GLAZE EPOCHS: EXTERNALIZING MATERIAL KNOWLEDGE THROUGH TANGIBLE DATA RECORDS IN A CERAMICS STUDIO

by

HEDIEH MORADI

THESIS

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Supervising Committee:

Dr. Cesar A. Torres, Supervising Professor
Dr. Ming Li
Prof. Nicholas Wood

I dedicate this thesis to my family, who are the most loving and supporting family. First, to my parents, Shahla Doostani and Peyman Moradi, who kept me going with their love and wisdom; my siblings Mahda, Maryam, Mohammad, and Hoda Moradi (UTA M.S.'18) and supported me in every way possible. And lastly, to my loving husband Joshua Roper (UTA B.S.'18) who has supported me unconditionally through every step.

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ABSTRACT

Glaze Epochs: Externalizing Material Knowledge through Tangible Data Records in a Ceramics Studio

Hedieh Moradi, M.S.

The University of Texas at Arlington, 2021

Supervising Professor: Dr. Cesar A. Torres

The "material turn" in HCI has placed a renewed focus on informing design from the relationships found in material-based interactions. While several ethnographic works provide insight into how practitioners converse with materials, it is less understood how these conversations transform into a skilled practitioner's mental model. I examine the material practice of glazing that gives ceramics its decorative and functional characteristics and involves fusing mixtures of silica, alumina, and flux onto a clay body through kiln firing. This practice evolves over decades, developing from multiple trajectories, including theoretical foundations, systematic experimentation, and happy accidents. This work describes virtual site visits with six expert ceramicists and documents how a glaze mental model is externalized in practice, teaching, and the studio environment. I synthesize these findings into a set of design principles that inform how material interactions can move beyond momentary material encounters towards lifelong material epochs. I instantiate these principles in Glaze Epoch, a tangible database system embedded within a ceramics studio, and motivate their value in documenting and tracking tacit knowledge.

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[1] Commercial glazes have proprietary licenses which will prevent access to their glaze recipes or glaze raw material formulas

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CHAPTER 1

INTRODUCTION

The “material turn” describes a transformation in how interaction designers think about relations between physical and digital materials [1]. This turn has placed a renewed focus on developing a vocabulary around how physical and computational materials are used in interaction design. Many of these approaches focus on making salient the rich interactions of materials with each other (e.g., *computational composites* [2], *making as correspondence* [3], *crafting proxies* [4]), the responsiveness of materials under investigation (e.g., *performativity* [5], or *material conversations* [6]), or as part of the larger experience of engaging in a craft practice (e.g., *making preciousness* [7], *wayfaring* [3]). As a relatively recent shift, there is less dialogue in material relationships that develop over time, especially given the centuries that many physical material practices span which I term *material epochs.* Within communities of practice, knowledge of these relationships rest with practitioners that have a lifetime of experience. It is crucial to understand how these relationships can be developed or transferred within creative technologies.

1.1 Problem Definition

I borrow from early HCI and cognitive science research [8, 9] to frame this problem as understanding a *material mental model*, specifically the knowledge that a practitioner has about how a material works, its component parts, their interrelations, and how one material influences another. Mental models have been used in HCI to help with skill acquisition or operation of a complex device [9], however their usefulness is predicated on being able to redesign a system to match a user's mental model, being able to update or refine a user's model through training [8], or transferring a mental model through metaphor [10]. Material mental models (MMM) by comparison are significantly more complex operating in a larger interaction space that takes years of training and redesign to develop. While parts of an MMM can be developed through textbook study (e.g., physics, material science), an MMM is further complicated by the large focus on tacit knowledge, or a type of knowledge often existing in one's subconscious or embodied in muscle memory that resists traditional forms of documentation.

In this work, I investigate how computational systems can support the storage and maintenance of tacit knowledge, especially in situations where tacit knowledge is accumulated over time. This core research question is divided into three components:

- **R1.** How can we **extract and identify** tacit knowledge?
- **R2.** How can we **store and encode** tacit knowledge into a digital archive?
- **R3.** How can we **maintain and update** tacit knowledge in such a digital archive?

1.2 Contributions

This work contributes the material mental model of six expert ceramicists with 163 years of combined experience in ceramic practice. Through a virtual contextual inquiry [11], I observed and probed how an expert's model has been developed and refined through the ways they work, setup their environment, capture, document, and store their findings, and transfer their material mental model to others. I place the focus of this work on the practice of glazing that gives ceramics its decorative and functional characteristics and involves fusing mixtures of silica, alumina, and flux onto a clay body through kiln firing. Glazing is rarely a deterministic activity;

a glaze can change dramatically from environmental phenomena (e.g., oxygen level inside a kiln), its application technique (e.g., dipped), its compositions (e.g., oxide balance), or its placement on clay body geometries (e.g., textures). The diversity and complexity of material interactions requires the development of a material mental model that is developed over years of practice to achieve an "ordered chaos" and exemplifies a deep material relationship that I aim to better understand. I synthesize the findings into a framework that describes how glaze is elected, the formal properties that are assessed, and the way that created glaze artifacts are resolved or update the practitioner's mental model.

To operationalize how the material mental model can be used to design systems that support material practices, I present a set of design principles to motivate the design of computational systems within material practices. To operationalize these principles, I describe the design and implementation of Glaze Epoch, a digital archive system that uses common radio-frequency identifiers (RFID) to reference physical glazing artifacts to digital records. These RFID tags are attached to different objects within the ceramics studio and used to track and encode material knowledge that was used to create them. The system is evaluated using demonstration and Olsen's heuristics constructed on real-world scenarios encountered during the contextual inquiry with master ceramicists.

1.3 Outline

This thesis first describes related work in the field of human-computer interaction and ubiquitous computing (Chapter 2). I then describe the approach for extracting and identifying tacit knowledge within glazing practices (Chapter 3) and present the findings in the form of a material mental model (Chapter 4). From this material model, I present the system design and implementation of the Glaze Epoch and describe some grounding walkthrough interactions (Chapter 5). Lastly, I present the evaluation of the system using two standard methods of assessment in the HCI community for user interface systems – demonstration [12] and heuristics [13] (Chapter 6). I then reflect on opportunities and challenges in integrating computational systems within the ceramics studio (Chapter 7). I discuss opportunities for creativity support tools to leverage these kinds of material mental model and pose opportunities to externalize such models to support knowledge transfer and skill acquisition in novices and move interactions beyond short material encounters and towards lifelong material epochs.

CHAPTER 2

Related Work

Material-based inquiry is an active research area explored by makers and designers with a special interest in the digital fabrication community. I review works in these areas focused on cognitive science, ethnography, and design research communities.

2.1 Investigating Interactions within Material Practices

Within HCI, studies of making and craft have been used to motivate the design of domain-specific tools, creativity support tools, and smart environments. Maudet et al. [14] conducted a study investigating how professional graphic designers create and structure layouts for digital and print media; their observations revealed that the "grid" only represented a small subset of the strategies used by designers, and presented a framework capturing these strategies to motivate the design of layout tools. The Glaze Epoch leverages a similar methodology to construct a framework for supporting ceramic design tools. Others ethnographic works have focused on understanding technological frictions with materials. Rosner et al. [15] presented findings from ethnographic interviews with six ceramicists to understand their material relationships with clay and obstacles in integrating clay with technology; this work further explores these relationships in artist-researcher collaborations by embedding electronics and audio signatures into clay forms. I build on this endeavor by narrowing the scope of the contextual inquiries to specifically glazes, and present the findings through a framework that can be used generalized to support material practices.

2.1.1 Inside the Ceramics Studio

Within ceramics, research has focused on connecting emerging technology to more traditional craft practices. Several studies have examined collaboration with artisans to understand how a computer numerical controlled (CNC) tools would be appropriated by craft practices in art furniture production [16] and ceramic [17] practices.

Other work has explored digital fabrication processes to enhance or extend ceramic practices. Zoran et al. reconstructed a broken ceramics object with 3D-printed elements exploring how uniqueness could be reimbued to an artifact through destruction and restoration [18]. Conductive materials and sound textures were used to identify tensions and opportunities in the combination of clay and computation [15]. Dick et al. [19] described a technique for controlling the cracking of glaze, or crazing, by identifying the relationship between surface treatment and glaze thickness; I include similar ceramic research strategies when interviewing ceramic engineers in the contextual inquiry.

Ceramics practices often keep track of glazing recipes through physical test tiles. Within ceramics research, the Ceramics Color Database aims to make available the 300,000 test pieces of AIST Japan, but the curation and entry of these tiles into a virtual database has stifled efforts, with only 4K openly available [20]. In 2020, community-driven efforts have led to the recent creation and adoption of Glazy.org [21], an open platform for sharing and analyzing over 6.8K ceramics recipes (at the time of writing).

2.2 Extracting Tacit Knowledge

It is hard to extract tacit knowledge due to the phenomenon that I refer to as cultural memory. Cultural memory defines as the need for the master-apprentice model. Master is an expert who can guide the student through all the task steps, and these types of knowledge (tacit knowledge) are resistant by nature to be added to the database. However, other researchers have done work in the past who are also interested in extracting tacit knowledge.Several methods have been proposed for identifying and capturing tacit knowledge in complex craft domains. Wood et al. [22] introduced an expert learner method for identifying tacit knowledge. In this method, a person with knowledge of a domain (expert learner) acts as an intermediary between a skilled or master craftsperson creating instructional material. This provides the benefits of transferring the skill quickly to the expert learner but allowing the expert learner to externalize the skill before it is internalized. Gowlland [23] described a video analysis of master ceramicists in China and Taiwan and the role image and video have in communicating the embodied experience of a skilled practice. Groth et al. [24] explored ways of making experiential knowledge more articulable by blindfolding an artist-researcher and augmenting their tactile sensitivity and awareness as they engaged in clay throwing tasks. Rosner [25] leveraged participant observation to document a three-month bookbinding apprenticeship focusing on the temporality of material practice. Dew et al. [26] described the temporality of living material in a timber-based house construction program. I draw a similar emphasis on making salient temporal relationships and distinguishing the many trajectories master ceramicists have to develop these lifelong relationships with materials. Maudet et al. [14] conducted a study investigating how professional graphic designers create and structure layouts for digital and print media; their observations revealed that the "grid" only represented a small subset of the strategies used by designers, and presented a framework capturing these strategies to motivate the design of layout tools. The Glaze Epoch leverages a similar methodology to construct a framework for supporting ceramic design tools.

2.3 Representing and Externalizing Material Knowledge

Cognitive science communities have explored the value and efficacy of externalizing mental models, or creating an external representation, for supporting cognitive tasks (e.g., reducing the cognitive load from spatial localization by using a physical model of a chemical molecule) and learning tasks [27]. However, these external representations are limited in their ability only to communicate *functional* mental models that describe how to use an artifact, but not how it works [28]. To achieve transfer of a *deep* mental model that communicates how something works, education researchers have proposed leveraging multiple external representations (MERs) in areas like math and chemistry [29], which offered larger learning effects if the learner creates their external representation from their internal representation [30]. The work identifies external representation within ceramics studios associated with glazing and builds a framework for understanding how internal representations (a material model) were developed and refined. As I will encounter in the contextual inquiry, glaze chemistry requires many concepts from formal chemistry, but the ceramics community has developed alternative methods for communicating these concepts.

Externalizing mental models has had traction within the tangible computing community. Khairuddin et al. [31] developed a tangible kit for communicating the intricacies and infrastructures of blockchain technologies, leveraging physical materials to communicate the affordances of different blockchain objects. Others within the design community have begun developing toolkits that aim to improve or transfer mental models. Murer [32] proposed a framework for designing un-crafting activities that place material under inspection (inquiry), explore variations of those materials (exploration), show the material in context (exposition), and attempting new material compositions from previous activities (inspiration). Wood et al. also propose bridging the expert-novice gap through a destructive analysis of practice to extract principles and capturing principles before they are internalized through practice [33]. Hummels et al. [34] introduced a moving studio based on participatory sensemaking that invites practitioners to share embodied interactions within a shared space, often with an object that had rich material affordances. The Glaze Epoch builds on further identifying these material activities, specifically for material models that are developed over time that experts use to refine and expand their personal practice.

2.4 Storage and maintenance of tacit knowledge

The main reason which makes storing this information hard is the messiness characteristic of this type of information. Also, these practices are held in shared studio spaces and workshops. Since these practices use physical materials in a limited physical space, such as studio tables, it can create a busy work environment. Knibbe et al. [35] approached this problem by introducing a smart maker space. Even though his approach to store and organize tools within maker space is novel and innovative, it does not pass the "messiness." Bell et al. [36] explained how messiness is in the infrastructure and not an added property to it. These infrastructures are inherently messy, and researchers need to design according to them. For example, in the maker space model presented by Knibbe, it only takes one student not to place the tool in the correct bin to make this environment less intelligent.

2.4.1 Tangible Databases using Ubiquitous Sensing (RFID)

Seamless connection of objects in the space is one of the usages of the RFIDs presented in multiple literature. Gummeson et al. [37] presented a system that connects user's bodily movement and location to the lightening system in the environment by using RFIDs. For example, when the user opens the cabinet door, the light bulb above that cabinet will light up and provides more light. RFIDs are also used in fields of transportation and tracking. Kubicki et al. [38] presented a tangible interactive table to simulate traffic scenario with the help of tangible and virtual objects. The table is network-connected, and the RFIDs are used to position the location of users. RFIDs nowadays exist in many things with which we interact daily, such as cards and keys. Martinussen et al. [39] used the unique properties offered by RFIDs such as inexpensiveness and flexibility to explore combining RFIDs with ordinary objects and studied various design possibilities with RFIDs when they were combine with everyday objects. More similar usage of RFID to the research can be found in Stark et al. [40]. Stark created a smart environment by using RFID and connecting different stations together. Stark's system is mainly designed to support users in using the stations to complete their tasks versus the Glaze Epochs system which is more focused on storing and maintaining them. There are many other works done using RFIDs to create tangible music blocks [41] and similar interactions. However, Marquardt et al. [42] presented a framework to enable users to create more advance and customized RFIDs for their interactions. Even though the Glaze Epoch system is leveraging the use of already economic and existing RFIDs in the market, being able to make customized RFIDs can assist users to advance their interaction and usage of the system, tailored for their need.

CHAPTER 3

Mapping A Ceramicist's Material Mental Model

In order to understand how a ceramicist builds, shares, and updates their knowledge of their practice, I leveraged a virtual contextual inquiry with 6 master ceramicists. I leveraged qualitative methods to iteratively code the data using common database operations; I then clustered and synthesized resulting themes into a model that describes the different kinds of decision-making and sense-making activities within glazing practices. The resulting model is presenting in Chapter 4.

3.1 Method

The specific goal of understanding and documenting glazing is an example of a "complex task" characterized by broad, unstructured goals and nonlinear workflows [43]. These complex tasks are common in specialized domains where a community of practice developed strategies for dealing with various unknown variables that over time result in diverse tools and platforms. This is especially salient for ceramics when factoring the high-loss value an artifact takes days or weeks of effort. With glazing in particular, there are limited opportunities to recover from errors once a glaze has been fired. This is further complicated by the large focus on experiential knowledge shaped by experiencing how different materials react with each other that is difficult to express in words and is developed over years of probing and predicting material behavior. As one informant describes,

> **Paul** Clay is such a tactile, basic elemental property and you really need to be in the experience. It involves everything. It is your sense of touch, obviously sight, the feeling of the moisture in the clay and all of that stuff.

One primary challenge of communicating tacit knowledge arises from the limited visibility of material mental models, especially within master-apprentice relationships best captured by the college instructor informant:

> **Edison** I have to find out how [my students] visualized the piece they made and get into [their] head, but [they] have to become vocal, but they do not know how to be vocal. It is a struggle with students, but it helps me because I can see how they see a pot and it may change the way how I see it.

In order to understand a complex task like glazing, I looked to leverage the expertise of ceramicists that had decades of experience dealing with glaze-based interactions. Because material mental models rely heavily on tacit knowledge, I elected to conduct a rapid design ethnography using contextual inquiry [44, 11]. Using contextual inquiry enabled us to achieve an interactive [44] and in-depth observation [45] from users in their own natural studio–workshop setup. While survey methods can provide summaries of user experience, it excludes the reasoning and motivation of actions since users are distant from that moment and experience relying on their ability to recall that process [45]. For the purpose of this study, it is crucial to study users' interactions with the material in the moment or space that they were used in. Contextual inquiry provides methods and process to achieve this level of observation while being mindful of users' rights and privacy at the same time.

3.2 Study

Participant Recruitment and Selection I conducted site visits with 6 ceramic artists (3 male, 3 female), age 34-72, with an average of 27 $\pm$ 1 years of experience. Informants were recruited initially through local ceramic listservs followed by snowball recruiting. Participants were pre-screened using a questionnaire to assess for expertise and to confirm that participants had access to a studio. This allowed us to gather informants from diverse fields of ceramics (Table 3.1), including expert

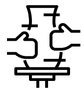
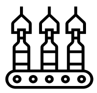
<table>
<tr><th>Ceramic Practice</th><th colspan="4">Informants (Gender | Age | Experience)</th><th>Background</th><th>Site</th></tr>
<tr><td>
Hobbyist Ceramicist</td><td>Seneca</td><td>F</td><td>34</td><td>12</td><td>Art Therapist - Expert Amateur Uses commercial glazes; formal training in ceramics.</td><td>Personal at-home studio. Occasional sales through Facebook Marketplace.</td></tr>
<tr><td rowspan="3">
Production/ Studio Potter</td><td>Ruth</td><td>F</td><td>70</td><td>30</td><td>Production potter; teaches studio classes.</td><td>Ceramics storefront and personal studio in backroom.</td></tr>
<tr><td>Edison</td><td>M</td><td>72</td><td>51</td><td>Studio potter. Teaches studio classes only to advance students. Donates his work to galleries to support the community and increase engagement.</td><td>Personal studio; uses sensor-retrofitted kiln.</td></tr>
<tr><td>Leila</td><td>F</td><td>49</td><td>30</td><td>Functional production potter.</td><td>Studio within a ceramics collective with 20 other ceramic artists.</td></tr>
<tr><td rowspan="2">
Ceramic Engineer</td><td>Paul</td><td>M</td><td>36</td><td>20</td><td>Instructor of college-level ceramics course.</td><td>College instruction ceramics classroom.</td></tr>
<tr><td>Jackson</td><td>M</td><td>43</td><td>20</td><td>Systematic documentation with professional photo rig. Runs online glaze workshop.</td><td>Glazing lab with chemical benches.</td></tr>
</table>

Table 3.1: Informant Backgrounds, Sites, and Practices. All names are pseudonyms to protect informant confidentiality.

amateurs, functional studio and production ceramicists, studio and college instructors, storefront owners and communal potters, and ceramic engineers. I were unable to recruit an informant from a purely artistic practice, although all informants had experience producing artistic work at some point in their careers. Because of the virtual nature of the contextual inquiry, the final informant pool were all US-based and covered a large part of the US cultural geography (e.g. East, West, South, Midwest). Some informants had experience with artist-in-residence programs abroad in Asia and Europe.

Procedure Five informants were interviewed virtually via Zoom (during the COVID-19 pandemic) and one informant was interviewed at their collective-based studio (before the pandemic). Informants were compensated at a rate of $25/hr. To maintain the benefits of a site visit, participants were asked to use their phones and their rear-facing camera during the virtual visit. Although the research team was familiar with many glaze practices, I was careful to frame myself as ceramics beginner to maintain a master-apprentice relationship with informants.

All interviews occurred in the informant's work–studio space for an hour. Notes were collected for each visit and screen recordings were audio transcribed; screenshots were extracted from video to form photo logs. Informants were then asked to give us a tour of their studio workspace and to show (when possible) the artifacts or processes that referenced when answering the interview questions. I probed specifically on their glazing process, documentation, use of technology, storage system, and sharing culture within their community of practice. To ensure observations were useful as a design framework specifically for information repositories, I structured the questions based on the four primary operations of persistent storage, or CRUD [46], and how mental models are transferred:

- **Create** How do informants create or expand their material mental model?
- **Read** How do they read or access this information?
- **Update** How do outcomes alter, update, or refine their material mental model?
- **Destroy** How is information that is not longer needed discarded or removed?
- **Transfer** How is information shared and communicated to others?

3.2.1 Dataset

The final dataset included 5.5 hours of video/audio data from 6 informants, 165 extracted and annotated screenshots, and 37 pages of audio transcripts and notes. A summary of each informant's background and experience is depicted in Table 3.1. I followed up with informants in situations where I needed a clearer image, needed to disambiguate one of the transcript items, or to ask for clarification on a concept or process discussed.

3.2.2 Coding

Two researchers with background ceramics knowledge independently applied the structured code set (CRUD+Transfer) to the dataset and generated memos. These memos were discussed and refined until a Cohen's kappa ¿ 0.9 was achieved. I then iteratively clustered memos until salient themes were identified. The resulting themes were organized based on whether the occurred primarily in a decision-making or sense-making process or whether they constituted the internal representation of the master ceramicist. I present these results in Chapter 4.

CHAPTER 4

THE GLAZE MATERIAL MENTAL MODEL (GMM)

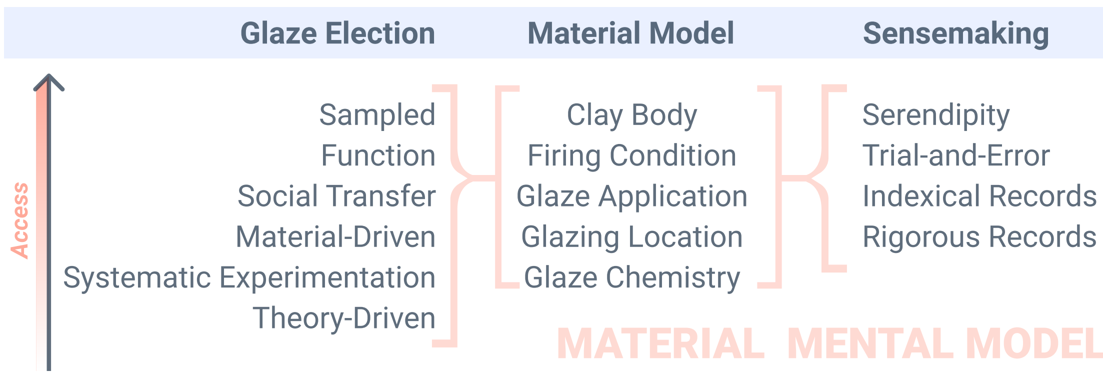


Figure 4.1: Glaze Mental Model (MMM) describes a practitioner's internal representation of glazes used in ceramics work. Interactions with this mental model are categorized into factors that are used to expand the material model (Glaze Election), the formal properties of the material (Material Model), and ways the material model is updated or refined (Sensemaking). I organized these factors based on a practitioner's access to tools, materials, or knowledge needed to engage with that factor.

To structure the discussion of the results and provide a design framework, I grouped themes identified through the contextual inquiry into one of three categories: (1) factors that use the mental model to drive creative choices (Glaze Election), (2) factors that constitute the mental model (in my case, the Glaze Material Model), and (3) factors which update the mental model through sensemaking strategies (Sensemaking). I have organized these factors based on a practitioner's access to tools, materials, or knowledge needed to engage with that factor.

I specifically draw attention to the depth of complexity, time, and uniqueness to each informant's practice. To protect confidentiality of the informants, I present my observations using pseudonyms.

4.0.1 Ceramics Terminology

In the descriptions, I elected to retain technical ceramic terminology to maintain the focus on the observations versus ceramics theory. I defined only the necessary terminologies needed to understand the context behind the informant's quotes. Foremost, when a practitioner creates a ceramic artifact, they first form the artifact from unfired clay. Clay in particular has a variety of compositions known as **clay bodies**. Once a clay body has been shaped into a form, it is shelf dried in a controlled environment before it goes through an initial **bisque** firing. Every clay and every glaze behaves differently based on its **firing schedule**, or the changes in temperature from heating to cooling that occur over several hours. Ceramicist use a temperature scale with a unit **cone**, sometimes abbreviated Δ, ranging from Δ 08 (955C or 1751F) used for bisque firing to Δ 10 (1305 or 2381) for porcelain clay bodies. After a clay body is bisque-fired, it becomes a ceramic (no longer able to return back to clay). In this state, the ceramic is highly absorbent (since all water in the clay was removed during the firing) and has a material structure similar to a sponge. Ceramicists then apply paint-like glaze mixtures, which are either hand mixed from chemicals or bought from commercial manufacturers. Many glazes contain large amounts of silica, which during the final firing **vitrifies** and gives ceramics their glossy glass-like appearance and their functional impermeability to liquids.

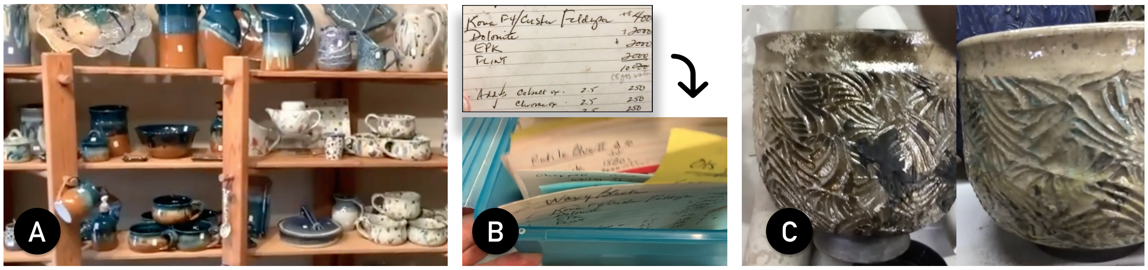


Figure 4.2: Glaze Election: A) Ruth's storefront, which she inventories for her students to pick a glaze, B) A glaze recipe box which contains cards up to a few decades - these cards are hand written and might get additional notations and updates over time, C) Edison's Raku fired mugs - an unclean Raku glaze (left) made through Raku firing technique and a cleaned version of this mug. Raku is a firing technique where rather than waiting for a kiln to cool, the pieces are removed while still hot and put in a bucket of combustible materials (e.g., banana peels).

4.1 Glaze Election

I use the term *glaze election* to refer to the stage before the artist physically applies a glaze to a clay body and needs to make a decision inside his/ her mind. Even though this process can be very fast for a master, a new students can be overwhelmed with number of possibilities, and struggle to come to a decision. Throughout the interviews I learned that there are different approaches taken by masters in the glaze election stage. Within these approaches, I identified similar techniques and processes shared among the community, and how each person adopts a common process that fits in their personal practice.

4.1.1 Sampling

Sampling refers to selecting a glaze based on outside factors such as nature, previous work, or the people in the space. Edison approaches this task with a palette in mind, looking for inspiration from the outside. Those with a readily accessible body of work, like production potters, leverage their inventory as their samples (Figure 4.2 A).

Ruth Every time I have a glaze class I go [to my studio's store] and I find a sample. I grab a finished sample of every glaze and as many combination as I have and I put it [in front of my class] and label them. [My students] can come over and look and see what a finished piece will look like.

Ruth produces in large batches, requiring her to make and keep large buckets of glazes, ready to be used (Figure 4.5 A). Using large container storage system is common across production potters and school studios. For Paul, he actively changes his environment, participating in artist-in-residence programs around the world.

Paul For me, [my process] changes so much with time like an ongoing revolution. I was in Japan last year doing artist residency and the the chemicals and recipes were so different.

Since sampling draws from the immediate environment, this method benefits practitioners that have a more active practice or shared space with other ceramicist. Their environments have a greater propensity to shift; for a newcomer, the shared studio is central to this mode of glaze selection; however this is predicated on access to the original maker of the artifact or a structured labeling system. Thus, the master potter serve as gatekeepers to this mode of selection. I found that most environments are collaborative, however it remains limited by the activation energy of keeping items documented or makers present.

4.1.2 Function

Function is a common way to distinguish between ceramics that serve an artistic or decorative role (e.g., a sculpture), a functional use (e.g., a mug), or a hybrid use (e.g., a decorative vase that holds water). The functionality of a piece can affect the glaze choice directly since some glazes are not food safe, while other glaze chemistry can produce matte or glossy finishes.

Ruth When I make functional pottery, I avoid matte glazes since they tend to leaves marks from spoons, forks, or the dishwasher. I often use glossy or semi-glossy glazes instead.

For Edison, he views his art as an experience to be perceived and used by others; his choice of glaze allows him the opportunity to share his vision.

Edison It might look like a functional pot or may not be functional, because I choose not to make it functional using the glaze I choose.

For others, the factors that goes into choosing a glaze is not as black and white as choosing between function and non-functional. For Seneca, they describe the electing process as complicated meticulous thinking:

Seneca If it is a piece that people are going to touch a lot, like a mug, the glossy just feels a little better I think. If it something that is more of a display or sculpture, I like the matte since it looks really cool, because it looks store-bought Pier One. I need to figure out the function before I go into color.

Selecting a glaze based off of function requires a practitioner to "live" with their object and understand how that object transforms over time. This forms a deeper relationship with the material that extends past its making or formgiving state that is considered the life cycle of that object. For instance, where the object fails (e.g., dishwasher, fingerprints), where it thrives (e.g., as a spectacle of an object), and how it changes over time (cultural moments). Extending a material model based on function requires a practitioner to become an active and varied user of the artifact.

4.1.3 Social Transfer

Social transfer refers to glaze selection based on social influences or driven from their social environment. These include current trends, community suggestions, word of mouth, or requests from students or customers. Ruth, who is a production potter, uses her store's inventory to drive glaze decisions, regularly accepting suggestions from customers that don't fit her personal aesthetic:

Ruth When I am ready to glaze, I take a look at what is out there, and if there is one glaze that still has a bunch of thing[s] out there, then we go so that is not selling as much as other things. It varies from time-to-time depending what is out there [popular trends] and what colors people use to decorate their homes.

Social transfer was a glaze election method that was actively resisted by the informants, often coupled with a feeling of "giving in" to someone else's personal practice:

Paul If there is a glaze that I do not like, or I do not think is working that well, or if I get a lot of requests from students telling me they really want a green glaze and we do not have a green glaze, only then will I add one.

Leila I don't do a lot of custom orders either. I'll do orders for people who are like "I like this bowl that you make in this design". I can do that, but I'm not going to do something that's like, "well I like this design but I wish it was green," I'm not going to do something like that. I figure you like what I'm making, or you don't like what I'm making.

As an expert amateur, Seneca found value from community suggestions. As a hobbyist potter, Seneca does not produce enough ceramic work to warrant mixing her own glazes. She regularly uses commercial glazes. A major source of information dissemination within the ceramics community are the ceramics stores.

Seneca So now it's going to the store and talking to the people that work there. Like "Oh, we got this one in, try this one out' [new commercial glaze]. And that has been really good to do that.

For ceramicists from research backgrounds, they leverage the open-endedness of community requests to test under-explored glaze chemistry.

Jackson We are personally open to exploring any topic in glazing. We will chase whatever is of interest, something that our students ask us about that day, really anything that catches our fancy.

While social transfer is an artifact of how a practice is situated as an economy, we found that it had the most value when it originated from a community of practitioners. [47]. All ceramicists reported being active contributors and consumers of Facebook groups; these communities are important to leverage the natural deviation across practitioners and the collective goal to grow the community and their corresponding social rewards. This form of glaze election leverages the social mechanisms that are a part of legitimate peripheral participation [48], allowing newcomers to gain entry as hobbyists and gradually identify with the larger ceramics community.

4.1.4 Material-Driven

Material driven refers to wanting to highlight the glaze's chemical or reactive properties that commercial glazes undermine. For instance, wanting to create a glaze what will break or crystallize on purpose. Since these unique properties are hindered in commercial glazes, they become the inspiration for a new glaze to a ceramicist. Navigating this landscape of effects evolves as new glaze formulations are introduced into a practice. Certain glazes require special treatments and handling in order to achieve the desired outcome, which inadvertently effects other decisions. Crystalline glaze is a glaze that is composed of distinct spherulites formed during the growth process [49]. It is a special case that we observed driving glaze selection:

> **Paul** There is a very specific technique and glaze that works best on certain surfaces and certain forms, such as with crystalline glazes. I will specifically design a form with that glaze in mind.

In ceramics and pottery, building a piece from scratch to the final product can take many days. If you were a new student in the field, not seeing the result of your hard work can be pretty unsatisfying and discouraging. But there are materials/ methods which can be used to help this situation to speed up the process and increase excitement. Raku glaze (raku is a firing technique where rather than waiting for a kiln to cool, the pieces are removed while still hot and put in a bucket of combustible materials (e.g., banana peels are very popular because of the color of potassium). Sometimes, these red hot pieces are dunked in water to cause a crackling effect.) is one of those materials (Figure 4.2 C).

Edison I have three different types of glazes and I do not have the matte glaze. I got the semi-matte. You can see the gloss there, on the goblet. I do a Raku glaze. I like to do this with students because it is an instant gratification and that day they have something.

Some artists aim for materials which deliberately can cause imperfections.

Seneca I just have certain colors and tones and hues that I prefer; some people really like the flat all yellow, I like that glazes that will break and do different things and texture and expose different hidden colors.

Clay shows one of the strongest propensities for experiential knowledge, producing haptic, aural, visual, and olfactory stimuli instantaneously. However, glaze offers a similar experiences, but with a significantly different temporal window requiring the high temperatures of a kiln. In this sense, glaze offers a larger reward from the delayed satisfaction of experience the results of a material manipulation. This is an important quality the drives the natural curiosity that drive material-driven explorations.

4.1.5 Systematic Experimentation

Glaze election can happen through systematic experimentation. Systematic experimentation refers to rapid creation, observation, and improvement. Since glazes are made from chemicals and are mixed based on formulas (aka. recipes), systematic experimentation is not uncommon in expert community to find new glazes from the already existing formulas, and they do it by by just adjusting small changes gradually.

Edison Two years ago, a [mining company] changed the mining site that they were digging it out of. This changes the composition of the [chemical], so you need to keep track of what they publish about the product itself that give you the percentage break down. If you do not know what you are doing, it will mess up your glazes. You have to be able to adjust it a little bit.

Like any experimentation the result might not match the expectations, and for ceramists who do these experiments professionally, this rule is applied to them as well.

Jackson For us is more trying to figure out the parameters of any glaze. So by that we do not put any expectations on result, we just want to see what happens when we cover our chemical bases and look with a systematic parameter, so if we see something that is of interest we take that and refine it and do it again. We look at the result and go “oh that is interesting” and then go back and make ten or twenty more formulas based on that and then try to batch up.

For a ceramist that’s been experimenting for a whole life time, there is a sense of pride and ownership intertwined with making a glaze from bare elements, to fire it, and enjoying it’s magical finished look. But for those who are not as interested, or do not have enough resources to drill deeper into every chemical and explore, there is still a way to achieve this goal. For new students in particular, the practice of rapid creation to follow the systematic experimentation method is very beneficial. Since they are just starting to develop their knowledge and the iterative cycle of rapid creation, observation, improvement, and creation they can increase their domain knowledge faster.

4.1.6 Theory-Driven

Theory-driven refers to following already established formulas and recipes for glazes rather than experimenting to find new ones. This is the method which artists can use when they want to have more control over every aspect of their process such as making the glaze from dry chemicals, but not going too deep into the science of it. Also it is essential to mention the cost of making glazes, as making batches or large amounts of glazes is significantly cheaper than buying the same glaze in a commercial bottle. Most of these recipes have been shared for years among communities in the form of books, online sources, etc. For artists, these trusted communities provide the chance to take ownership over their process without spending extra time and resources on experimentation (Figure 4.2 B). This information is commonly shared through master's notes, handbooks, online based communities, school and education systems, social sharing in conferences, etc.

Edison I have a tons of recipes given to me. We change them a little bit and that is why you have to go into the formula to understand the relationship of [chemical name] to glass to [chemical name].

Paul So it is "glazy.org". So that is a collection of over twenty thousands glazes over there which all are user generated. So people as they are doing their own glaze research and testing they can share their recipes and test tiles on this website and then anyone can go on it and search.

For artists who follow theory to create their glazes, I have noticed there is still some level of experimentation and personal annotations involved. However, these adjustments were not as detailed as other groups to be labeled as scientific method of experimentation. For new students who are interested in making their own glaze, it is an absolute step to start from already made and proven recipes and learn the material, the oxidation, and chemicals well enough to begin their free style experimentation. And these type of information is very well documented to be shared through the aforementioned resources, which will provide plenty opportunities for students to start from.

There are artists who do not like to chose any glaze, and they prefer to use methods of pottery which allows them to avoid this process completely.

Paul I personally hate glazing, it is my least favorite part of the ceramic process. I do not know I feel it feels a bit forced. I do clay because I love making and working with my hands and creating the forms and the pieces. So I would fire in an atmospheric kiln. Because in that kiln, you do not have to glaze a piece.

This study showed us that even for a selection of a glaze, there are many factors that can effect the decisions. Factors such as the current state of mind, life, location, process, community, social trends can sway these decisions.

Figure 4.3: Material Model: A) Rendered sketch based on Paul's description of how his students sketch their glaze process before making their pieces. They annotate their drawing with ordered steps, methods of application, and the glaze names. B) Same glaze (TP20 AMACO [1]) applied on both artifacts using brush. On the top picture the TP20 glaze is applied on a Stoneware clay and bottom picture the same glaze is applied on a Earthenware clay, C) Seneca uses a masking technique to apply doodles on her piece. First she applied yellow glaze, then placed her stickers and covered the rest with black. Stickers are later burned off during kiln firing, revealing the pattern, D) Using Unity Molecular Formula (UMF) chart to explore possible results for a glaze.

4.2 Material Model

From the glaze election stage to cone firing, there are various formal properties that play a role in the final outcome. I have identified the properties that the informant ceramicists consider when preparing for a final firing. I consider both material interactions with each other, with the way they are applied and handled, and the ways in which kiln-firing transforms them into iconic ceramic artifacts.

> **Leila** Well you're dealing with heat, and you're dealing with time and you're dealing with water and you're dealing with steam, and all of these are different . . . and then you're dealing with chemistry, so I would say the most problems I have are during the glaze firing, and a lot of the problems are either the kiln is fired too fast, or the kiln has cooled off too quickly, or the kiln didn't make it to the correct temperature or I'm using a glaze that doesn't fit my particular clay body, or the clay is offgassing, and the glaze is still melting, and so it bubbles.

4.2.1 Clay Body

Clay body refers to what kind of a clay has been used to make the artifact. Each one has its own firing limits, and there might be possibilities that we have thermal mismatch between the glaze and the clay body. Besides the technical collisions, glaze will look and feel different depending on the clay body (Figure 4.3 B). Some artists chose their clay bodies based on its ability to highlight a desired glaze characteristic.

> **Seneca** It's important to know what the clay body is, especially if I am talking to other [ceramicists]. I use a mix of earthenware and porcelain so glazes will look very different on that as opposed to terracotta or black pearl bodies.

Not only aesthetic but also the function of the piece and the price will interfere with the artist's decision. For Leila who is a production potter, it is important to consider more than aesthetics in her clay body choice.

> **Leila** I made those [vases] out of porcelain . . . porcelain is much more, way more, expensive. . . . It's also more prone to warping and cracking, but the porcelain has lower absorption rate, so you wouldn't want to use stoneware for a vase because you might end up with leaking.

Knowing properties of clay bodies is important. Some glazes are not compatible with specific clay types due to firing conflicts. Also, the look and feel of a glaze can differ from one clay body to another. These types of information is much easier to communicate through codified resources like books, however I observed that working through issues relies on the developed material mental model of another practitioner.

> **Leila** I was hand-building porcelain and I was having problems. My [ceramicist neighbor] took me into her studio one day and showed me how to make it from beginning to end; now, I use many of the techniques that she uses.

For these type of knowledge transfer, diverse shared studio spaces supported regular dissemination of tips, techniques, and bespoke tools.

4.2.2 Firing Condition

Firing condition refers to the cone fire, cycles, and kiln type (gas, electrical, salt, wood), weather, level of oxygen, etc. These components can cause different effects on the glaze which is important for the master to be aware of and be able to adjust these elements to get the expected result. Or in case of Paul, the practitioner can use the randomness in the process to his benefit and use it to be part of the piece.

> **Paul** Wood firing is like using wood as the fuel, and so the ash will fly around the kiln and attach itself to the clay, and create it's own glaze. You can use glaze in the wood kiln, but the ash hits the glaze differently and it is harder for me to remember what I used [glaze] because it looks different than just in the traditional gas kiln.

Some artists assign designated firing conditions based on the final functionality of the piece in mind. Due to the cost of firing, many ceramicist must "batch", or prepare many ceramic artifacts to fire at once. The change in thermal mass in a kiln also contributes to different firing conditions.

More experimental practitioners like Edison, aims to rigorously control the firing condition. He goes into details and documentation of the temperature, oxygen level, humidity, and other environmental factors. This documentation empowers him to gain more control over his process and eventually gather enough data to automate this stage.

Controlling environmental factors and keeping rigorous documents serves as an example of the capacity to codify the material model. Gas kilns, due to their size and price, are mostly limited to exist in formal studio spaces while electric kilns are better able to exist in a home studio. Being able to experiment with diverse methods of firing is one of the shared experiences amongst the informants. They explained the wide range of glaze expressions from controlling firing conditions. For new students, access to these facilities remains a challenge and limits their ability to experientially develop this knowledge. Even though major portion of these information can be read through sources, subtle details like the behavior of everyday organic materials (Figure 4.2C), remain largely a exploratory practice.

4.2.3 Glaze Application

Glaze application is a general term to cluster ways that glaze can be applied on the clay. Some common techniques are: pouring [inside the object], dipping [usually used to cover the external surface, refers to when artist dips the item into a bucket of glaze], brushing [detailed application, allows artists to be more precise and focused on specific areas, used for highlighting features such as a pattern], spray [some glazes are not spray safe, they contain little pieces such as crystal bursts which will limit their ability to be used in spray technique]. Practitioners can use multiple techniques on one piece and create more colorful artifacts. Capturing glaze application details and documenting it can be very useful, so the artist can improve on the result later. Clay will absorb the glaze into itself. Therefore, it will make a difference if we apply two coats or three coats, since the hue will be different due to water absorption property of the clay.

Seneca If I paint with a paintbrush the glaze it can look very different than if I had poured it on or dipped it into a big bucket.

Some practitioners use methods of application which are not as common, and it has been personalized to their individual practice. Leila is a modernist designer, when it comes to styling her pottery pieces, she loves Asian aesthetics, but she deforms them in minimal forms, mostly lines and only few colors. She uses applicator bottles (has a needle on top, which allows artist to create linework) and a catch-all plate to “sketch” her glaze design on their pieces.

Leila Once I bisque fire [a mug] then I do all the drawing afterwards, I use a squeeze pin-bottle [applicator bottle] and I use the designs [her own sketch], and then paint that, and then dip everything in glaze and fire it again.

For Seneca, she keeps a sketch book and occasionally draws some doodles and patterns on it. For a long time she was trying to find a way to map her doodles on her pieces. After some failed attempts, she finally figured out a way to create stickers from her sketches and tried masking technique to implement them (Figure 4.3 C). Masking technique uses a material such as tape, to block some areas when user applies color, the tape will prevent the areas which were masked to receive color. Later on those masking tapes can be removed.

Seneca I figured out how to make stickers in my shapes and put them on the piece, then glaze over it, and fire it. The stickers would burn away leaving the shape.

Glaze application for new learners can be one section that each artist can become as creative as they want. There are still limitation on what glazes can be fired together, or if their properties allows them to be use in customize settings. But in it's core, it is like painting. Students can start from following the standards so they can develop the necessary base and gradually create their own style personalized to their interest.

4.2.4 Glaze Location

Glaze location is another method developed by practitioner over the course of years to increase the level of customization and control. In the study I recognize various scenarios in which artist intentionally used methods and techniques to control where the glaze will be placed. Some glazes are too runny, which means when they get into cone fire, they melt and run down to the kiln shelf. This can cause fusion between the pottery piece and the kiln shelf and eventually cause failure. For Seneca, as many other artists in practice, this incident is not new.

Seneca If it's [glaze] really runny, I'll use it on the inside of a bowl and it won't run off.

Jackson had a different solution to catch drips on his glaze keys, (Figure 4.5 C) is a shot from his kiln fire where all tiles are in a Popsicle shape and each Popsicle is attached on a little tray. These trays have been designed to make sure any drips caused by melting glaze will be caught and therefore prevent possible fusion problems.

Beside these scenarios, glaze location is considered when the object contains surfaces with different clay thickness, such as patterns. Some glazes will completely change color when the thickness changes, and this knowledge will determined how the location of glaze needs to be plan to achieve the desirable outcome.

Ruth It has to have some degree of translucency. It breaks on the high parts of the texture, then it is thinner [texture, clay thickness] so then it gets you the lighter or paler shade, then where it's thicker [clay thickness], it falls in between and it's going to be darker. You can get a look of multi-colors from a single glaze on a single piece.

Edison If I am doing a lot of texture, I want a glaze that will enhance the texture. Not take away from it.

Some of this information can be passed through words, but some scenarios such as glaze's reaction to thickness requires more making than reading. There are still questions to be answered for students to be able to create these colorful pieces, such as how much thickness is thick enough for glaze to react? How shape geometries can effect the glaze? These questions are immediately analyzed and resolved in a master's mind due to thousands of creations, but for new students it is not as easy. Extended experimentation with glaze location on various geometries and thicknesses is the key to unlock the answer to these questions.

4.2.5 Glaze Chemistry

Glaze chemistry can be similar to a recipe composed of ingredients containing silica, flux, and oxides. Glaze chemistry has a tight link to firing condition, factors such as color, thermal expansion, melting temperatures, hardness are dependent on the oxides which makes the specific amounts of oxides within a glaze. Jackson, a glaze researcher, regularly studies these relationships to uncover new glazes (Figure 4.3D).

Jackson We were looking at some of the variables that control that gold color. Some [of these iterations] have more gold, but the gold dissipates as we move through different chemistries. We're seeing if it gets more intense or less intense and figuring out what those overall defining parameters are. But anything and everything, like the viscosity of the glaze or crystallization patterns, is relevant because it feeds to a greater perspective as to how this glaze works. We use that as a reference to how all glazes work, because there are general trends to behavior.

Some practitioners like Edison, spend years to curate their glaze chemistry to perfection.

Edison I spent two years working on the chemistry. You can see that is a deep purple, but if you get closer you can see it goes to a royal type purple on the inside.

For practitioners who follow recipe base glaze chemistry and do not use UMF charts to predict the effects, the experiment relies on experiential knowledge.

Ruth I tell [students] that it is a trust-walk when they are glazing. It does not look like in the bucket as it does in the finished product.

Seneca Those are more specific [test tiles] that I use when I am working on a specific project and need to know how to do something. When it comes to just blank glazing, like blue or teal, I know what that is going to look like so there is no need to make test tiles.

Glaze chemistry can be manipulated through a scientific approach to gain deeper knowledge on the material. Edison and Jackson for example control their kiln and studio environments and isolate the specific glaze ingredients that affect a target formal glaze expression. Others like Seneca and Ruth take a more experiential approach to unlock new glazes. Both groups learn to predict and anticipate a glaze behavior through studying it's chemistry. Because of the many different parameters, firing conditions, and material interactions, theoretical discussions are limited compared to the larger space of glaze design choices.

4.3 Sensemaking

Within ceramics, working with clay is a process that gives practitioners instantaneous feedback. However, since glazing primarily works with fired pieces, the ability to gain feedback to refine or question a practitioner's material mental model can take

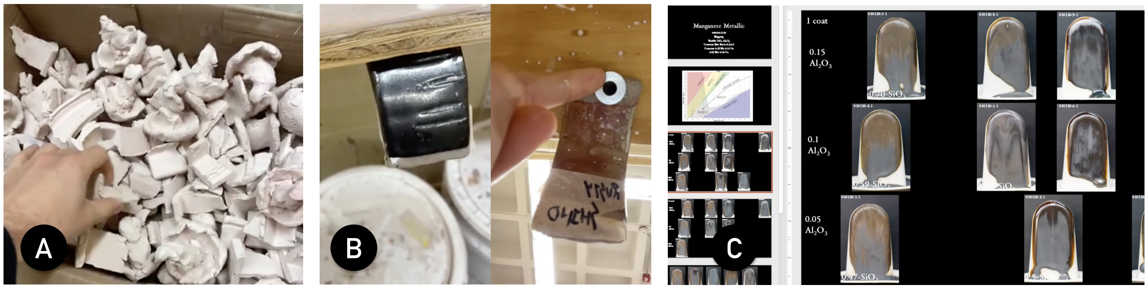


Figure 4.4: Sensemaking: A) A bucket of scrap pieces in a university ceramic studio, ready for students to use for glaze testing. Some pieces are even annotated with student's initials and a number, on the bottom of the scrap piece. B) Glaze keys (a.k.a test tiles) in a university ceramic studio which has been screwed to the bottom of the shelf to prevent it from getting lost. C) PowerPoint slides made from a firing batch result analysis of a glaze in Jackson's glaze chemistry workshop.

entire days depending on the firing process. Furthermore, glazed pieces cannot be reused — firing a glazed piece means committing to the final outcome. Despite the range of expertise of each informant, I encountered a range of sensemaking activities that confirms the epistemological pluralism that exists within ceramics. I describe these sensemaking strategies in the context of the informant's personal practice and their teaching practice.

4.3.1 Serendipity

Race et al. [50] describe serendipity as "the happy accident of discovery" that is more than just blind luck, but a phenomena that can be influenced and cultivated through actively searching for serendipitous opportunities. These sites for serendipity arose naturally from glazing practices that are often unpredictable and temperamental. For all of the informants, this unpredictable quality in ceramics is openly accepted and cherished part of ceramics work, especially when coupled with the anticipation from leaving a glazed object overnight to fire followed by a great reveal from opening a kiln.

While overtime, ceramicists develop more control and knowledge of how glazes will react, they still maintain elements of their practice open for serendipity. Edison, with more than 51 years of experimenting in ceramic and glaze chemistry, still found openings for moments of serendipity.

> **Edison** These pitchers that I have [two different colored regions separated by a line] made with the texture of the pot itself. I can [control] the two colors, but I let the line overlap for the glaze to do its magic. That part [the line] I cannot control, because when they bleed you can only control so much . . . that's the fun part about it.

Across all informants, I found a common practice of collecting leftover glazes in a common container. This "mystery glaze" serves both a functional purpose (to reduce waste), but established an opportunity to run its course. Sometimes, the mystery glaze would produce "a really beautiful glaze" (Paul), while in others it would "eventually arrive at some sort of green"(X). Notably, the contents of a mystery glaze were never documented and contributed a playful role in shared studios that contributed to the contents. Serendipity is not a failure, instead it is used by ceramicists to add excitement and wonder in their work. While this form of sensemaking is more difficult to be used to refine a material model, in instead invites practitioners to encounter new unknowns and seed future material investigations that expands the scope of their material model.

4.3.2 Trial and Error

Trial and error refers to a mode of problem solving where a person learns by trying out new strategies, rejecting errors until a adequate solution is found. I use this term to further describe behaviors that are opportunistic, or make use of the immediate actions available posed by a situation. This behavior typically results in a lack of external documentation and is highly dependent on a practitioner's ability to remember their choices, processes, and outcomes.

Most resources on glazing and informants who teach encourage students to create glaze keys, typically in the form of a sacrificial tile, to test out a glaze before committing to fusing to it to their more valuable clay form. However, I rarely found the expert ceramicist making use of this strategy. For one informant, they found that the chemicals used to compose a glaze changes over the year from manufacturer discontinuations or from new mining sites:

Edison That [pot] was a test fire. Since I can make these [pots] as quick as I can make [tiles], I use a pot as a test tile and let it go. I learned to use little test tiles in school. I got out of doing it because the chemical kept changing on me and you cannot guarantee [the veracity of the test tile over time].

The value they found in documenting their work was significantly affected by the futility of the record being accurate over time. While artifacts around their studio still served as a point of reference, many of the informants rarely needed to review these references.

Ruth I remember it by heart. I can even tell [what my students] use. I tell them to write it down, but they never do.

Paul If a student asks me what glaze I used, I just remember in general.

This form of sensemaking often resulted in the informant ceramicists becoming the gatekeepers of information; their reliance on their personal memory led to proclivity for common "errors" accepted as natural part of doing ceramics.

Edison This piece is double-dipped in different glazes - here you see the overlap of one Shino glaze with another Shino glaze. You could keep them separate, but it's more like an artist when they are painting — you understand that two colors will react, you remember that, and store it in your brain. But the mistake [i.e., accidentally overlapping colors] will occur again from stupid mistakes. Sometimes it is a mistake, while other times I like the mistake and do it again.

Sensemaking through trial-and-error was a common strategy for informants that taught introductory classes, encouraging students to make many samples, to drive their glaze selection from personal interest, but simply to establish a practice that allowed them to generate more experiences to build their material mental model.

> **Ruth** I ask [my students] to bring me their least favorite pot first and [try out a glaze]. I encourage them to try as many colors and combinations as they can so that they can see what it actually looks like on their pieces.

This learning strategy was predicated on the lack of utility in external documentation, which in turn supported uninterrupted workflows with more continuous and frequent interactions with glazes. While glaze keys (e.g., test tiles) were an acknowledged "best practice", the reality for these experienced ceramicists was to leverage their memory for bookkeeping. Occasionally they used fired scraps or finished pieces as a boundary objects for instruction, but rarely for their own personal practice. Errors that resulted from lapses in memory were reframed as sites for serendipity.

4.3.3 Indexical Records

Indexicality has been used to describe a photograph's ability to capture a moment in time and to attest to its occurrence [51]. I use this term to describe the ways that ceramicist and their students treat their records in their respective practices. These keys served to mark a moment in time, but were often temporary and brief in their use.

In Paul's classroom, students make keys from scrap pieces and labeled the bottom of their keys with their initials and an identifying number (Figure 4.4 A), but remained largely unused over time.

> **Paul** Students often do not keep the test tiles with their work. The tiles would be great to use in future semesters, but they take end up taking them home or losing them.

For more established glazes in the studio, glaze keys were screwed into the glaze container storage shelves to guarantee their safety and availability(Figure 4.4 B). Others like Seneca would use the temporary intention of glaze keys and misfired objects to attend to the emotional labor of ceramics work, keeping them in a bucket overtime and breaking them on stressful days.

Some other artists like Leila will keep her tiles hanging on the wall (Figure 4.5 B) or stored in boxes and drawers so she can find them later if she needed.

> **Leila** I'll be making something a year from now, and [remember that] I tested that already.I'll dig through my test tiles, and I'll find the test tile. I'll [use to be figure out if] it worked or didn't work [against] what is in my mind of what I want to make.

Indexical records served as a form of sensemaking that served the immediate needs and purposes of ceramicists. These records provided information for a particular moment in time, serving as more of a memory aid than a shareable artifact. This type of sensemaking benefits from creating artifacts that are able to access internal memory of process and outcomes. For a master ceramicist, their recollection of these artifacts is reinforced from repetition, which places a newcomer at a disadvantage. While some efforts with the ceramics community aim to standardize the ways that information is recorded, indexical records remain the most pragmatic method that material mental models are refined.

4.3.4 Rigorous Records

Some practitioners keep rigorous records of their experiments, treating every fired piece as a point of reference to guide future glazing iterations. Glaze keys are difficult to document since writing or labeling them directly is limited to using an underglaze pencil. For Leila, these marks detract from the aesthetic value of an object. She instead used a textured pattern to pair a sacrificial key with a finished artifact and encoding the key with pertinent information. In her communal studio, she regularly created many glaze keys to gift to other potters. She would display her collection prominently in her studio and often use it to drive her design decisions (Figure 4.5B).

Others leveraged digital record-keeping forms like Excel-based documents or PowerPoint presentations; these records are often used to discover relationships between formal properties, plotting relevant data into charts and computing stoichiometric calculations. For glazes it is common to plot the chemistry on Unity Molecular Formula (UMF), or Stull chart, which have become the standard method of understanding glaze behaviors through community-driven recipe repositories like glazy.org [21]. Figure 4.4C displays a screenshot from a PowerPoint file which is used to describe one ceramicists parametric exploration through several batches of a specific glaze recipe. This method of documentation is most common within the user groups who are heavily involved in systematic experimentation and glaze chemistry.

The ceramic engineer informants drives a large part of their ceramics practice from systematic experimentation. To control for the environmental variance of firing environments, Edison automated the documentation process using sensors embedded in his kiln environment:

> **Edison** Now the kiln actually fires itself. I turn it on and monitor it. If something happens I can go to my notes that go back to the six years that I've been firing out of this kiln. I have six years of bisque firing, glaze fire, and temperature. Was it cloudy outside? Was it rainy? Was it cold? Was it hot and humid? All of these are important.

Other informants used a rigorous record keeping practice as a means of communicating glaze material knowledge to others. In particular, Jackson prioritized the maintaining the veracity of his records through digital documents (a photo rig and color correction routine) and physical documents (bagging, labeling, and storing all test tiles).

> **Jackson** We never throw anything out. Everything is worth keeping.

The improbability and fickleness of the firing process is a universally experienced quality of a ceramics practice; for those that use rigorous records to make sense of outcomes, the experience is akin to controlled chaos. Despite the richness of the data that is recorded, indexing records by date remains the primary method of referencing date.

> **Jackson** We label everything with an underglaze pencil. We use the date on the key and label every tile multiple time so if it gets disfigured in some way we have a backup reference.

> **Jackson** We work exclusively by date because you only have that date once and even if you make multiple samples on a date you can subdivide those into sets. Searching for them is pretty easy because you can just enter the date from reference tile [and retrieve the record].

While glaze recipe repositories aim to enable grassroots citizen science contributions to advance the space of glaze expressions, I found that the idea of a "rigorous record" carried different meaning across practitioners. For example, Jackson was cautious of using other ceramicists results due to potential and uncontrollable deviations in how the glaze was prepared or from the differences in the firing environments between two potters. The shareability of records remain conditioned on a practitioner's trust in similar environment, process, and background of other ceramicist. For shared studio spaces where technique and materials are more uniform, rigorous records serve as a sensemaking strategy that can be used to develop and refine mental models through codified knowledge versus other sensemaking activities that rely on experiential knowledge.

4.4 Discussion

From the contextual inquiry, I synthesized a framework oriented around the concept of a material mental model. While the inquiry is centered on glazing, elements of the model can be generalized and applied to the larger domain of physical and

Figure 4.5: Extracted Images From Contextual Inquiry: A collection of photos gathered through the contextual inquiry. photos are from user's studio spaces and pieces. A) A ceramics instructor labels custom-mixed glazes sampled from her repertoire of ceramics work. B) A production ceramicist hangs a collection of glaze keys that allow her refer to and share her glaze and clay body combinations with others in her communal studio. C) A ceramics engineer systematically fires variations of a glaze recipe for analysis. D) Multiple pictures from a ceramic engineer' studio and work who is focused on chemistry of glazes. E) A ceramic hobbyist uses customize methods of application to create patterns. F) A ceramic places unglazed pieces on shelf for glazing. G) A ceramic engineer experimenting with glaze mixtures.

digital material practices. I then discuss the utility of the framework in motivating design decisions around emerging technologies in these practices, smart environments and workflows, and methods of supporting a more comprehensive range of material behaviors in interaction design. Informants in the contextual inquiry were skewed towards practitioners that mix their own glazes; Seneca remained the only informant that used commercial glazes. Her feedback gave us an indication of how expert amateurs [52], or practitioners that do not engage professionally with a practice but are senior members of the hobbyist community, have different modes of foraging and resolving information. Since experts can easily lose sight of what it was to not know [53], I see the value in expanding the scope of the inquiry to what Nicola Wood describes as the modern journeyman [22]. These journeypeople include those that serves as an intermediary between the expert and novice, having not completely internalized the tacit knowledge inherent to material practices. The author's backgrounds helped to mitigate this bias in observation, but could have benefitted from longer contextual inquiries or more in-depth participant observation. To further understand how to transfer material models, it is imperative to understand the learner's perspective. Conducting a large part of the site visits virtually placed limitations on what the informants chose to show us. I see less issue here since ceramic studios are not generally private spaces, but instead found that virtual contextual inquiry allowed the informant to show us their viewport (figuratevly and literally) and understand where they attend to in the wide breadth of stimuli present in a studio practice (Figure 4.5).

4.4.1 Extending bricolage through social transfer

Our framework isolated how master ceramicist creates opportunities to expand their existing material model. What these methods hold in common is a need for a ceramicist to place themselves in unfamiliar spaces. I realized this through searching for inspiration and creative direction from the environment (sampling) the provided sites for serendipity. This method coincides strongly with the concept of a bricolage practice where a practitioner leverages the materials, tools, and knowledge at hand to navigate different material parameters and interactions. This has been an emerging design strategy in and digital and hybrid fabrication tools. For instance, Efrat et al. [54] leveraged a parametric model of a textile smocking pattern to generate a gallery of forms and deviations in the placement of elementary stitching patterns. This act of externalizing the interconnection of elementary operations was also visible in test tiles often used and displayed in public spaces in studios (Figure 4.5B) particularly useful for making salient the interaction of the same glaze on different clay bodies. I also see this present in the plotting and curation of glaze recipe variations on a UMF chart (Figure 4.4C), which makes salient the underexplored glaze design spaces. While visibility and access to materials and tools are important to bricolage, I encountered social transfer as having similar effects: from informal interactions like a store attendant curating knowledge of the latest and most popular glaze trends, to structured interactions of a ceramicist collective coming together for monthly exhibitions and seeding each others curiosity. While more tenable to achieve with novice practitioners, integrating social transfer interactions among skilled practitioners is heavily predicated on identifying with a community of practice. Many ceramicists maintain relationships with social network groups. With the growth of glazy.org and other crowdsourced platforms, HCI opportunities to support the collection and curation of material knowledge.

4.4.2 Refining material knowledge

At one extreme, I uncovered practices that aimed to document every single motion, ingredient, and environmental phenomena that came into contact with a glaze. Each practitioner takes their personalized approach to analyze the outcomes of their work. At the same time, some are comfortable with intense scientific documentation, while others take mental notes of important effects and store them in their memory. The complexity and lack of control of glaze and a firing cycle complemented one of the cherished values of serendipity in ceramics.

4.4.3 Externalizing material knowledge

The site visits revealed a wealth of artifacts used as boundary objects to communicate different glazing decisions and glazing outcomes. This included glaze keys that ranged from simple test tiles (Figure 4.4A), referential glaze keys (Figure 4.5B), to streamlined standard systematically repeatable forms (Figure 4.5C) curated on Stull Charts (Figure 4.4C). However, the rare unexpected results had the most significant potential to seed inquiry, alter a creative practice, and develop resiliency.

> **Leila** I don't think I've ever had a single kiln load in my career where every single piece is fine. I think I've always had something...and some of the pieces are not like "oh gosh, this is a disaster," and I'm going to throw it away. Some of them you can reglaze and fire again, so it's not really the end of the world.

While some were able to "redo a mistake," others like Edison made it an integral part of his practice to track provenance, recording any changes in the environment that could use to replicate a result. This has been an emerging trend with computational notebooks that allow data scientists to engage in exploratory data analysis, try out different parameters, visualize, and maintain a record of their trajectory through their exploration. While such a system would benefit ceramic practices, a significant focus on experiential knowledge suggests a need for tracking provenance tangibly. This could also hold value to other physical practices that require biology or chemistry labs.

CHAPTER 5

SYSTEM

5.1 System Design Principles

Using the Material Mental Model and the empirical data from the contextual inquiry, I identify four design principles for supporting the tacit knowledge that is generated from engaging in a creative process. And then used these principles to motivate system design decisions.

P1 **Documenting process should not disrupt or replace existing workflows.** In these practices, which share characteristics such as "messiness," designing a system that does not disrupt the workflows is essential to achieve maximum focus and productivity needed for creation. IoT (Internet of Things) systems are mostly reliant on using the internet and network connections to be functional in the space. However, it is possible to lose connection. If the designed system loses connection, what will happen to the users? A good system should present an alternative solution in such scenarios for the users to still be able to continue their work without massive disruption and break.

P2 **Support searching for records using associative cues.** I learned that users use their memory as their primary storage to hold and retrieve information from the contextual inquiries. Memories are linked in their mind through series of events and ques. They use these cues, such as the time and date of the creation, to recall the item and its properties. Even though some users keep some notes and journals, their location is more accessible for them to remember something rather than the description written on the notes. Also, most of them do some marks and sketches rather than a detailed explanation of the process. Therefore, the system should value visual representation connected to our memory cues more than the word-based description of the same item.

P3 **Enable a community of practice to access and share information.** Creative domains such as ceramic and electronics are dependent on "maintenance" to be organized and productive and are primarily placed in a shared environment and studio spaces. There are many tools and equipment needed to do a task and follow the "cultural memory" model, which relies on the presence of the master to guide the student throughout the process. Due to the shared characteristics of these spaces, the system needs to support sharing within the community and be able to handle a large number of users simultaneously. Students are focused on their process and work in a workshop or studio space, but they all might need to access the system for their procedure. Therefore, the system should support a large number of users accessing the system and modifying it. There is also an element of access through time; if some students record their process into the system, can others access that information for their work? Researchers are encouraged to focus on their primary domain to understand how information is shared within the community.

P4 **Support an open-ended, flexible, and dynamic schema.** The creative domain that shares "Messiness" characteristics are resistant to being stored in a database and generalizing. A good system design for such spaces should support the flexibility of this messy information and environments. These domains of practice are prone to growth and change. Users build on each other's work, and the system should support such linked information.

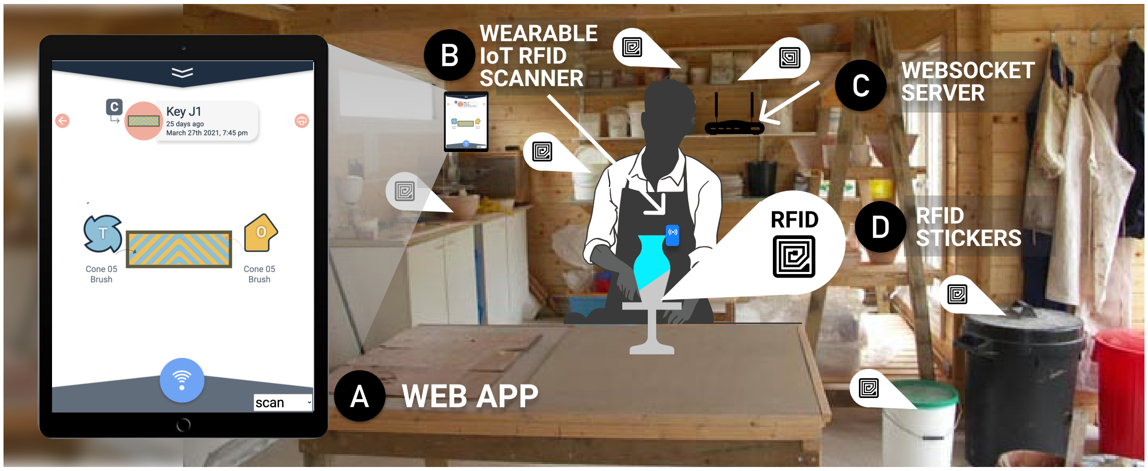


Figure 5.1: System Architecture: A) A web application provides visual access to a database containing records of glaze, key, and container artifacts, B) a wearable Internet of Things RFID scanner can be worn by practitioners to quickly retrieve or create database records, C) a cloud server coordinates interactions across all devices using persistent web-sockets, D) contactless 13.56MHz RFID sticker tags ($0.33 USD/tag) are placed on finished artifacts, containers, recipes, and failed experiments.

5.2 System Design

Insights from the contextual inquiry drove the principle need to create a system that can withstand the messy studio environment without interrupting existing work-flows. The Glaze Epoch system makes use of Radio Frequency Identification (RFID) sticker tags (13.56MHz 25mm) commonly used in inventory systems to access virtual database records using simple, contactless interactions. These tags are readily available, reusable, and cheap ($0.33 USD/tag). Besides the economic benefits of using RFID stickers, they are also waterproof, adhesive, and flexible. Each RFID sticker provides us with a unique identification string (a hex string) to store the entry and link it to other entries.

Unlike a traditional inventory system, the Glaze Epoch system creates associations between different artifacts within a glazing practice to track creative trajectories, document provenance, or record systematic experiments. I use these stickers to associate database records with artifacts such as containers, notebooks, pages, fired artifacts, and glaze bottles (Figure e 5.2).

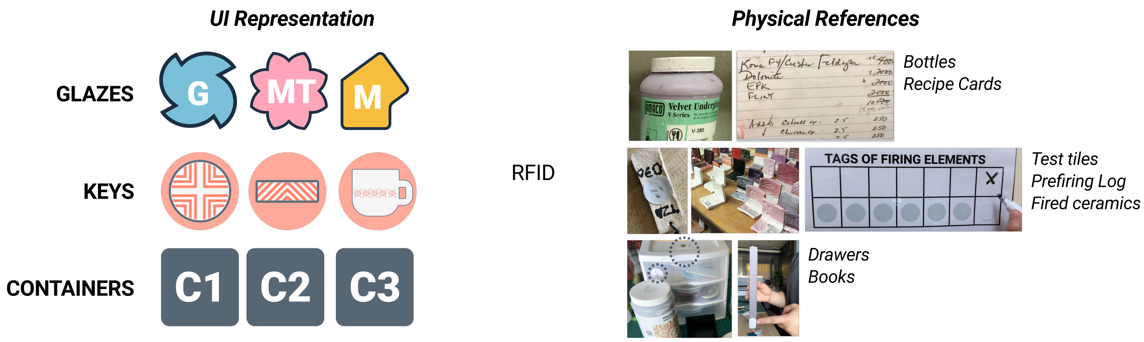


Figure 5.2: RFID stickers: A) an example of an RFID sticker placed on the lead of a glaze bottle. B) a key with an RFID sticker on the back. C) notebook is a container, and we can see it has been labeled with a sticker on the side. D) displays a parent container (the cabinet), shelves as the children's containers, which each one has their children. And also another example of RFID placed on the glaze bottle.

Three types of records can be generated and associated with an RFID tag and are uniquely represented in the user interface using structured icons (Figure 5.2:

- **GLAZE** A glaze tag is used to record the contents of a custom-mixed glaze (ingredients x amounts) as well as commercial glazes. When scanned, the system displays functional properties of a glaze (e.g., food-safe, sprayable) as well as a record of all artifacts that have been fired using that glaze (or key).
- **KEY** A key tag is used to annotate a glazed and fired artifact with its corresponding glaze application and firing conditions. A key can be associated with one or more glazes. When scanned, the system displays shows a structured diagram, or *keymap*, of the clay body and associates glaze records to different regions of the body (e.g., glaze A outside dipped, glaze B inside poured). These annotations are displayed as an ordered list since the order in which glazes were applied is important to glazing practice.

- **CONTAINER** A container tag can be placed on a physical container and be used to track the location of other tags in a space. When a container is scanned, it's contents and their relationships to one another are displayed on the system displays.

The Glaze Epoch system uses off-the-shelf RFID readers (RC522 readers ($7 USD)) retrofitted with a WIFI enabled Adafruit Feather M0 ATWINC1500 ($34 USD) to wirelessly scan RFID tags distributed throughout the ceramics workshop (Figure 5.1). Some RFID readers are worn (on the wrist or apron), while other have been integrated into key locations within a ceramics studio. When scanned, these readers send a tag's ID to a cloud-based server that coordinates data exchange across all connected devices using websockets. This server allows other connected devices to subscribe to these data streams.A custom web application (React with Ruby on Rails) listens to scan events and brings up appropriate information for each class of tag stored in a MongoDB database on the cloud server.

5.2.1 Tagging an Artifact

To create a record using the system, I aimed to minimize input interactions that could disrupt workflows. Instead, creating a record involves first scanning an unassigned tag, specifying a tag class, and associating the following information:

- **GLAZE** Glazes are pulled from the glazy.org repository [21] of user-submitted recipes or scrapped from the AMACO commercial glaze website. A user searches for a record and then can alter ingredient amounts or properties. **Commercial glazes such as AMACO brand, do not share their detailed recipe material and amount**, therefore, for those glazes the system will not display the recipe table. Glaze keys are identified by a unique shape, hue, and letter-number identifier. Glaze icon can have five different shapes, and each form can hold a color from 8 choices and a letter. The letters displayed on the glaze icon are a representation of the glaze final and finish look. For example, the letter G means gloss. Other letters are presented as follows: M for matte, SG for satin gloss, SM for satin matte, S for satin, and TM for textured matte (Figure 5.2).

- **KEY** To create a key, a user first chooses the most similar geometry from a set of common clay forms (e.g., mug, plate, vase). Each clay form has a set range of glaze annotations. For example, a vase form can have different glazes applied to the inside, outside (brim and base), and handle. When a region is selected, a user can then scan a glaze tag and specify the application technique (e.g., pour, spray, brush, etc). The respective glaze records receive this key record as a child element.
- **CONTAINER** A container name is restricted to a letter number combination. Users can then switch the container to toggle an ADD mode, which assigned any subsequent scanned artifacts to the container.

5.3 Walkthrough Interactions

This section covers some interactions extracted from real-world scenarios, such as adding a new record to the system or retrieving already existing information. Figures in this section are extracted from video demonstrations snapshots. I present three top scenarios in the following order: read key and glaze record, create new glaze record, create a new key record. Even though create a new container record and read container is not presented here, it has been implemented, and the interactions are very similar to others. To create a container it is as simple as scanning a tag and assign it to the container class. If the user wants to add an item into that container, she only needs to keep scanning the tag from things she wishes to add to the active container.

To showcase the system interaction, I used three scenarios that I extracted from the interviews. I recorded videos of these interactions for demonstration purposes, and here I present these using screenshots captured from these videos in a storyboard-type narrative.

5.3.1 Sampling from the Environment.

Figure 5.3: Sampling for Glaze Inspiration: 1-2) A user compares and contrasts existing test tiles in their ceramic studio. 3-5) She uses the RFID scanner to retrieve the information for a glossy yellow key (Key O) that has caught her eye. 6-8) From the structured key map, she sees that a yellow glaze (Glaze J) has been brushed onto the surface of the key; she pulls up more information about the glaze. 9) She locates the corresponding glaze, and 10) applies the gray glaze to her new piece, which, after firing, will transform into a glossy yellow (see Video Appendix B.1).

Scenario one is focused on presenting how users can elect their glaze through "sampling" and be able to use the already established samples as their source of selection. For example, in some ceramic studio spaces, there are hundreds of samples made by multiple users so that each person can access their samples for reference and access samples made by others. Similar to using the "social-transfer" method of election in an inactive way, since the transfer is not happening through the user, it is through their work that inspires others. Therefore, a mix of glaze election through "sampling" and "social transfer" is presented in this scenario. In this scenario, Amy uses a set of test tiles available in the studio space for her glaze election method. First, she compares the existing test tiles to her new and unglazed tile to choose the one she needs. Next, she selects one of the tiles and continues to scan the RFID tag on the tile to get access to the glaze information and the container which holds the glaze. After locating the glaze on the tile, she finds the bottle and uses the same application technique from the source tile to recreate the same look (Figure 5.3.)

5.3.2 Updating Inventory

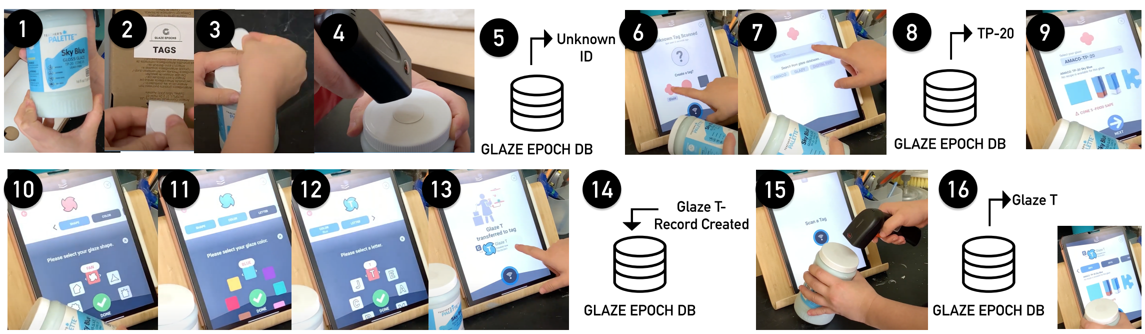


Figure 5.4: Updating inventory with newly purchased glaze: 1-4) A user is creating an entry for a newly purchased commercial glaze. She grabs an unassigned RFID tag from the dispenser and places it on the lid of the bottle. 5-8) She scans the tag and follows the prompts on the Glaze Epoch UI to assign a glaze by searching for the record from our glaze database. 9-14) She creates a unique icon for the glaze by choosing a shape, color, and a letter. 15-16) The information is stored in the database (see Video Appendix B.2).

This scenario is showcasing the system's ability to create a new entry record for a glaze. As presented in Figure 5.4 users can create a new entry in less than a minute. Here I placed the new RFID tag on the lead of the bottle, but since a ceramic studio is "messy" and a shared environment, there is always a chance that these leads get mixed and end up on another glaze bottle. These human errors are widespread, and over time users can develop their own rules to avoid such mistakes. For example, they can place a new tag on the glazed body rather than on the lead. Since the RFID stickers are very economic friendly, it provides the ability for the users to experiment and find what setup works best for their practice.

5.3.3 Creating a Complex Key Entry

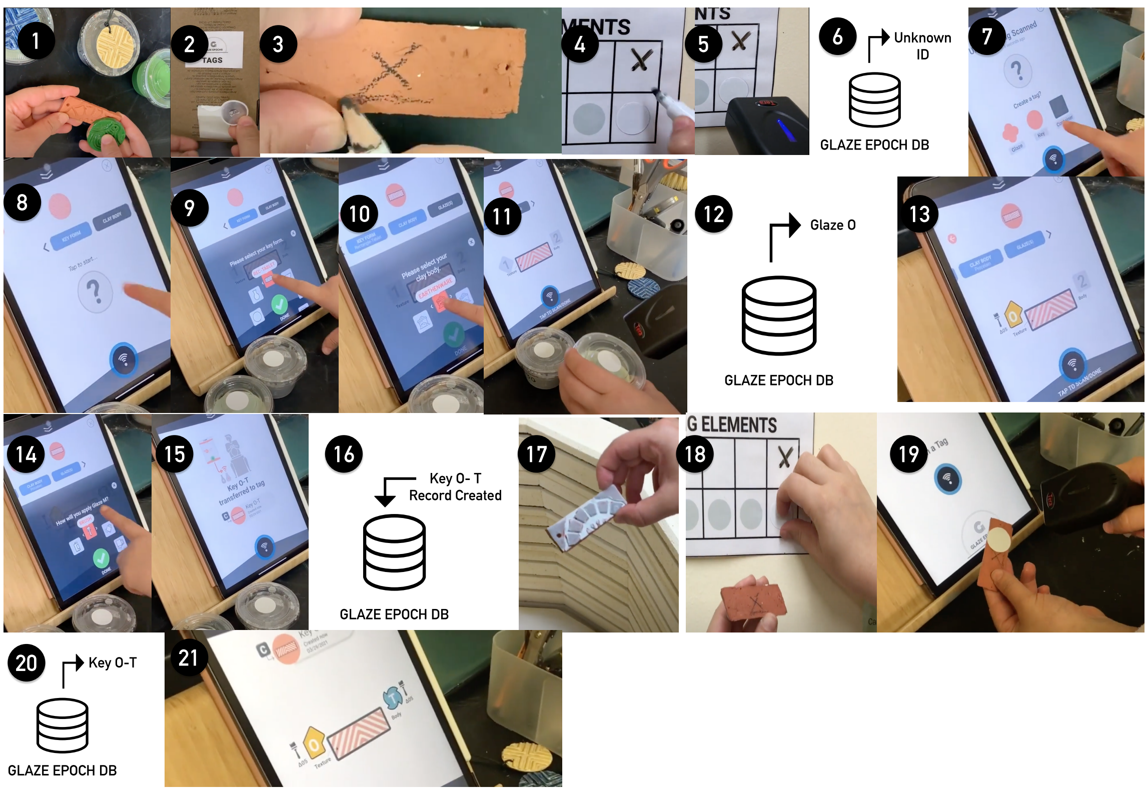


Figure 5.5: Using two mono glazed keys to create a complex key and introducing a new record: 1-6)A user chooses two separate glaze keys for her new artifact. She marks the back of the bisque fire clay key with "X" using an underglaze pencil. She places a new sticker on the "Tags of Firing Element" chart and marks the sticker with the same mark "X." She scans the new RFID sticker from the chart. 7-16) the Glaze Epoch recognizes a new unassigned ID. She selects the key option and follows the steps for choosing a shape for the key, clay body, selecting applicable regions from the keymap, and scans the corresponding glaze tags to assign to each region; she chooses the application method for each glaze and finishes the creation process. 17-21) She glazes and fires the key, then finds the corresponding RFID tag using from the wall record. She scans the tag, and the system retrieves the record (see Video Appendix B.3).

This scenario showcases the unique ability of the Glaze Epoch system to create a new key record for the system. Figure 5.5 covers the overall steps of these interactions. Since RFID tags are not fireable, when creating a new key, the user can mark the clay body with an underglaze pencil, which is safe to be fired in any cone temperature without causing issues for the kiln. Then the user can use the same mark on the wall-chart above the corresponding RFID for future connection. Creating a key using multiple glazes can be very hard to annotate on the clay body directly due to the physical constraints of the key. The keymap feature designed in the Glaze Epoch system allows artists to mark each significant region of the key with the glaze they are using. It also allows them to annotate it with essential details such as application techniques. Users can use one of the following techniques for each glaze: brush, dip, pour and spray.

5.4 Implementation

Implementation of the Glaze Epoch system consists of two sub-sections: system architecture and database Schema. All the UI components have been created in the Figma app, and I used Google Colab application, a cloud-based editor. The backend is written in Python3, and the front-end components are HTML, CSS, and PaperJS. For the database, I used MongoDB which uses JSON.

5.4.1 System Architecture

Glaze Epoch system is designed with a centralized WebSocket server which provides wireless two-way client-server communication. Figure 5.6 displays the overview of the architecture composed of a Mongo database, a Ruby on Rails web application, and RFID readers.

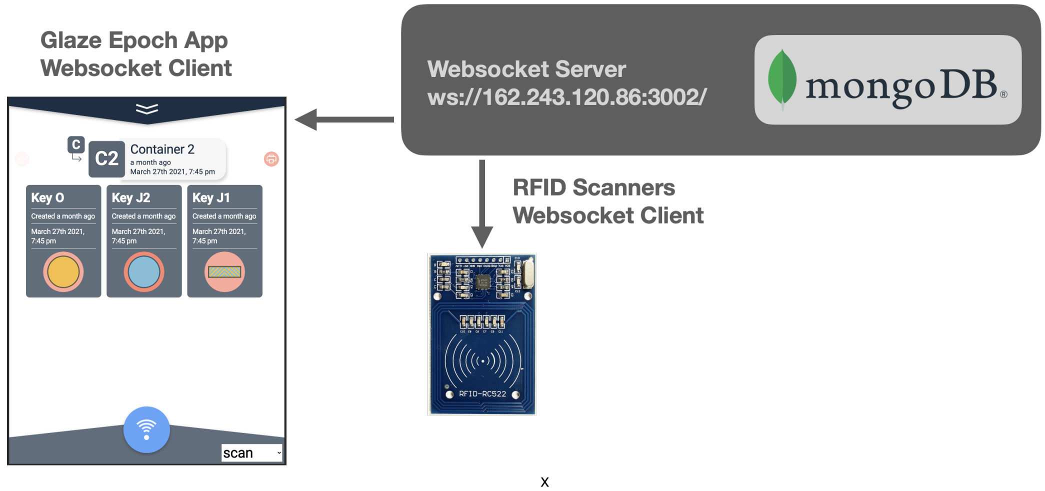


Figure 5.6: System Architecture: The architecture of the Glaze Epoch system uses a client-server central WebSocket connection. This server is connected to a MongoDB database, web app, and the RFID reader scanner.

In real-world scenarios, multiple users can scan items and access a common database. Notably, this architecture removes the limitation of having all resources saved on one person's device. While the cloud-based websocket server was used in the implementation, this server can also run on a local network with a commodity WIFI-enabled computer. For studios with large numbers of practitioners, the ability to collaborative develop and maintain glaze records is beneficial.

5.4.2 Database Schema

Figure 5.7 presents the overview of the database schema of the system and mirrors those used in graph databases. Using this sectional schema allows us to divide the class properties accordingly and be able to design unique connections through pointers within records. The Glaze Epoch schema is built on two main blocks. The top block placed on top of the screen reserves information mutual across all three classes: keys, glaze, and container. These mutual properties are extracted from the RFIDs. In the top block the app has icon of the class, name, date, etc. The larger

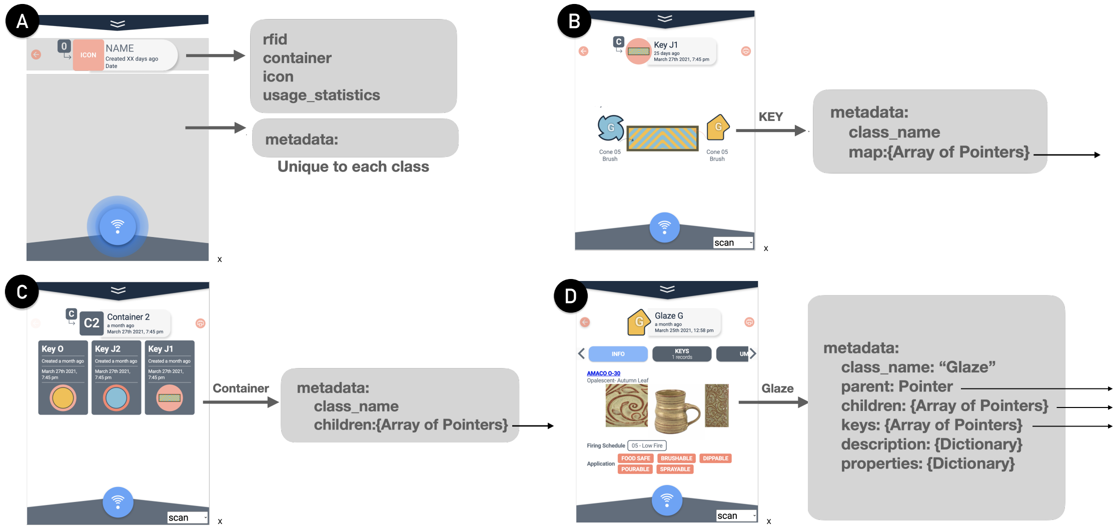


Figure 5.7: Database Schema: The Glaze Epoch web app is divided into two major blocks, A) The top block is reserved for the RFID properties, which is shared within all the record types. And the bottom and larger block holds the metadata unique to each kind of three classes: glaze, key, and container. B) Key metadata contains the class name and map, an array of pointers to link to glazes used on the key. C) Container metadata holds the class name and children, which is an array of pointers pointing to the unique ID of its children. D) Glaze metadata is structured a bit differently and holds more objects inside compare to other classes. These array of pointers and dictionaries are designed to connect the glaze to its variations, children, all the keys made with it, and its unique properties.

block design in the schema holds unique information for each class. This block gets its content from the metadata in the schema. Metadata is a dictionary which depending on the class has different objects inside. The simplest of all three classes is the container class. Which only has the class name and children. Children is designed to hold an array of pointers which each one is a unique RFID string and links the id to the actual object. A container can have all classes as its child.

The glaze metadata schema is structured a bit differently due to the complexity of this class. For example, I learned that users start experimentation on one recipe and do systematic experimentation with changing one ingredient's amount. This systematic experimentation on glaze variations can be saved and linked together through parent and children array of pointers provided in the glaze metadata.

Lastly, keys are designed to hold pointers to each key made using that glaze. And each glaze contains its unique properties, such as firing cone, finished look, food-safe, sprayable, etc.

I learned ceramicists mainly source their recipes and glazes from established sources such as glazy.org, digitalfire.com, and commercial brands. I managed to develop a Python Scrapy program to extract data from these websites and structure it to the database schema with this information. Overall it resulted in more than 3100 recipes. Some challenges in the scraping process were due to the structure of the websites and API calls. Eventually, I used scrapy selenium middleware to force the program to wait for the website to load all API calls. Also, since the schema has more unique options such as icon, RFID, properties details, matching the relevant information from the extracted JSON was a bit challenging. As I mentioned, due to the inherent messiness of these infrastructures, I was anticipating these challenges to map accurate data to its place and match it with the schema. For example, some materials were presented with different unit measurements like lbs or grams. The code used has been provided in Appendix C.

CHAPTER 6

EVALUATION

Ledo et al. [12] describes four methods of evaluation for these types of User Interface systems: demonstration, heuristics, user study, and performance. Due to the pandemic and physical meeting constraints, a user study or *in situ* system deployment was not feasible. As an open-ended design, the system itself was also susceptible to the fatal flaw fallacy [13] since many unique edge cases could cause the system to fail; the aim was not to assess the usability of the system, but instead to demonstrate the bounds of the system in capturing and maintaining tacit knowledge (evaluation by demonstration). To better address the external validity of the system, I use real-world scenarios from the contextual inquiry to motivate the value of the proposed interaction, juxtaposed against the extract system design principles. Additionally, I leverage Olsen's heuristics [13], a set of principles for evaluating UI systems, to describe the Glaze Epoch's ability to support open-ended activities.

6.1 Evaluation By Demonstration

We present four demonstrations of the system. These demonstrations are showcasing the system's compatibility with the design principles. I used my personal experience in ceramic and glazing as a student and shared information from the users to design these scenarios. I aim to demonstrate how the Glaze Epoch system, web app, and workflow use the extracted design principles. I will present areas in which the system is robust and share some current system limitations according to the developed principles.

6.1.1 RFID stickers supports flexible record tagging.

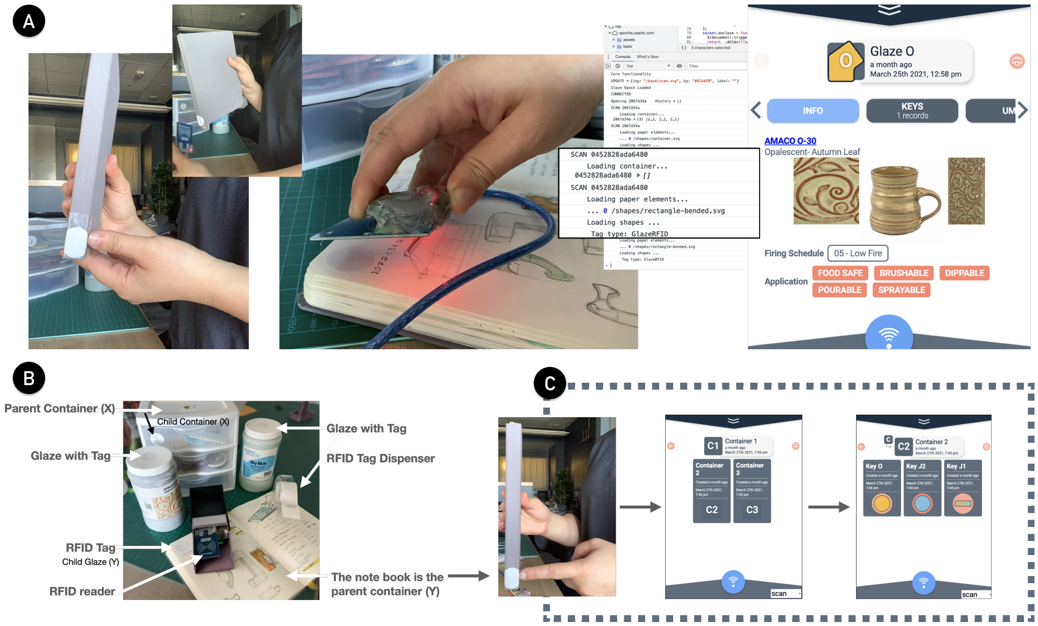


Figure 6.1: Flexible Record Tagging: A) A notebook appears as a container in the Glaze Epoch system; B) A page in the notebook, containing details of a glaze recipe is scanned, appearing as a glaze record; C) a plastic storage container is marked as a parent container; individual shelves are child containers. Scanning a shelf reveals the key records stored within on the Glaze Epoch app.

Ruth, one of the interview informants, keeps a recipe box and folders of recipe index cards that contain recipes as old as 30 years. She makes her batches for her production and teaching classes from these recipes. Any surprises and changes in the glaze get updated on the back of the recipe card for future references. She makes many of her most used glazes and places them in 5-10 gallon buckets all around her studio. She also teaches classes, and more often, she has to ask her students to find these index cards from the box or scattered in different folders and locations.

The Glaze Epoch system accepts any comfortable method of the physical container as a valid container. So Ruth can label the recipe folder and her recipe box as containers and allow each page of the recipe to enter the glaze. Through this mechanism, her students can almost immediately find the intended recipe and locate the physical bucket which holds the already made glaze in it.

This demonstration aims to present how the web app interaction and flow follow design principle number One. Figure 6.1 displays an overview of this demonstration.

A notebook has an RFID sticker on it which is presented as a container in the system. Inside the notebook, pages also have their unique stickers. The user can scan one RFID and access the data through the web app. Moreover, the web app structure is a linked structure. Therefore, with one scan, the user can access many items and elements in the system and retrieving the location (container) which holds it. Additionally, if the network is causing some connection problems or the internet is down, since the physical record of the glaze exists in the studio, it does not provide extraction and disruption to users' workflow.

6.1.2 Improving the memorability of records

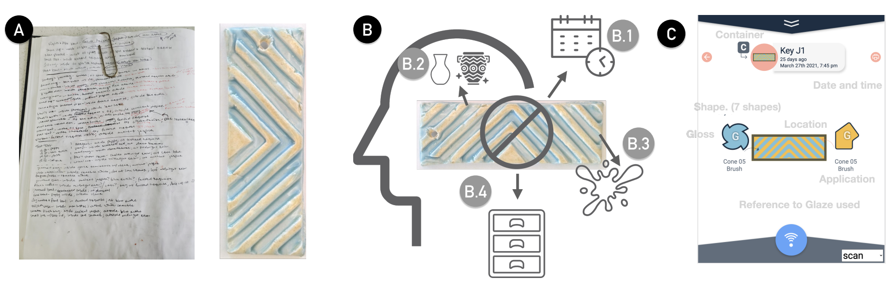


Figure 6.2: Searching Using Associate Cues: A) On the left: a written description of a glazed ceramic tile; on the right: a picture of the glazed ceramic tile. B) Illustration of some of the ways that users can remember a specific item. B-1: Based on the time and date of creation, B-2: Through the most memorable piece which they made with the item, B-3: Based on some out of the ordinary event, like a substantial accidental drop of glaze from the brush, B-4: User doesn't remember the item, but remembers the location of it. C) The Glaze Epoch web app screenshot from a key page labeled with cues that were the inspiration of the design.

Amy wants to access an artifact which she made months ago. Since then, she has created many more pieces, and it is hard for her to find the artifact. However, she only remembers an estimated time and date of her creation and the storage she was using to store that season's work.

With this information, Amy can go to the storage that she thinks she placed the item and use the RFID reader to scan the tag placed on the storage. The system will display all the children inside the storage space, and with having an estimate of the date of creation, she can scroll to find the artifacts she wants.

In this demonstration, the focus is to present how the web app uses principle number two, which is search by memory versus keyword. First, I reviewed the interview conversation with the users. I noticed most of them rely on their memory as their primary storage structure since they obtain many years of experience in the domain and possibly lack physical storage space. Then, as presented in the Figure 6.2, I describe an artifact that can be difficult to scan and find detailed data from it. Next to it, I illustrate ways that one person might remember an item from their memory. I used this information to design a representation of the keys which values cues connected to the memory more than a written description. To achieve this, I display the location of that item, time and date, each glaze with the cone and application method, and different regions of the glaze on the key. These visual and memory base annotations are driven from the leanings through the contextual inquiry.

6.1.3 Extending studio documentation

Advance users interested in glaze chemistry mostly build on top of their findings or get inspired by other artists' conclusions and research. In a university ceramic studio, some students are interested in experimenting on certain glazes and advancing their knowledge in the domain. However, with many enrolled students and only one

Figure 6.3: Sharing process over time: A) Sara is a student in a glaze class in the Fall semester; she is very interested in a unique glaze and continues to do extensive experimentation on glaze chemistry. She keeps a rigorous record of her experiments. She adds her findings into the system by labeling the notebook with an RFID and assign it as a container. The notebook holds pages of information that have unique stickers. She finishes the semester, graduates, and leaves the university. B) John joins the same class a semester after and finds himself interested in the same glaze; he gets access to Sara's notebook. Through that, he manages to continue her research and contributes to the finding rather than starting from the beginning.

or two studio managers, it is almost impossible to maintain the process and document all the experiences conducted by students. Therefore, each semester, the new group of students mostly go through the same path as the ones before them and, due to time limitations, won't be able to have their own noble discovery. The Glaze Epoch system allows each student to individually record and update their process in the system without the manager's need. Other students can then access these individual records by scanning the artifact or the notes that remained from past students. This way, members can pass their knowledge to others without the time constraint, and others can use the experience of previous educators and discover their novel glazes.

Supporting sharing within a community is not limited to literary sharing glazes or artifacts. It can also refer to the ability to share knowledge without any constraints of time and even location (if a cloud server is holding the data versus a local server). For example, Figure 6.3 illustrates the timeless sharing scenario between two students from different semesters. Through the system, users can contribute and use each other's knowledge over the years and keep building on others' work. They can also discover many different possible solutions for their work.

6.1.4 System adapts to the problem size

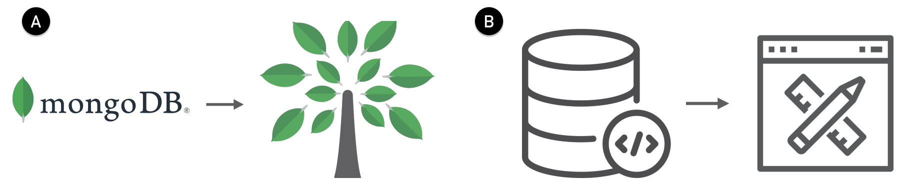


Figure 6.4: Flexible Structure: A) The MongoDB database logo, a conceptual transition from a leaf to a tree representing growth in data size. B) Illustration of the database on the left will be displayed on the web app screen shown with an arrow transition to a web app icon.

Creative practices are very flexible and inherently open-ended. For systems to survive and be functional in these spaces, it is essential to support such flexibility. I used a flexible and non-relational database to be able to keep up with these changes. Consider the following scenario: Jackson, one of the masters we interviews, runs a studio with glaze chemistry and experimentation on glaze recipes. His studio fires hundreds of keys weekly which are often slight variations from one parent recipe.

The glaze schema in the Glaze Epoch system was specifically designed to support these types of chained, systematic experimentations. A parent glaze entry keeps track of these children variations through an array of pointers. This schema supports tracking process of multiple experiments that may arise from different glaze variants over time. Therefore, Jackson can maintain an up-to-date the process of his experiments.

MongoDB gives the flexibility that I need to store and maintain this information; however, maintaining the schema of the database and its presentation on the user-facing web app interface requires significant time and effort, especially in situations where users need to input and update information (Figure 6.4).

6.2 Olsen Heuristics Evaluation

Heuristic evaluation provides external validation of the system and how it would function in the real world. Even though the ideal situation is to conduct a user study to test the system, Olsen argues it won't be beneficial if the system is not fully functional. Therefore, he presents series of guidelines for researchers to evaluate effectiveness of their system when user study is not possible. I will present each guideline and compare the Glaze Epoch system's strength and limitations for each one.

6.2.1 Importance

Olsen defines importance as a necessity for any system. The system needs to demonstrate why it is "important." The importance of a system depends on who are the users (U)? What is the task that users need to achieve by using the system (T)? And what is the end situation? How often do users find themselves in that situation?

I present the Glaze Epoch system as a tool for ceramicists (U) to assist them in their glaze selection, documentation, and communication of their knowledge with other artists (T) using a tangible database and interactive web app. The ceramicist population can be divided into multiple groups. A high-level clustering of these groups can be divided into artists who are more active on the production side who also sell their work. Plus, educators and artists engaged in the artistic/ conceptual aspect. However, most artists are not only active in one category, such as Ruth. She teaches students as well as keeping her store and production business. She identifies herself mainly as a production potter. She uses recipes extensively and makes her glazes. Therefore she holds a record of her variations and materials. Her studio space is divided into pottery and the other for the glazing section (S). She also produces various artifacts. Therefore she uses different keys and glazes for each category. This information needs to be transferred to her students, and she expresses how there is no tool existing to enable her with this communication. Glaze Epoch system supports customized documentation and entries unique to each artist and studio space. By introducing the ability to assign containers and locations, studio spaces such as Ruth's can benefit from this personalized documentation and ease of maintenance.

6.2.2 Problem Not Previously Solved

There are currently existing websites, blogs, digital and local communities, which are active, and members share their findings, recipes, and glazes. I identify one application that would assist potters with calculating their glaze recipe and do cost calculation for the artists depending on the size of the batch. But I did not find any tool/ system which can provide services as Glaze Epoch. The design method and toolkit are derived from a detailed interview session with six masters. These masters share more than a century of experience, and their knowledge can be the guideline for novices in the field. I have gathered data that was analyzed carefully to extract a focused material mental model. The result MMM opened the ability to extract four important and necessary design principles to be practiced by researchers. I used these principles to design the Glaze Epoch system, and all interactions are derived from real-world scenarios. Some limitation for the system is not supporting material calculation and other advance glaze analytics. Unfortunately, this limitation will force the users to still rely on using applications focused on glaze calculation.

6.2.3 Generality

Olsen defines this guideline as to the system's claim to support several users (U) who have diverse tasks (T) without a currently effective solution. So based on this claim, if the system can support all the populations to achieve their tasks, it can then meet this guideline. The Glaze Epoch system is focused on the ceramic domain, in the core of it, the glazing stage of the craft. However, even though the web app and schema have been designed to support this craft, I believe it can be changed to support any other domains that share characteristics such as being messy, follows the master-apprentice model, and is hard to maintain. For example, electronics shares these characteristics. So with using the MMM and the presented principle, the web app can be designed to meet the needs of the population. Also, since the system uses RFID stickers for its structure, there is no difference if the RFID is placed on a container that holds ceramic pieces or electronic components. However, it requires time to study other domains well enough to make sure they share these characteristics. Also, researchers need to design their schema to meet their users' needs and necessary changes to the web app. Therefore, even though the MMM, principles, and Glaze Epoch system can be adapted to be used in other domains, it is not an instant change, and researchers still need to do some work to adjust it for that specific domain of practice.

6.2.4 Reduce Solution Viscosity

Refers to the amount of effort needed to go through iterations. Olsen suggests a way to reduce solution viscosity by demonstrating flexibility, expressive match, and expressive leverage.

Flexibility Olsen defines the flexibility of a UI tool as it's the ability to change rapidly and be evaluated by users. This design toolkit is flexible in its data schema and storage. Since I am storing tacit knowledge into the database, it's vital to choose a tool that supports these "messy" clusters and information. MongoDB supports these types of data since it does not require designing a relational database schema like SQL. Transferring these updates and maintaining them requires modifying the code on the front-end side. Thus, the need for development can be one limitation of the system when scaling to the actual problem size.

Expressive Leverage The number of choices to accomplish a task is the primary concern for this guideline. Olsen refers to expressive leverage as a way to accomplish more by expressing less. One way to achieve this leverage is through the elimination of repetitive choices. The Glaze Epoch system values a one-finger interaction with the application versus using a traditional mouse and keyboard interaction. Users can create entries and records of the glaze, containers, and keys by a simple scan followed by few screens supporting one-finger interaction. The system provides a limited option (8 options maximum) in each screen so users can make decisions faster and move to the next screen. These limited options can provide shorter interaction time and might take some time to get familiarized with the visual language.

Expressive Match Olsen refers to how close the means of expressing design choices are to the problems being solved. The example presented by Olsen is the difference between a reference to color through its hexical value versus a color picker tool (which shows the actual visual of the color). The color picker is more accurate than the real problem (finding/ choosing color) compared to using some lexical value of the same color. The Glaze Epoch system satisfies this guideline best in the keymap screen. Figure 7.1 displays a photograph from one of Seneca's works which are presented as a key. On the right, we see the exact representation of that key in the keymap structure. Users can choose regions for each glaze through the keymap representation and display detailed and essential glazing properties, such as application technique. Taking a picture can disrupt the workflow as well as lack of annotation, which I will cover more deeply in the discussion chapter. However, the system currently does not support unique techniques such as masking, which Seneca used to create these bowls.

6.2.5 Empowering New Design Participants

This guideline is about how the toolkit can enable new participants and encourage them to participate in the design process. Participatory design is to involves the end-user in the design process. The Glaze Epoch design method aims to gather tacit knowledge from users and communicate the learning outside the master-apprentice isolated relationship. Since the data is coming from tacit experience, the toolkit is very driven and designed to the user's specific needs. This claim will be most supported after a user study is conducted further to evaluate the system. I used real-world scenarios to design the system. But still, there is much room left for each space to develop its own culture and methods on how this system can best serve them. Various usage of the system will include designers to be participants in the system. However, developing a working function within the community can be time-consuming and requires a learning curve for members to be familiarized with the visual language used in the system to optimize their use of it.

6.2.6 Power In Combination

Refers to displaying the effectiveness of the system by supporting a combination of building blocks.

Inductive Combination The Glaze Epoch system supports inductive combination by allowing users to retrieve information from any tagged artifacts in the environment. It will enable them to select their wanted elements and match them with others. For example, the user can choose the glazed look from scanning a key and retrieving the blue glaze and scanning another key to learn which glaze provides the texture, and through this inductive combination, be able to make the glaze she wishes to. However, the system at the current stage does not notify users if the glazes are not comparable and the required cone temperature is different.

Simplifying Interconnection Using RFID tags provides link base access from one scan to many other components. For example, once the user scans the tag on a container, she can continue exploring through all the children of the container; she can go through keys and use the linked keymap to explore multiple glazes and all the keys made with that glaze.

Ease of Combination The Glaze Epoch system supports ease of combination best in the container class. Containers can be combined from notebooks to cabinets, shelves, and buckets. However, the current stage of the system does not support merging containers, but it does link all to the parent container. A notebook can be parent containers, and chapters can be child containers, and each chapter can hold pages as their children and so on. The key class supports this guideline by allowing many glazes to be combined and used on a key. Even though each glaze's cone temperature, finished look, color and application method can be combined with the keymap. It does not support advanced details such as layering and overlapping of multiple glazes together. Key interaction also provides many combinations of shapes that users can use.

For glaze records, the system supports experimental variations of one recipe by providing the ability to select one glaze as a parent and others versions as children which can stand on their own. But the system does not support mixing two different glazes in the current stage.

6.2.7 Can It Scale Up?

Lastly, it is crucial to compare the designed UI to the actual problem size rather than the sample size, as Olsen describes. The glaze database is extensive since it is an experimental field, and like chemistry, many combinations can create a glaze. These materials are kept inside buckets, bottles, and cabinets which can be hectic for new users to find what they need due to the messy environment. Some users like Edison does not keep their glaze keys due to lack of storage space, but some, like Jackson, holds thousands of keys in their workshop. Finding a glaze recipe or an artifact through all these containers is very chaotic, even for the lab manager. This is most problematic if the primary storage to hold this information is memory versus a sustainable database. We used MongoDB as the primary database structure, enabling the system to quickly scale up and down easily and satisfy users' needs. In addition to scaling, the system's architecture is based on a centralized WebSocket that connects to the web app, RFID reader, and database. This structure removes the constraint of how many users can access the system at the same time. Even though I can keep the database updated with the current status of the studio, it does requires the user to manually input some data to the system.

6.3 Discussion

To evaluate the Glaze Epoch system, I used two methods: evaluation by demonstration [12] and evaluation by heuristics [13]. Evaluation by demonstration is done to avoid The fatal flaw fallacy and not fall into the user trap, as explained by Olsen. However, to externalize the assessment, I continued evaluating the system to Olsen's guidelines. This provides external validity and some perspective on how the system would function if implemented into these spaces. However, the user study is still needed to ensure and guarantee the system functionality and do necessary iteration through user feedback. To do this study, I faced some challenges such as time and resources to finish full development. The current stage of the system does not some actions, such as redo, undoing entry records, or deleting an artifact from a specific container, etc. These limitations will cause the user study to fail since users can experience these flaws and not focus on anything else. Therefore, I will hold system evaluation through user study to make sure the system is fully functional with features that allow users to make mistakes, recover from their mistakes, and freely explore the system.

6.3.1 Referencing glaze data records

The Glaze Epoch system benefits from three significant decisions for successfully storing data. First, using RFIDs to get a unique ID for each record, a WebSocket connection to provide two-way communication with the system, and using a non-relational database such as MongoDB to update and maintain information as flexible as needed. Also, this DB allows us to scale the data to match an actual world size problem, for example, using Python Scrapy Spiders to automatically scrape glaze information from sources like glazy.org, which contains more than 3,000 glaze recipes to the system. I discussed some benefits of these decisions; however, it is essential to cover its limitations. Using RFID stickers is economically friendly. These stickers are flexible and bendable. They also survive in water-based craft spaces such as ceramic studios due to their water-resistant abilities. However, one vivid limitation of these stickers is the lack of adhesiveness when applied to rougher and textured surfaces. Even though this limits the artifacts comparable to be labeled with these stickers, they attach well to paper and smooth surfaces. Since paper records are the most common documentation method, the system can still function and be valid.

6.3.2 Feasibility of system

I will provide a summary of all the components needed to start interacting and using the Glaze Epoch system and create alternatives for components if it is not feasible for users to make their own, such as the RFID reader. To use the Glaze Epoch system user needs to have internet access for WebSocket connections. The data can be stored either on a cloud-based server or any local computer with valid memory placed in the space. The centralized access to the data is essential to support large number of users at the same time. To start adding entries to the system user need to have RFID stickers and RFID readers.

Most studio spaces are equipped with an internet connection, and I do assume users have access to one computer in these spaces. We decided to build the app as a web app to remove access constraints, and all users with a functional digital device can load the app with an internet connection. RFID readers can be purchased from online stores, or users can take it as a group DIY project and build it themselves. The code needed to be run on this device is open-sourced and can be accessed online. RFID stickers are best to be purchased online, and users can buy as many as they need. These are all elements required for users to start the Glaze Epoch application and use it for their space.

CHAPTER 7

DISCUSSION

7.0.1 Integrating technology into real environments

While access to craft practices are held as one of the strengths within interaction design, ceramics acts as a counterexample. The cost to engage in ceramics requires both space and specialized equipment, akin to the requirements we see in makerspaces and scientific laboratories. However, unlike these spaces, the messiness of clay make computing technologies and user interfaces inhospitable.

> **Jackson** We run a fairly technologically advance studio space but the dust is continuously a problem. We have monitors and mice in hidden work station around there and we have equipment that uses computers but the dust is the real issue ...

For ceramicists, computers in the pottery studio were so different in nature from the material they work, however adding technology into those spaces were not foreign endeavors, but also incompatible with physical workflows.

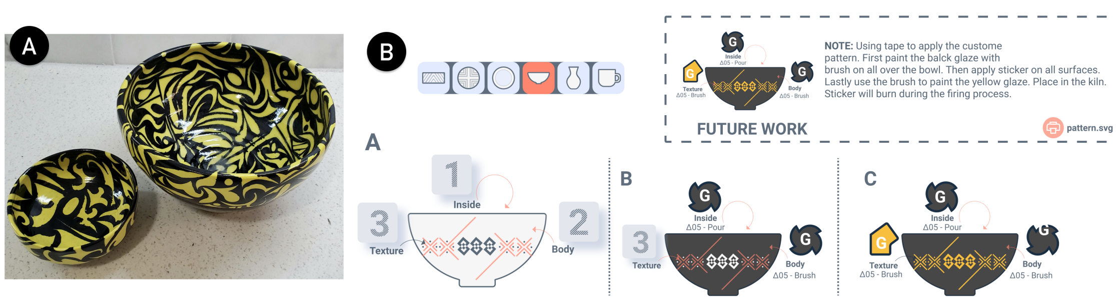


Figure 7.1: Keymap Representation of A Ceramic Bowl: A) An image from one of the bowls made in Seneca's home studio, she uses a masking technique to create these customized patterns on her pieces. B) Displays the Glaze Epoch representation of an annotated bowl, similar to the image on the left.

Jackson Our assistants have a hard time tracking what they have done on the monitor. We decided to stick with paper because you literally just cross off and know what was completed

Wearable technologies has been proposed as a solution for bringing technologies into "harsh environments" in outdoor field studies [55]. We see similar opportunities for wearable systems that can integrate within a ceramic studio spaces and support externalizing material mental models. As a data rich practice, we see databases and other forms of information repositories to be useful for tracking provenance when happy accident occur, uncovering relationships in systematic experimentation, or supporting sampling by democratizing access to information. Unlike traditional database use cases, the material model resists being encoded into a static schema - for instance, glazes can be applied in a variety of different ways, in different orders, at different temperatures that is often unstructured and open-ended. Maintaining a glaze database that is useful for seeding creative exploration requires the ability to fluidly add and update records in a physical environment. We see value in wireless technologies like RFID and NFC that build on contextual and proxemic interactions to fluidly integrate into a practitioner's natural workflow.

7.0.2 Keymap versus photo representation

Figure 7.1 displays a comparison between a photo and the keymap representation of a ceramic artifact. One of the dominant methods of documentation is photos and pictures. However, even though a photograph can provide a realistic representation of the artifact, it is also time-consuming, not easy or fast to add detailed annotations, lightening can cause issues to capture the true color of the glaze, no link access to used glazes, and the process of taking the photo, editing, uploading, can be very time consuming and disrupt the workflow. Therefore, the Glaze Epoch system uses a keymap representation of ceramic artifacts to provide an easy and fast decision by clustering the items into similar groups such as plates, patter tablets, vases, mugs, and bowls. The keymap method also provides the ability for users to select regions and tag each one with its linked glazed and display details of the process. An example of these details is cone comparability of the glazes with clay body and application method. As we can see in figure 7.1 future work block, I aim to provide a section for users to input personalized notes and descriptions and any extra files needed to remake the piece. In this example, Seneca can also upload an SVG or other formats of her pattern if she wishes to, so others can download and recreate the same artifacts.

7.1 Future Work

I evaluated the Glaze Epoch system through demonstration and heuristics. Although our evaluation used real-world scenarios derived from empirical data from our contextual inquiry, a formal user study could provide external validity to our approach. Like many UI systems of this size and complexity, significant iteration is needed to avoid the fatal flaw fallacy [13]. I aim to deploy the Glaze Epoch within a ceramic studio, in order to obtain more insights into user challenges and activities over time. Since ceramics is not an instantaneous process, instead requiring several days to complete, evaluating such systems requires longitudinal study.

In order to reduce the time needed to input a record into our database, I omitted capturing more fine-grain annotations. These types of annotations are especially important as most kinds of tacit knowledge exist in this form; for example, annotating that a glaze was "brushed on thick", or the time between coats, can significantly change the brushing technique and final effect. One way to support these types of details from the maker is to have some open-ended comments section. However, adding text input can increase interaction time, and using too many icons can confuse users while inputting these details. One approach may be to extend the tangible user interfaces available in the studio environment; for example, a tangible user interface could be customized to record video or audio snippets to more completely describe the activities being encoded within a record.

I discussed the benefits of using structured illustrations of ceramic pieces versus more realistic photograph-based representations. Such photographs more faithfully reproduce the item being recorded, the act of capturing and post-processing this data is more time-consuming and lack annotations, preventing structured encoding useful for data science and data mining techniques. I used structured illustrations to improve memorability or records as well as provide useful methods of querying and clustering glaze applications and mixtures. Such data could be beneficial to existing work with generative adversarial networks (GAN) [56] that leverages similar data to present underexplored areas in glazing practices that present exciting new horizongs for human-AI creativity.

Since the Glaze Epoch system is based on an Internet of Things architecture, it could be used by multiple studio sites, including private, educational, and commercial studios to grow a shared repository of glazing knowledge. Systematic methods of visualizing and mapping the glazing space is already an active practice with online glaze recipe repositories [21]. Visualization techniques such as the Unity Molecular Formula (UMF) allow users to plot glaze chemistries along a 2D space and is useful for predicting glaze behavior more accurately. Using existing repositories of glaze recipe data, the Glaze Epoch's records could be further augmented to provide support for UMF mapping. By using a non-relational database such as MongoDB, the Glaze Epoch is more flexible in supporting these shifts in data collection and schema structure.

CHAPTER 8

CONCLUSION

In this paper, I motivated the need for material-centric interaction design to consider relationships with materials that occur over years of practice. I framed this problem through the lens of cognitive science as identifying a skilled practitioner's *material mental model*. Unlike a traditional mental model, this kind of deep mental model is more complex and highly dependent on tacit knowledge. First, I described a rapid ethnography method used to synthesize a material mental model of glazing. Then, through virtual studio visits of six master ceramicists with a combined 163 years of experience, I leveraged contextual inquiry to understand the tacit practices involved in making, documenting, and tracking the behaviors of glazes from kiln firing and how this knowledge is shared with others. Finally, I presented our findings through a framework that identifies a material model specific to ceramic glazing but describes the practice of expanding and refining that model that is generalizable across material practices. Using the material mental model framework, I developed four primary design principles to be followed by researchers and designers interested in this field. These principles capture the essential qualities that a system and tool need to be functional in these creative practices. From there, I introduced the Glaze Epoch system, which contains an interactive web app, and a WebSocket communication with the environment through tangible objects as data entries. The Glaze Epoch system has three major classes as data entry which are: keys, glazes, and containers. And these classes can communicate information through RFID stickers which also requires an RFID reader to scan the tags and send the unique ID to the MongoDB. Then I used two common evaluation methods for User Interface systems in the HCI community to evaluate the system. I used demonstration method [12] and heuristic guidelines by [13]. Through the evaluation, I discussed the strengths and limitations of the Glaze Epoch system. Finally, I presented my plan for this work and some possible solutions to the system's limitations and overall improvements.

APPENDIX A

Contextual Interview Guide

The contextual inquiry involved virtual and on-site visits to an informant's ceramic studio. For virtual visits, we used the Zoom platform and asked informants to use a a video-chat capable smartphone with a front and rear-facing camera.

Procedure Participants are asked questions related to their creative process. Participants were asked to show and walk us through their techniques for documentation, organizing, discovery, and using tools, materials, and glazes. We observed their process while taking notes and recording the session. Interviewers probed on the following points for major events during the session:

- **Process** – Imagine if you have a piece. How would you choose what technique, material, tool to use?
- **Documentation** – How do you document your discoveries? When do you revisit this information?
- **Failure and success** – Tell us about your mistakes and the learning process. How do you avoid them in your future work? What happens if your process fails or you get an unexpected result?
- **Constraints and limitations** – What are your constraints and limitations throughout the steps of retrieving, documenting, organizing, and learning from your work? How do you think these limitations can be lifted?

Documentation To document the session, we used the screen-capture of the Zoom video to generate a transcription of spoken audio; we also used the video to screenshot instances where the informant presented an artifact or showed a process. Any identifying information was destroyed 3 months after the study concluded.

Followup Procedures We reached out to informants via email to clarify any ambiguities in the video or to request higher resolution photographs of key artifacts.

APPENDIX B

Video Resources

Figure B.1: Choosing an existing glaze sample

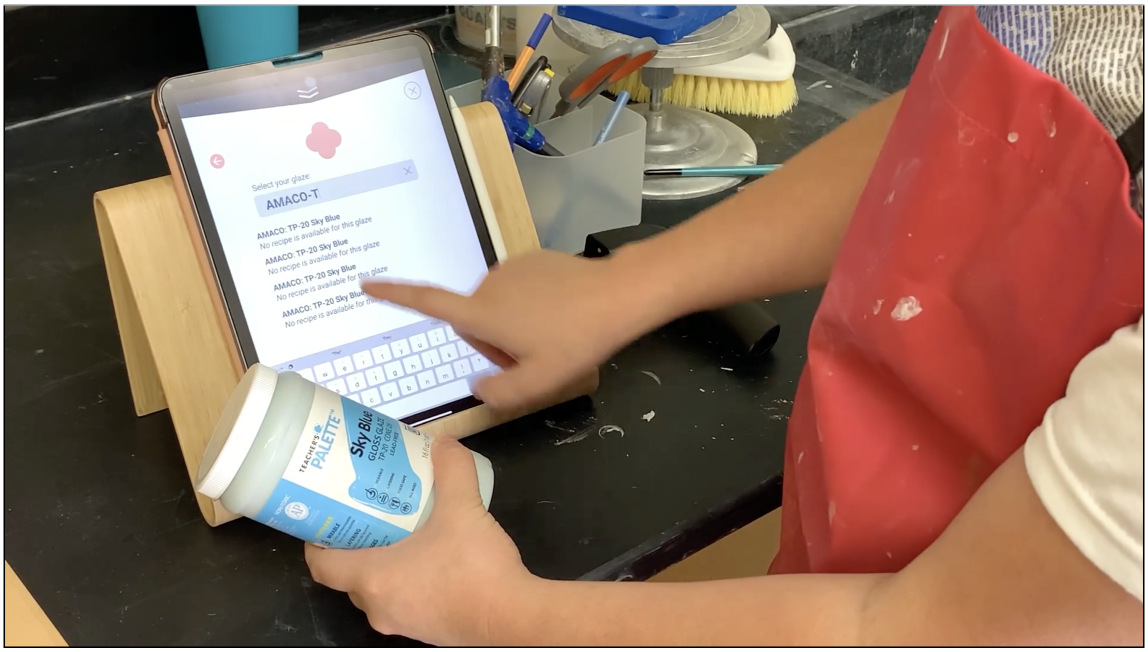


Figure B.2: Updating inventory with newly purchased glaze

Figure B.3: Using two mono-glazed keys to create a complex key

APPENDIX C

Code Repositories

The **Glaze Epoch** web application and server code is available through Github:

https://github.com/The-Hybrid-Atelier/glaze-epochs

The **scraper** program used to retrieve records from digitalfire.com and glazy.org websites and JSON conversion programs are available through Github:

https://github.com/The-Hybrid-Atelier/scraper

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BIOGRAPHICAL STATEMENT

Hedieh Moradi was born in Tehran, Iran, in 1991. She received her B.S. degree from The Azad University (Central Branch), Tehran, in 2014. She also graduated with her Master of Fine Arts (MFA) degree in Visual Communication from The University of Texas at Arlington in May 2019. She started her M.S degree in Computer Science in the Summer of 2019. During her MFA, her research was focused on using design to improve the quality of life for others. She received The McDowell travel award to go to Iran and work with one of the pioneer design institutions in Tehran to improve their design curriculum. She also received Lone Star scholarships during her M.S. for her outstanding academic records. Her current research is focused on using tangible databases in creative studio spaces.