing and fingertip accelerometers, but users found the setup cumbersome. Adjustments included improved wristbands for more stable FMG readings, wireless data transmission, and integrated haptic feedback to ensure comfort and reduce environmental interference.

- **Haptic Integration and Data Processing:** Noise filtering, Gaussian smoothing, and clearer signal mapping stabilized the tactile feedback. The combination of fingertip vibrations and skin-stretch stimulation offered a more cohesive sensory experience, allowing learners to understand nuanced force application without being overwhelmed by complex on-screen visualizations.

- **Video Perspective and User Comfort:** Initial first-person and spatial videos caused visual discomfort. Attempts to leverage 3D displays and eye-tracking introduced complexity and even dizziness for some users. Ultimately, a mirrored video presentation proved most effective, reducing cognitive load and allowing learners to more intuitively relate their recorded actions to the tactile feedback provided.

User feedback guided these iterative improvements. The final integrated system is more comfortable, stable, and user-friendly, offering a seamless synergy between tactile and visual information to support more effective skill reflection.

In essence, this chapter details the end-to-end design journey—discovering the problem, proposing a concept, building and testing prototypes, analyzing user feedback, and making informed revisions. The outcomes highlight the importance of iterative refinement and user-centered design when dealing with embodied, tacit knowledge transmission in traditional crafts, laying a foundation for future enhancements and evaluation.

Chapter 4
Proof of Concept

4.1. User Test

In the previous chapters, we introduced the conceptual framework of the EmbodyCraft system, which is centered around two key use cases that were identified in the conceptual design phase. Drawing on Schön's notion of Reflection-on-Action and Kolb ' s concept of Reflective Observation, these use cases reflect how visual and haptic feedback can enrich the reflective practice process in craft skill transmission.

4.1.1 Use Cases

Use Case 1: Post-Action Self-Reflection
This scenario focuses on learners reviewing their own recorded performance after completing a training session. By replaying synchronized visual and haptic data, users can more accurately sense how their actions influenced the material, gaining deeper insight into subtle force application and movement nuances.

Use Case 2: Reflective Observation and Communication Based on Others ' Experience
Here, learners engage with recorded data from other practitioners. The combination of visual and haptic feedback aims to help users better understand the qualities of another ' s skill execution, facilitating discussions and shared understanding of movement characteristics that may be difficult to convey through visual or verbal information alone.

4.1.2 Research Objectives

This study aims to enhance reflective practice in the transmission of pottery skills by investigating the impact of visual and haptic feedback on skill understanding. The visual feedback consists of recorded videos of the pottery throwing process, showcasing detailed movements and techniques of the craftsman during the shaping of clay on the pottery wheel. The haptic feedback, precisely synchronized with the visual content, comprises time-series tactile cues derived from the craftsman's recorded muscle activities and fingertip vibrations. These cues are designed to provide an embodied sensory experience, enabling participants to perceive the physical exertion and tactile sensations involved in pottery throwing.

4.1.3 Hypotheses

Specifically, the study tests the following hypotheses:

- **Hypothesis 1:** In both post-action self-reflection and reflective observation scenarios, incorporating visual and haptic feedback increases users' attentiveness to nuanced skill movements, enabling them to capture finer details and deepen their understanding of movement quality.
- **Hypothesis 2:** In post-action self-reflection, combining visual and haptic feedback further enhances the depth of users' reflective experiences and their sense of engagement, encouraging more active evaluation and improvement of their skills.
- **Hypothesis 3:** In reflective observation and communication based on others' skill data, integrating visual and haptic feedback provides additional information (e.g., rhythm, force) that cannot be fully conveyed through visual or verbal means alone. This richer feedback modality supports more meaningful interactions, facilitates deeper skill exchanges, and helps establish a shared understanding of movement characteristics and skill logic.

4.1.4 Experimental Method

Participants and Roles

The study involved two distinct roles, each contributing to different phases of the research:

- **Roles:**
  - **Skill Recorder:** An experienced potter engaging in self-reflection on their own recorded skill performance.
  - **Skill Observers:** A group of participants different experience focusing on understanding and reflecting on another practitioner's recorded skill performance.
- **Number of Participants:** 6 individuals (1 Skill Recorder and 5 Skill Observers).

Experimental Conditions

- **Condition 1: Visual Feedback (Baseline)**
  - Participants observe skill actions through video.
  - No haptic feedback is provided.
  - Serves as a control condition to measure the basic effect of visual observation on skill learning.
- **Condition 2: Visual + Haptic Feedback (Intervention)**
  - Participants observe skill actions through video supplemented with haptic feedback devices that present information on force application and movement timing.
  - Haptic feedback complements visual information to verify the effectiveness of combined sensory inputs in enhancing skill understanding and reflection.
  - Haptic signals are generated based on pre-recorded expert movement data.

Tasks

- **Session 1 (Post-action Self-Reflection of Skills)**
  - Observe their own skill videos with only visual feedback and engage in **Speak Along** (verbalize their thoughts).
  - Re-observe the videos with added haptic feedback while continuing **Speak Along**.
  - After each observation, participate in a discussion with the researcher to share how haptic feedback assisted in reflecting on their skills.
  - **Sample Question:** "How did haptic feedback contribute to your awareness of your skills?"
- **Session 2 (Reflective observation to understanding Others' Skills)**
  - Observe others' skill videos with only visual feedback and engage in **Speak Along**.
  - Re-observe the videos with added haptic feedback while continuing **Speak Along**.
  - **Special Session with skill recorder:**
    - Skill recorder attends to provide insights.
    - Skill observers discuss their understanding of others' skills based on both visual and haptic feedback.
    - Skill recorder comments on the differences between their own skill experiences and Skill observer's interpretations.
  - **Sample Questions:**
    - "How did haptic feedback help you better understand the characteristics of others' skill actions?"
    - "What additional information or sensations did haptic feedback provide that were not apparent through visual feedback alone?"

Data Collection

- **Qualitative Data**

- Conduct semi-structured interviews to record participants' impressions of haptic feedback and gather insights into their learning processes.

Data Analysis

- **Thematic Analysis**
  - Conduct thematic analysis of interview results, summarizing theme frequencies, deriving insights, and comparing them with practical examples to validate the hypothesis.

Procedure

- **Introduction**
  - Briefly explain the purpose and overview of the experiment.
  - Demonstrate how to operate the haptic devices and view the visual videos.
  - Present consent forms and address any questions from participants.
- **Condition 1: Visual Feedback (Baseline)**
  - Present visual videos while participants engage in **Speak Along**.
  - After observation, conduct a discussion with the researcher to document initial understanding.
- **Condition 2: Visual + Haptic Feedback (Intervention)**
  - Present videos with integrated haptic feedback.
  - Participants continue to **Speak Along**.
  - Conduct a similar discussion post-observation to evaluate the impact of haptic feedback.
- **Special Session for skill recorder and skill observers (Understanding Others' Skills)**
  - skill recorder joins to facilitate a discussion.

  - skill observers share their enhanced understanding based on haptic feedback.
  - skill recorder provides feedback on the alignment between skill observer's interpretations and actual skill actions.

- **Closing**
  - Conduct final interviews to collect overall impressions and suggestions for improvement.

4.2. Session 1:Post-action Self-Reflection of Skills

Skill recorder S is a seasoned potter at Ikutouen with over ten years of experience, particularly skilled in the wheel-throwing (forming) stage. In this study, he watched recordings of his own work process under two conditions: Condition 1 with visual feedback only (video only), and Condition 2 with both visual and haptic feedback. He reflected on his hand movements, force application, and rhythmic control when comparing these two conditions.

Figure 4.1 Skill recorder S reflecting on his own skill

Condition 1 (Visual Only): Emphasis on Basic Differences and Macroscopic Control :

Under the visual-only condition, S ' s observations focused on surface-level phenomena and overall operational tempo. For instance, he first noted the impact of wearing gloves on tactile sensation:

- **S stated:** " ビニール袋をつけている…思った以上に、水切れが早い "
  (Translation: " Wearing a plastic bag (glove) ··· the water dries out faster than expected. ")

This situation forced him to add water more frequently to prevent the clay surface from drying too quickly and causing difficulties in wheel-throwing. Compared to his usual practice without gloves, this was atypical and required extra caution. During this phase, S ' s discussion centered on adjusting fundamental parameters —such as how often to add water and how to keep the surface even—as well as relying on the thumb, index, and middle fingers as the main controlling trio:

- **S stated:** " 親指と、指し指と中指、この *3* つの指がメイン "
  (Translation: " The thumb, index, and middle fingers are the main ones. ")

When judging the force and rhythm, he largely depended on visual cues and experience. He inferred the magnitude of force by looking at how the clay deformed and how much mud stuck to his hand:

- **S stated:** " 手につく泥の量で、その人がどれだけ力をやっているか…参考になる "
  (Translation: " The amount of mud sticking to the hand can serve as a reference to gauge how much force a person is using. ")

Although he could glean a general idea of force application and skill level, this approach remained relatively coarse. He observed the clay ' s movement first, then adjusted his actions accordingly, but did not delve into the finer details of how each finger modulated force at any given moment.

Condition 2 (Visual + Haptic Feedback): From Macroscopic to Microscopic Exploration :

When haptic feedback was introduced, S ' s analysis gained significant depth. He no longer relied solely on visual cues and guesswork, but rather used synchronized tactile information to directly perceive how force was distributed and varied among his fingers. He explicitly noted a shift in attention from the material to his hand actions:

- **S stated:** " 動画だけだと土 *7* 割、手 *3* 割…触覚がある場合は逆転して手 *6* 割土 *4* 割 "
  (Translation: " With video only, about 70%of my attention is on the clay and 30% on my hand… With haptic feedback, this ratio reverses to about 60% on the hand and 40% on the clay. ")

This change in ratio meant he began scrutinizing the precise locations and timings of force application. When tactile feedback revealed distributions of force that contradicted his expectations, he was surprised:

- **S stated:** " 力を入れていた覚えのないところに入れていたり…逆に入れていたはずなのに入れていない "
  (Translation: " There were places I had no memory of applying force, yet I had; conversely, places where I thought I had applied force, I actually hadn ' t. ")

Figure 4.2 illustrates such a tactile discrepancy, highlighting a mismatch between perceived and actual force application. The participant S initially believed that, when pressing the clay from top to bottom, both hands were applying symmetrical and evenly distributed force. However, due to stronger skin stretch feedback in his right hand, he began to rethink his perception of where and how force was actually being applied.

Figure 4.2 Illustration of the discrepancy between perceived (blue) and actual (red) force application during clay manipulation by S

Originally, he assumed that he was using the fingertips of his left hand and the palm of his right hand to press against the clay from opposite directions to shape it. Unexpectedly, though, he felt vibration feedback in parts of his right hand that were not supposed to be in direct contact with his left hand's fingertips. This led him to conclude that his right fingertips were likely covering and applying more force than anticipated, whereas his left hand contributed less force than he initially believed.

This tactile discrepancy helped him realize that his actual force application did not align with his prior expectations. Such insights prompted a deeper examination of his hand movements, force distribution, and the role each part of his hand played in manipulating the clay's shape.

This " unexpected discovery " prompted him to reconsider the functional roles of each finger. He realized that depending solely on the main three fingers wasn ' t ideal—perhaps involving the ring and little fingers more effectively could ease the burden and refine the clay ' s shape more efficiently.

Additionally, S mentioned that haptic feedback led him to examine the video more persistently, as if “searching for errors”:

- **S stated:** “触覚があると…間違い探しをするように集中度が増す”
(Translation: “When there’s haptic feedback… it’s like looking for errors, and I become more focused.”)

In other words, tactile input not only helped him detect concealed patterns of force application but also motivated him to invest more time and cognitive effort into understanding why he applied too much or too little force at certain moments. Under these conditions, he not only watched and thought more thoroughly but also formed concrete improvement strategies—for instance, fine-tuning how he distributes force among different fingers or adapting the pressure according to the clay’s moisture level. This process represented a shift from a basic experiential judgment to a more analytical, detailed exploration of his hand movements.

Furthermore, S emphasized that this multi-sensory input transformed learning from a purely conceptual level to a bodily one:

- **S stated:** “触覚が来ると…体で学ぶ”
(Translation: “When tactile feedback is involved… I learn with my body.”)

Through tactile information, he turned abstract concepts of force into tangible bodily sensations. This bodily anchoring would presumably help him recall and apply these insights more readily in future practice sessions.

Macroscopic Comparison and Significance:

In summary, under Condition 1 (visual only), S mostly addressed macro-level adjustments (water frequency, surface flatness, and basic finger positioning) and made relatively broad, experience-based judgments. Under Condition 2 (visual + haptic), he delved into the micro-level aspects of force distribution, timing, and coordinated finger roles. This transformation from surface-level observation to in-depth inquiry fundamentally improved the precision and duration of his reflective process. He became more interested in “digging in” and “troubleshooting” the subtle points of his technique.

By contrasting visual data with tactile feedback, S developed a richer cognitive model of his actions and found more systematic ways to think about improvements. These observations vividly illustrate the potential value of multi-sensory feedback in the reflection and refinement process of traditional craft skills.

Summary of Session 1 Findings

With visual-only feedback, S ' s self-reflection remained at an overall strategic and basic skill point level. In contrast, with visual-plus-haptic feedback, his analysis grew more in-depth and systematic, revealing the intricate logic and fine control points behind his movements. Tactile input turned what was once an experiential, vague sense of force into a precise and analyzable field of inquiry. This aided him in internalizing the essence of the technique and provides a grounded basis for future research on how multi-sensory feedback can deepen skill reflection and understanding.

4.3. Session 2 : Reflective observation to understanding Others' Skills

In Session 2, five observers with varying levels of craftsmanship experience—Observer T, Observer Y, Observer M, Observer N, and Observer O—first watched the skill recorder ' s recorded actions under the Visual-Only Condition, engaging in a **Speak Along** process to verbalize their immediate interpretations. They then re-watched the same data under the Visual + Haptic Condition and the skill recorder joined the discussion, providing insights and responding to observers' interpretations.

Figure 4.3 Skill observer M reflecting on other's skill

Visual-Only Condition: Macro-Level Impressions

Under the Visual-Only Condition, Observer T relied on the clay ' s visible shape changes and the general positioning of hands to infer the skill recorder ' s technique. Without haptic cues, it remained challenging to determine exact force distributions, the timing of force application, and the subtle interplay of different fingers.

- **T stated:** " 表面上の土の動きや手の形から、他者の上げ下げ動作は分かるのですが、具体的な力加減や指の使い分けなどは視覚情報だけでは把握しにくい。"
  (Translation: " From the visible shape changes and hand forms, I can guess how the clay is being raised and lowered, but it ' s hard to identify the exact force distribution or which fingers are doing what with just visual information. ")

In the absence of tactile cues, observers could form broad impressions—such as noting the use of the entire palm for lifting the clay or recognizing a fast spinning speed—but they struggled to detect when and where specific forces were applied.

Their attention remained mostly at a macro level, concentrating about 60% on the clay ' s evolving form and 40% on general hand movements.

- **N stated:** "指跡や泥量からなんとなく想像はできるが、実際どれほど力を入れているか、またどの指を主体に使っているかは映像だけでは難しい。" (Translation: " You can imagine certain things from finger marks or the amount of mud on the hand, but you can ' t really tell how much force is being applied or which finger is dominant by just looking. ")

Visual + Haptic Condition: Micro-Level Insights and Rhythmic Understanding

When switching to the Visual + Haptic Condition, the introduction of tactile feedback led to a significant shift in perception. Observers no longer focused solely on the clay ' s overall shape; instead, they began correlating the tactile sensations with the on-screen movements, attempting to synchronize what they felt with what they saw.

- **M stated:** " 触覚が加わると、自分も手を動かしたくなる。画面の動きと自分が感じる力の変化を合わせて考えることで、どのタイミングで力を入れ、どこで緩めているかが明確になる。"
(Translation: " With haptic input, I feel compelled to move my own hands, as if aligning the screen ' s movements with the tactile signals. This makes it clearer when force is applied or released. ")

Tactile feedback revealed a previously inaccessible layer of information: the dynamic rhythm and intensity of force application. Observers noted that they could now perceive not only the clay ' s movement rhythm but also the subtle patterns of increasing, maintaining, and decreasing force over time.

Observer T also discovered discrepancies between their expectations and what they felt. In particular, moments where they expected force but did not sense corresponding tactile signals prompted them to analyze other body movements, such as elbow positioning, which may have contributed to stabilizing the action.

- **T stated:** " 本来力が入っていそうな場面で、触覚フィードバックが弱いと、逆になんで力が入っていないんだろう？… 体の他部位（肘、腿）によ

る安定化を想像させる。" (Translation: "If I expect force but feel none, I wonder why. It makes me think of body support—like elbows or thighs—broadening my understanding beyond just the clay.")

For instance, Figure 4.4 provides a concrete illustration of such a discrepancy. Initially, when the clay ' s shape is highly irregular, it is generally expected that practitioners must apply substantial force to stabilize and prepare the clay for subsequent shaping. According to Observer T, this stage typically involves exerting force through the forearms. However, the observer noted that the skin-stretch feedback device attached to the forearm did not indicate a strong force application as anticipated. This lack of corresponding tactile feedback prompted a reassessment of both the skill recorder ' s method and Observer T ' s own assumptions.

Figure 4.4 Illustration of the discrepancy between perceived (blue) and actual (red) force application during clay manipulation by T

Upon closer inspection, Observer T discovered that the skill recorder ' s elbow was firmly braced against the inner thigh, effectively using the leg to anchor the arm ' s position. Rather than relying solely on muscular force from the forearm, the skill recorder employed body positioning—pressing the elbow into the thigh—to achieve stability with minimal direct exertion. Through this realization, it became evident that what appeared to be a force-intensive step could, in fact, be managed by skillful body support and strategic alignment rather than raw strength. In this way, the figure underscores the subtle yet critical differences between the initial expectations of force application and the recorder's actual bodily strategy for controlling the clay.

This phenomenon was not unique to Observer T—it was similarly noted in Observer Y and Observer N's discussions, suggesting that the role of body stabilization in skill execution had not been explicitly considered in visual-only observation.

Observer Y, a craftsman with over ten years of experience, usually applies force using hand-thrown centering, relying more on arm and hand control. When experiencing the haptic feedback, he realized that the skill recorder was stabilizing their body against the wheel, which was something he hadn't paid much attention to before. On the other hand, Observer N, a pottery apprentice with three years of experience, had mostly focused on upper-body control, and the haptic experience made him realize that lower-body engagement was also a way to stabilize the clay.

- **Observer Y:** "最初は前腕の力で支えていると思ってたんだけど、実は身体をろくろに押し付けることで安定させてたんだなって気づいた。" (Translation: "At first, I thought the force came from the forearm, but I realized that they were actually stabilizing by pressing their body against the wheel.")
- **Observer N:** "今まで腕とか手の動きばっかり見てたけど、触覚フィードバック受けて、下半身の使い方がけっこう大事なんだって分かった。" (Translation: "I used to focus only on arm and hand movements, but after feeling the haptic feedback, I realized that lower-body usage plays a pretty important role.")

With haptic feedback, observers could now perceive not only the clay's movement rhythm but also the nuanced control of increasing, maintaining, and decreasing force over time. This deeper understanding extended beyond hand and forearm actions, revealing how the entire body participates in force modulation.

Rather than prescribing a single correct approach, the experience allowed observers to compare different techniques and reflect on which method felt more natural for them.

Since Observer T also teaches beginners at a pottery workshop, he often thinks about how to verbally explain skills in a way that makes sense to novices. Through the haptic experience, he found that previously abstract concepts, such as when to relax force or how to maintain fingertip contact, became easier to communicate. Instead of relying solely on visual demonstration, the addition of tactile feedback provided a more concrete way to describe subtle techniques.

- **T stated:** "指先を土につけたまま、このタイミングで力を緩めるんだよ、って初めての人にも説明しやすくなる。" (Translation: "Tactile information helps me tell beginners: 'Keep your fingertips on the clay, ease force at this moment.' It's easier to explain things that were vague with only visuals.")

By experiencing these tactile cues himself, Observer T realized how haptic feedback could supplement verbal instruction, providing a shared sensory reference for learners. This not only made skill explanations more precise and intuitive but also allowed students to internalize the feeling of force modulation more effectively.

Summary of Session 2 Findings

Under the Visual-Only Condition, Observer T's understanding remained macroscopic, identifying broad patterns but missing finer details of force timing and subtle hand adjustments. The Visual + Haptic Condition, however, enabled a shift to micro-level insights. Tactile feedback revealed force rhythms, subtle pressure changes, and the importance of body posture, allowing Observer T to form a richer, more analytical understanding of the skill recorder's technique.

Compared to Session 1, where the skill recorder reflected on their own performance, Session 2 shows how multimodal feedback helps observers comprehend another practitioner's skill more thoroughly. The tactile component sparked a more investigative mindset, enabling the translation of complex, embodied knowledge into clearer, teachable insights. This suggests that haptic feedback can significantly enhance skill transmission, making it not only more understandable but also more communicable in a teaching context.

4.4. Thematic Analysis of the Result of Semi-structured Interview

This study employs Thematic Analysis to systematically organize interview data and understand how visual + haptic feedback influences observers' skill perception and communication.

To achieve this, we designed a code scheme that categorizes participants' statements into four main categories: Attention Detail, which examines how observers allocate their focus; Depth of Reflection Self-Evaluation, which explores how they describe, analyze, or adjust their skills; Skill Understanding Improvement, which investigates how they recognize key movements, receive feedback, or refine their techniques through trial and error; and Communication Shared Understanding, which looks at how observers discuss, compare, and collaboratively interpret skills.

As shown in Figure 4.5, this thematic coding framework provides a structured way to classify and analyze interview data. By analyzing the frequency and percentage of occurrences in each category and integrating qualitative insights from the interviews, we assess the impact of haptic feedback on observers ' reflection processes and validate our research hypotheses.

Figure 4.5, which organizes participants' statements into four main categories.

Main Category	Subcategory	Definition/Description	Example Quote/Keywords
Attention & Detail	Focus on Clay	Focus on the state of clay, including moisture, texture, deformation, etc.	'Only focusing on how the clay moves...'
	Focus on Hands	Focus on hand movements, positions, angles, or points of force.	'I thought I was using my right hand, but actually...'
	Focus on Tools/Context	Focus on tools like gloves, water supply, or context-specific influences.	'The gloves make it feel different than usual...'
	Detail Awareness - Rhythm	Observation of rhythm and transitions in movements.	'When to lift or press the clay...'
	Detail Awareness - Force Variation	Observation of variations in the strength or intensity of force.	'Judging force by the amount of clay sticking to hands...'
	Detail Awareness - Posture	Description of how hands grip or conform to the clay.	'If I could use my ring and little fingers better...'
Depth of Reflection & Self-Evaluation	Descriptive Reflection	Surface-level descriptions of actions or phenomena without deeper analysis.	'Here I'm just lifting the clay...'
	Analytical Reflection	Explaining the reasons for actions or their impact on subsequent processes.	'Whether this step is done properly affects the next stage...'
	Actionable Reflection	Proposing improvement ideas or practical plans for next steps.	'Next time, I'll try using my fingers differently...'
	Comparisons to Ideal/Others	Comparing one's actions to an ideal or others' actions.	'My mentor adjusts to clay texture within 2–3 touches...'
	Awareness of Limitations	Pointing out weaknesses or areas needing improvement in skills.	'I might have added too much water, which caused...'
	Intention to Adjust/Improve	Expressing willingness to adjust or improve actions or habits.	'I need to adjust the pressure from my thumb...'
Skill Understanding & Improvement	Critical Moves	Description of key steps such as 'centering the clay' or 'pulling'.	'At the start, avoiding drying the clay too much...'
	Key Feedback	Feedback cues like clay texture, vibration, or sound to judge actions.	'Judging force control through clay accumulation...'
	Self-Exploration	Improving through personal experience and trial-and-error.	'I figured this out through repeated failures...'
	Peer Reference	Learning ideas by referencing others' videos or discussions.	'I learned from watching another potter's video...'
Communication & Shared Understanding	Mutual understanding	Understanding others' actions through video or verbal communication.	'Estimating others' force through their video...'
	Joint Interpretation	Group discussions on the quality of movements or improvement suggestions.	'This part needs more pressure, as discussed...'
	Reaching Consensus	Consensus or differences on rhythm or force among team members.	'Some feel the force is too strong, while others...'

Figure 4.5 Code scheme for thematic analysis

4.4.1 Verification of Hypothesis 1: Enhanced Awareness of Fine Movement Details and Force Dynamics

To validate Hypothesis 1, we analyzed the average frequency and percentage of themes related to attentiveness to skill details and movement quality across six participants in two scenarios: post-action self-reflection and reflective observation. Specifically, we examined how participants' focus on hand movements, awareness of force variation, awareness of rhythm, and identification of key feedback changed under the Visual-Only and Visual + Haptic conditions. This analysis specifically compares the Visual-Only and Visual + Haptic conditions to examine their impact on participants' perception and evaluation of skill execution. Specifically, this hypothesis suggests that:

- **Hypothesis 1:** In both post-action self-reflection and reflective observation scenarios(n=6), incorporating visual and haptic feedback increases users' attentiveness to nuanced skill movements, enabling them to capture finer details and deepen their understanding of movement quality.

As shown in the Figure 4.6, with the addition of haptic feedback, participants' attention shifted from primarily focusing on the clay (accounting for 26.3%) to focusing more on their hands (increasing from 10.3% to 16.6%), providing a foundation for more detailed and in-depth perception of hand movements. At the same time, attention to finer details also increased significantly, with awareness of force variation rising from 4.0% to 7.2% and awareness of rhythm increasing from 3.1% to 6.1%. These improvements in detail awareness offered participants more references, helping them better understand movement quality. The growth in key feedback further supports this finding, indicating that tactile cues played a crucial role in enhancing participants' ability to evaluate and adjust their actions. Supported by this heightened awareness, participants also demonstrated improved judgment of critical moves, with their frequency increasing from 3.0% to 7.4%.

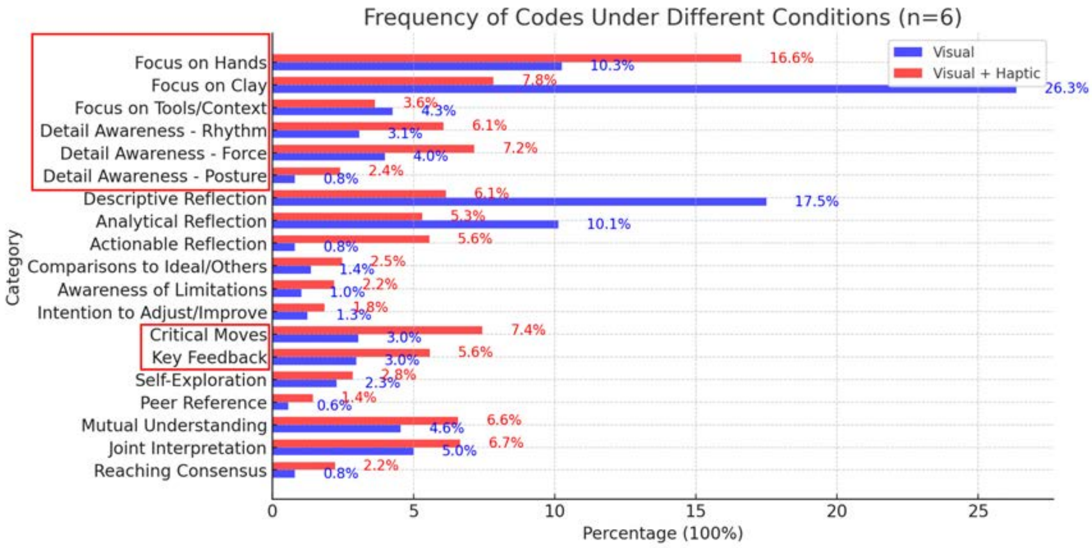


Figure 4.6 Theme percentage under tow conditions(n=6)

For instance, the previously mentioned discrepancy in force perception—where some participants initially assumed force was applied primarily through the forearm but later realized the importance of leg stabilization—further illustrates this shift in attentiveness. With haptic feedback, participants not only became more aware of subtle variations in force application but also reconsidered the mechanics of skill execution beyond just hand movements. This heightened sensitivity enabled them to distinguish between different stabilization strategies and refine their interpretation of movement quality. As a result, their ability to evaluate movement precision and efficiency improved, reinforcing the hypothesis that visual and haptic feedback enhance attentiveness to finer details in skill execution.

4.4.2 Verification of Hypothesis 2: Deepened Reflective Engagement and active evaluation and improvement of their skills in Post-Action Self-Reflection

To validate Hypothesis 2, we analyzed user interviews on reflective engagement and self-improvement under two conditions: visual-only and visual + haptic feedback. Specifically, we examined how participants' depth of reflection varied, categorizing their responses into descriptive reflection, analytical reflection, and actionable reflection—three levels of reflective engagement that indicate increasing depth in post-action self-reflection. Additionally, we assessed themes related to awareness of limitations and intention to improve, which reflect participants' recognition of errors and motivation for skill refinement. This hypothesis suggests that:

- **Hypothesis 2:** In post-action self-reflection(n=1), combining visual and haptic feedback further enhances the depth of users' reflective experiences and their sense of engagement, encouraging more active evaluation and improvement of their skills.

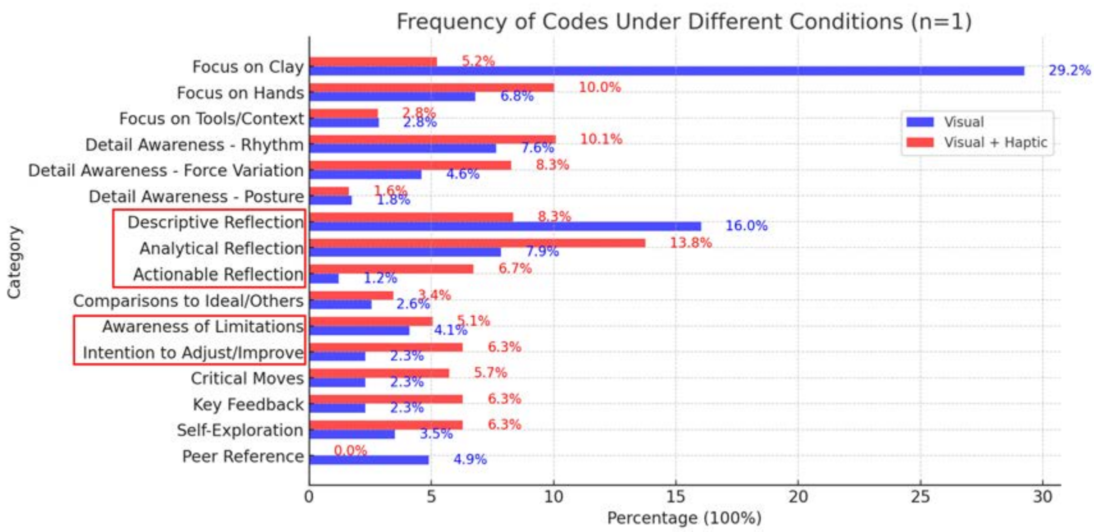


Figure 4.7 Theme percentage under two conditions(n=1)

As shown in the Figure 4.7, the results showed that in the visual-only condition, descriptive reflection accounted for 16.0% of responses, while with haptic feedback, analytical reflection increased significantly (7.9% to 13.8%) and actionable reflection increased (1.2% to 6.7%). Additionally, themes such as awareness of limitations and intention to improve grew notably, with the latter rising from 2.3% to 6.3%. This enhanced reflective engagement highlighted participants' ability to identify shortcomings and plan actionable adjustments.

As demonstrated in Session 1, skill recorder S initially believed he was applying equal force with both hands while raising the clay. However, the stronger skin stretch feedback on his right hand and the more intense vibration feedback on his left fingertips prompted him to reassess his posture. Upon closer observation, he realized that his right fingers were overlapping his left, effectively pressing down to apply force. This insight led him to reconsider his technique, aiming for a more balanced force distribution to enhance stability. These findings highlight how combining visual and haptic feedback deepens reflective engagement, enabling participants to move beyond surface-level observations to more precise analysis and actionable self-improvement strategies, thereby supporting our hypothesis 2.

4.4.3 Verification of Hypothesis 3: Supporting Meaningful Interaction and Shared Understanding in Reflective Observation

To validate Hypothesis 3, we analyzed the frequency and percentage of themes related to reflective observation and communication across five participants under two conditions: visual-only and visual + haptic feedback. Specifically, we examined the occurrences of mutual understanding, indicating the extent to which participants comprehended skill execution; joint interpretation, reflecting how frequently participants engaged in collaborative skill analysis; and reaching consensus, representing instances where participants aligned their interpretations to establish a shared understanding. This hypothesis suggests that:

- **Hypothesis 3:** In reflective observation and communication based on others ' skill data, integrating visual and haptic feedback provides additional information (e.g., rhythm, force) that cannot be fully conveyed through visual or verbal means alone. This richer feedback modality supports more meaningful interactions, facilitates deeper skill exchanges, and helps establish a shared understanding of movement characteristics and skill logic.

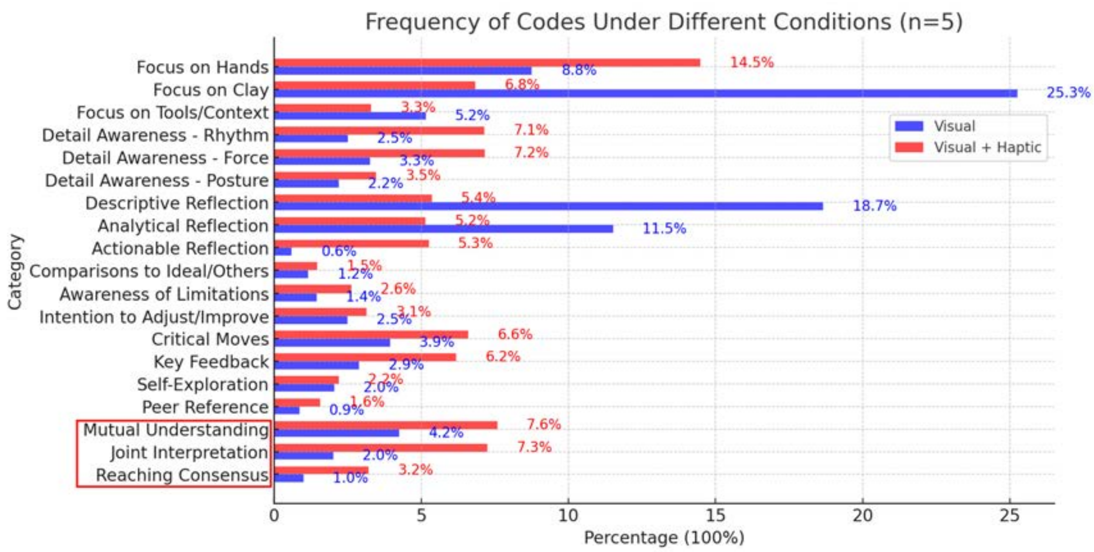


Figure 4.8 Theme percentage under two conditions(n=5)

As shown in the Figure 4.8, the result shows that haptic feedback increased mutual understanding (4.2% to 7.6%), joint interpretation (2.0% to 7.3%), and reaching consensus (1.0% to 3.2%).

Users noted that tactile cues complemented verbal communication by conveying details like force and rhythm, aiding skill interpretation.

Participants noted that tactile cues complemented verbal communication by conveying details such as force and rhythm, aiding skill interpretation. Observer O, a beginner in wheel-throwing, commented:

- **O stated:** "先輩と話すとき、自分の感覚や力加減をうまく言葉にできないことが多いです。でも、触覚の情報があると、映像では分からない力の違いが見えて理解しやすくなりました。*S*さんの説明とも合わせやすかったです。" (Translation: "When discussing with experienced practitioners, I often struggle to express my sensations and force control. With haptic feedback, I could perceive force differences not visible in the video, making it easier to understand and align with S's explanations.")

These results suggest that haptic feedback facilitates skill communication by supplementing verbal descriptions with sensory information, leading to deeper interpretation and shared understanding.

4.5. Discussions

4.5.1 Reflection on the Study Boundaries and Limitations

While this study demonstrates the potential of combining visual and haptic feedback for reflective practice in pottery skill transmission, it is essential to acknowledge its boundaries and limitations. These considerations offer valuable insights for refining the current system and expanding its applicability in future work —while initial findings support the hypotheses in a limited scope, larger-scale studies with diverse participant profiles will be necessary to validate the broader generalizability of the approach.

Challenges in Data Recording and Processing

The process of recording, synchronizing, and processing multiple streams of data —including forearm muscle activity, fingertip vibrations, and video footage— presents inherent complexities. Achieving precise alignment of these data streams requires meticulous calibration and processing, which can be time-consuming and technically demanding. This complexity may pose challenges in real-world applications, where users need intuitive and efficient systems. Simplifying the data recording and alignment process, while maintaining accuracy, remains an area for further improvement.

Beyond the Forearm: The Role of Full-Body Dynamics

While this study primarily focuses on forearm muscle activity as a key factor in pottery skill execution, it is crucial to recognize that pottery-making involves the coordinated use of multiple body parts. The entire body—particularly the torso, elbows, and even legs—plays an integral role in stabilizing movements, adjusting pressure, and maintaining balance during the wheel-throwing process. For instance:

- The torso provides a stable base, supporting smooth and controlled movements of the hands and forearms.
- The elbows may brace against the thighs to anchor positions and distribute force more effectively.

- Subtle shifts in posture and weight contribute to achieving symmetry and rhythm during shaping.

This holistic, full-body engagement underscores the importance of expanding the scope of measurement beyond forearm muscle activity. Incorporating additional sensors to capture body posture, joint movements, and weight distribution could provide a more comprehensive understanding of pottery techniques. Such an approach aligns with the embodied nature of craft practices, where skill emerges from the dynamic interplay between the body and material.

The Limits of Tactile Feedback

While haptic feedback effectively conveys subtle force dynamics and tactile sensations, it cannot fully replicate the rich and nuanced experience of direct clay manipulation. For instance:

- Clay ’ s material properties—such as moisture, elasticity, and texture—are central to the potter's sensory experience but remain difficult to simulate using current haptic devices.
- Haptic feedback is limited to discrete sensory channels (e.g., vibration or skin stretch), which may oversimplify the complexity of tactile interactions in pottery-making.

Addressing these limitations will require advancements in haptic technology to simulate a broader range of tactile sensations more realistically. Integrating richer haptic modalities, such as temperature variation or material resistance, may enhance the fidelity of the embodied experience.

Study Scale and Order Effects

Although this study provides promising insights, its generalizability is constrained by the relatively small sample size (6 participants), which may not capture the full diversity of skill levels and learning styles in pottery practice. A more extensive participant pool, including both novices and experts of varying backgrounds, would help verify whether the observed improvements and interactions hold across a broader population.

Additionally, the study design involved exposing participants first to the Visual-Only condition and then to the Visual + Haptic condition. This sequential arrangement could introduce order effects, such as a learning or novelty bias, where participants' second exposure inevitably benefits from prior familiarity with the task. Future research might address this limitation by employing a counterbalanced design (e.g., randomizing the order of conditions) or by incorporating a washout period to minimize carryover effects.

Lastly, the present study does not assess long-term skill retention or development over time, since it focuses on immediate post-action reflection and observation sessions. Conducting longitudinal or repeated-measures studies could provide deeper insights into how haptic feedback influences the consolidation of craft skills and whether these benefits persist in actual workshop practice.

4.5.2 Future Directions

Building on these reflections, future work should explore:

- **Simplified Data Integration:** Developing more streamlined and automated methods for recording and aligning multimodal data to improve system usability.
- **Full-Body Interaction:** Expanding the system to include sensors for posture, joint movements, and weight distribution to capture the holistic dynamics of pottery-making.
- **Enhanced Haptic Fidelity:** Investigating advanced haptic technologies to simulate a wider range of tactile experiences, bringing users closer to the authentic material interactions of pottery.

By addressing these boundaries, the system can evolve into a more robust and holistic tool for supporting reflective practice, deepening skill understanding, and preserving the embodied nature of traditional crafts.

4.6. Summary of the Proof of Concept Study

This Proof of Concept study explored how combining visual and haptic feedback could influence reflective practice in pottery skill transmission. Across two scenarios—post-action self-reflection (Session 1) and reflective observation based on others' experiences (Session 2)—the introduction of tactile information prompted more nuanced and detailed analyses of skill execution.

In Session 1, the skill recorder's shift from macro-level observations to micro-level exploration highlighted how tactile cues can deepen one's self-reflection, making previously unrecognized force distributions and subtle finger roles more apparent. The additional sensory input encouraged a more analytical approach, moving beyond basic experiential judgments to a careful examination of action timing, force intensity, and the interplay of different body parts. By transforming abstract notions of force into tangible bodily sensations, the skill recorder could internalize these insights, offering a stable foundation for future improvement.

In Session 2, the skill observer's experience indicated that haptic feedback likewise enhanced the comprehension of another practitioner's skill. Rather than relying solely on visual cues, the observer correlated tactile sensations with on-screen motions, uncovering hidden force rhythms and subtle adjustments in posture and force application. This more investigative mindset led to deeper inquiries and broader consideration of support strategies (e.g., using the leg rather than simply applying forearm strength). In addition, the newfound clarity facilitated the articulation of once-vague techniques into teachable concepts, potentially improving how these skills are communicated to beginners.

In essence, this proof of concept indicates that integrating haptic feedback into the reflective practice process provides a promising perspective on the complexities of craft skill. Rather than merely confirming existing assumptions, the tactile component often prompted participants to reevaluate their techniques and discuss nuances that might otherwise go unnoticed, fostering deeper inquiry and richer interactions between learners and experts.

Although the sample size and scope of this study are limited, the qualitative and quantitative findings offer preliminary support for the three hypotheses: participants reported heightened awareness of subtle movements (H1), deepened self-reflection leading to actionable improvements (H2), and increased shared understanding in group discussions (H3). Future work should expand the number and diversity of participants, refine data-capturing methods (e.g., broader body tracking), and explore more sophisticated haptic modalities to better capture the embodied nature of craft practices. By addressing these areas, the system can further evolve into a robust tool for supporting and communicating traditional skills through multimodal reflective practice.

Chapter 5
Conclusion

This study, through the introduction of the EmbodyCraft conceptual framework, integrates multimodal data streams—forearm muscle activity, fingertip vibrations, and video recordings—to explore new directions for the transmission of traditional Japanese pottery skills. In close collaboration with the Ikutouen workshop and employing a participatory design approach, this research addresses the challenges faced by the current apprenticeship-based skill transmission model. By centering on haptic feedback and drawing from Schön ' s Reflective Practice Theory, Kolb ' s Experiential Learning Theory, and Material Engagement Theory (MET), the study highlights that the transfer of tacit knowledge cannot rely solely on visual and verbal feedback but must incorporate muscle dynamics and tactile feedback to externalize tacit knowledge intuitively and deepen understanding.

Through the capture and replay of forearm muscle activity and fingertip vibrations in real-world scenarios, this study demonstrates the feasibility and practical value of technologies such as Force Myography (FMG) sensors, skin-stretch feedback devices, and vibro-tactile actuators. In the contexts of Post-Action Self-Reflection and Reflective Observation of Others' Skills, participants, when exposed to synchronized haptic cues alongside visual information, gained a clearer understanding of force distribution, timing of force application, and body posture. This multimodal reflection-on-action support mechanism not only enabled participants to examine subtle changes in their actions but also helped them reflect on the intricate physical dynamics of their craft. By providing an embodied perspective on skill reflection, the system supports the transmission of subtle yet critical tacit knowledge, allowing learners to develop a deeper, more intuitive understanding of craft techniques. This lays a foundation for future applications of digital media interventions in the preservation and teaching of traditional crafts.

However, the study also identifies areas for further improvement, such as simplifying data recording and processing, capturing full-body dynamics, and advancing the fidelity of haptic feedback. Future work could explore richer haptic modalities, aligning more closely with MET ' s emphasis on the co-creation process between maker and material. By doing so, the system could more comprehensively represent the tacit knowledge and tacit dimensions of craft skills.

In summary, this study ' s EmbodyCraft system and related experiments offer innovative approaches for supporting the digital transmission of traditional craft skills. By combining visual feedback, tactile feedback, muscle activity signals, and video recordings, this multimodal framework demonstrates its potential to enhance understanding, facilitate reflection, and provide a robust foundation for supporting the embodied transmission of craft knowledge. By integrating haptic feedback into skill reflection, the system enables learners to not only observe but also physically experience the nuances of craft techniques, fostering a more immersive and intuitive approach to skill acquisition.

References

[1] Noriji Sato. Current challenges facing the traditional craft industry, and the possibility of future business development. *Ritsumeikan Business Review*, 57(4):59–74, 11 2018. doi:10.34382/00001334.

[2] Chieko Narita, Yutaro Shimode, and Nobuyuki Kida. Problem identification of skill succession in traditional crafts industries. *Bulletin of Kyoto Institute of Technology*, 9:13–30, 01 2017. URL: https://cir.nii.ac.jp/crid/1050282812559273728.

[3] Jeanne Gamble. Modelling the invisible: The pedagogy of craft apprenticeship. *Studies in Continuing Education*, 23:185 – 200, 2001. URL: https://api.semanticscholar.org/CorpusID:145689730.

[4] Trevor H. J. Marchand. Muscles, morals and mind: Craft apprenticeship and the formation of person. *British Journal of Educational Studies*, 56:245 – 271, 2008. URL: https://api.semanticscholar.org/CorpusID:144305506.

[5] Michael Polanyi. *Personal Knowledge: Towards a Post-Critical Philosophy.* University of Chicago Press, Chicago, 1958.

[6] Ingar Brinck and Vasudevi Reddy. Dialogue in the making: emotional engagement with materials. *Phenomenology and the cognitive sciences*, 19(1):23–45, 2020.

[7] Donald A Schön. The reflective practitioner. *New York*, 1979.

[8] Tim Ingold. Making: Anthropology, archaeology, art and architecture, 2013.

[9] Richard Sennett. *The craftsman.* Yale University Press, 2008.

[10] Charlene Tan. Revisiting donald schön ’ s notion of reflective practice: A daoist interpretation. *Reflective Practice*, 21(5):686–698, 2020.

[11] David Allen Kolb and Ronald Eugene Fry. *Toward an applied theory of experiential learning*. MIT Alfred P. Sloan School of Management, 1974.

[12] J. Q. Cosh. Peer observation: A reflective model. *Elt Journal*, 53:22–27, 1999. URL: `https://api.semanticscholar.org/CorpusID:54974142`.

[13] Mark Hughes and Karen Heycox. Using observation for reflective practice with older people. *Educational Gerontology*, 34:185 – 205, 2008. URL: `https://api.semanticscholar.org/CorpusID:143721167`.

[14] Ingar Brinck. Craft thinking: A relational approach to making and design. In *Craft and Design Practice from an Embodied Perspective*, pages 30–39. Routledge, 2024.

[15] Lambros Malafouris and Maria-Danae Koukouti. Where the touching is touched: The role of haptic attentive unity in the dialogue between maker and material. *Multimodality & Society*, 2(3):265–287, 2022.

[16] Mamiko Abe, Tomoyuki Yamamoto, and Tsutomu Fujinami. A dynamical analysis of kneading using a motion capture device. 2003. URL: `https://api.semanticscholar.org/CorpusID:8379633`.

[17] Avshalom Karasik, Liora Bitton, Ayelet Gilboa, Ilan Sharon, and Uzy Smilansky. Quantitative measures of the uniformity of ceramics. 2004. URL: `https://api.semanticscholar.org/CorpusID:15311636`.

[18] Dimitrios Ververidis, Sotirios Karavarsamis, Spiros Nikolopoulos, and Ioannis Kompatsiaris. Pottery gestures style comparison by exploiting myo sensor and forearm anatomy. In *Proceedings of the 3rd International Symposium on Movement and Computing*, MOCO '16, New York, NY, USA, 2016. Association for Computing Machinery. `doi:10.1145/2948910.2948924`.

[19] Yilin Elaine Liu, Michael Nitsche, and Benjamin N Sugar. Reflection on tacit knowledge-effect of providing emg visualization on reflections on throwing clay. In *Proceedings of the 2019 Conference on Creativity and Cognition*, pages 619–625, 2019.

[20] Thomas Smith, Simon J Bowen, Bettina Nissen, Jonathan Hook, Arno Verhoeven, John Bowers, Peter Wright, and Patrick Olivier. Exploring gesture sonification to support reflective craft practice. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*, pages 67–76, 2015.

[21] Pei-Ying Chiang, Han-Yu Chang, and Yung-Ju Chang. Potterygo: A virtual pottery making training system. *IEEE Computer Graphics and Applications*, 38:74–88, 2018. URL: `https://api.semanticscholar.org/CorpusID:4858803`.

[22] Jun Nakamura, Sanetake Nagayoshi, and Nozomi Komiya. Skill transfer of traditional pottery techniques: Exploring the effects of metacognition through gaze movement. *Procedia Computer Science*, 192:1705–1712, 2021.

[23] Alina Glushkova and Sotiris Manitsaris. Gesture recognition and sensorimotor learning-by-doing of motor skills in manual professions: A case study in the wheel-throwing art of pottery. *Journal of Computer Assisted Learning*, 34(1):20–31, 2018.

[24] Francisco J Varela, Evan Thompson, and Eleanor Rosch. The embodied mind. *(No Title)*, 2017.

[25] AR Damasio. Descartes ’ error: Emotion, rationality and the human brain. *Grosset/Putnam*, 1994.

[26] Shogo Tanaka. Intercorporeality as a theory of social cognition. *Theory & psychology*, 25(4):455–472, 2015.

[27] Jacques Launay, Bronwyn Tarr, and Robin IM Dunbar. Synchrony as an adaptive mechanism for large-scale human social bonding. *Ethology*, 122(10):779–789, 2016.

[28] Claire Petitmengin. Describing one’s subjective experience in the second person: An interview method for the science of consciousness. *Phenomenology and the Cognitive sciences*, 5(3):229–269, 2006.

[29] Jules Françoise, Yves Candau, Sarah Fdili Alaoui, and Thecla Schiphorst. Designing for kinesthetic awareness: Revealing user experiences through second-person inquiry. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems*, pages 5171–5183, 2017.

[30] Jun Nishida and Kenji Suzuki. Biosync: A paired wearable device for blending kinesthetic experience. In *Proceedings of the 2017 CHI conference on human factors in computing systems*, pages 3316–3327, 2017.

[31] Raquel Breejon Robinson, Elizabeth Reid, James Collin Fey, Ansgar E Depping, Katherine Isbister, and Regan L Mandryk. Designing and evaluating'in the same boat', a game of embodied synchronization for enhancing social play. In *Proceedings of the 2020 CHI conference on human factors in computing systems*, pages 1–14, 2020.

[32] Ekaterina R. Stepanova, John Desnoyers-Stewart, Philippe Pasquier, and Bernhard E. Riecke. Jel: Breathing together to connect with others and nature. In *Proceedings of the 2020 ACM Designing Interactive Systems Conference*, DIS '20, page 641–654, New York, NY, USA, 2020. Association for Computing Machinery. doi:10.1145/3357236.3395532.

[33] Barbara Montero. Proprioceiving someone else's movement. *Philosophical Explorations*, 9(2):149–161, 2006.

[34] Xiao Xiao and Hiroshi Ishii. Mirrorfugue: communicating hand gesture in remote piano collaboration. In *Proceedings of the Fifth International Conference on Tangible, Embedded, and Embodied Interaction*, TEI '11, page 13–20, New York, NY, USA, 2010. Association for Computing Machinery. doi:10.1145/1935701.1935705.

[35] Rébecca Kleinberger, Stefanakis George, and Sebastian Franjou. Speech companions: Evaluating the effects of musically modulated auditory feedback on the voice. In *The 25th International Conference on Auditory Display, ICAD 2019*, 2019.

[36] Marco Iacoboni. *Within Each Other:Neural Mechanisms for Empathy in the Primate Brain*, pages 45–57. 10 2011. doi:10.1093/acprof:oso/

9780199539956.003.0005.

[37] Martijn J.L. Kors, Gabriele Ferri, Erik D. van der Spek, Cas Ketel, and Ben A.M. Schouten. A breathtaking journey. on the design of an empathy-arousing mixed-reality game. In *Proceedings of the 2016 Annual Symposium on Computer-Human Interaction in Play*, CHI PLAY '16, page 91–104, New York, NY, USA, 2016. Association for Computing Machinery. doi:10.1145/2967934.2968110.

[38] Claudia Núñez-Pacheco and Lian Loke. Getting into someone else's soul: Communicating embodied experience. *Digital Creativity*, 10 2020. doi:10.1080/14626268.2020.1835987.

[39] Dan Morris, Hong Tan, Federico Barbagli, Timothy Chang, and Kenneth Salisbury. Haptic feedback enhances force skill learning. In *Second Joint EuroHaptics Conference and Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems (WHC'07)*, pages 21–26. IEEE, 2007.

[40] Arata Horie, Yunao Zheng, and Masahiko Inami. A wearable system integrating force myography and skin stretch feedback toward force skill learning. In *2023 IEEE World Haptics Conference (WHC)*, pages 190–196. IEEE, 2023.

[41] Hidetoshi Miyaji. Tsuboya-yaki ni okeru kama o meguru mondai ni tsuite: Amerika senryō-ki o chūshin ni shite. 2024.

[42] Harunobu Taguchi, Yulan Ju, Youichi Kamiyama, Kota Kitamichi, Kenta Kan, Kenta Watashima, Hironori Ishikawa, Yoshihiro Tanaka, and Kouta Minamizawa. A personalized haptic sharing platform over the internet.

[43] Rodan Umehara, Harunobu Taguchi, Arata Horie, Yusuke Kamiyama, Shin Sakamoto, Hironori Ishikawa, and Kouta Minamizawa. Feeltech wear: Enhancing mixed reality experience with wrist to finger haptic attribution. In *ACM SIGGRAPH 2024 Emerging Technologies*, SIGGRAPH '24, New York, NY, USA, 2024. Association for Computing Machinery. doi:10.1145/3641517.3664395.

Appendices

A. Semi-Structured Interview Questions for User Test

A.1 Session 1: Post-Action Self-Reflection of Skills

1. Understanding of Skill Characteristics

- What aspects of your recorded actions stood out to you the most? Why?
- Did you notice anything about the rhythm or intensity of your actions? If so, can you describe it?
- What do you think was the purpose or intent behind the actions you observed?

2. Awareness of Subtle Details

- Did you notice any moments where adjustments in your actions, such as force application or movement smoothness, might have been helpful?
- Was there anything unexpected or surprising about your movements or force application?
- If you were to replicate these movements, what parts would you find most challenging? Why?

3. Reflection on Your Own Skills

- Did watching the video change your understanding of your own skills? How so?

- Did you gain any new insights or perspectives about your actions, such as how you distribute force or adjust movements?
- Were there moments where you felt confident or saw areas for improvement? What stood out to you?

A.2 Session 2: Reflective Observation of Others' Skills

1. Understanding Skill Characteristics

- What aspects of the observed skill movements stood out to you the most? Why?
- What did you notice about the rhythm, force application, or other characteristics of the movements?
- What do you think was the intent or purpose behind the observed actions?

2. Effectiveness of Haptic Feedback

- What was your experience with the haptic feedback?
- Were there any details you noticed through the haptic feedback that were less clear in the video?
- Did the haptic feedback clarify any parts of the movements that initially seemed unclear?

3. Comparison Between Visual and Haptic Feedback

- How did the haptic feedback change or complement the visual information you received from the video?
- Were there any aspects of the haptic feedback that felt particularly informative or unique? Why?
- Did the haptic feedback affect how you perceived the flow and logic of the movements?

4. Open Reflection and Comparison

- How did your interpretations align or differ from the explanations provided by the skill recorder?
- How would you describe the differences between using only visual feedback and the combination of visual and haptic feedback?
- If you were to explain this skill to a beginner, what kind of feedback would you use to clarify the movements?