TuneCatalogs: Capturing the Goldilocks Zone by Framing Opportunistic Tuning Practices

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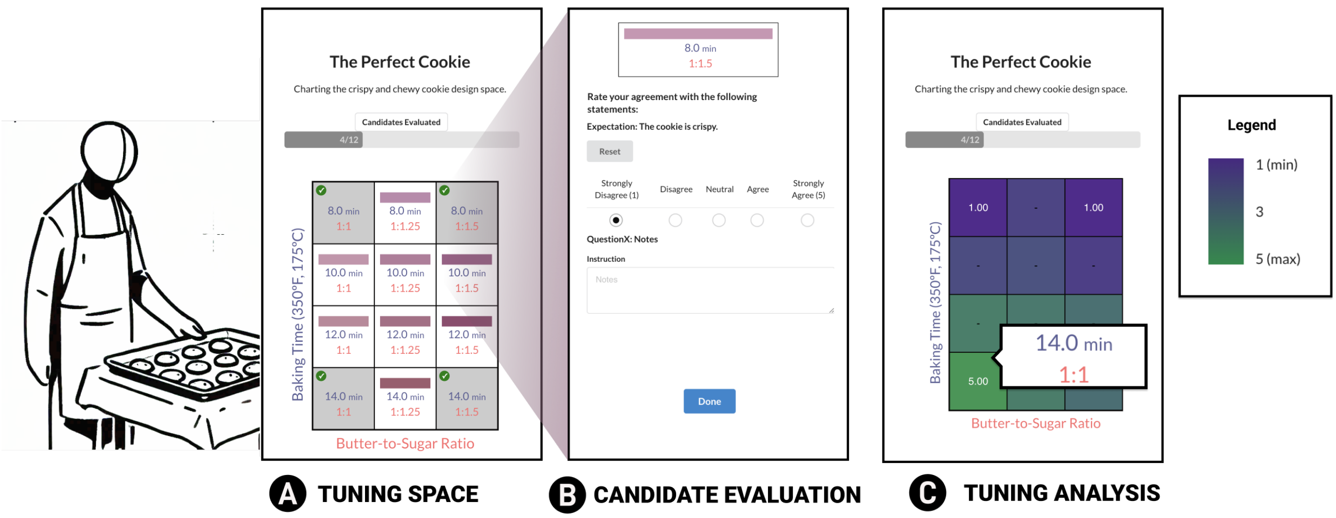

Figure 1: The TuneCatalog Workflow. Most experiments require tuning parameters. For example, baking a crispy or chewy cookie involves adjusting the butter-to-sugar ratio and baking time. A) TuneSpace defines all possible experiments (TuneCandidates) within a parameter range; B) Each TuneCandidate is evaluated to see if it meets the set criteria and captures other design observations; C) The developed catalog presents the evaluated TuneCandidates as a heatmap, helping users select the best option and effectively communicate experimental or design parameters.

Abstract

An often overlooked aspect of making is the art of achieving the perfect fit, property, setting, or aesthetic. Tuning is a common practice, but many in-the-moment adjustments are internalized and rarely documented, resulting in wasted materials, time, and effort. In many cases, only the ideal outcome is recorded, leaving the boundaries of the "Goldilocks Zone" undefined and elusive. To address this, we examined different tuning practices across making communities and developed a tuning documentation tool that enables users to author standardized tuning experiments, log and evaluate different candidates over time, and synthesize insights about the tuning space. An applied tuning study with 10 participants and a two-week diary study with 5 participants reveal that cataloging tuning experiments enhance the literacy of tool and material capabilities and aid in sharing and addressing tuning needs. We discuss how formalizing tuning practices can reciprocally support exploratory practices and foster different tuning workflows.

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CCS Concepts

• **Applied computing → Computer-aided manufacturing**; • **Human-centered computing → Interactive systems and tools**; *Interaction paradigms*.

Keywords

Documentation, Evaluation Tool, Tuning, Shared Experimentation

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1 Introduction

Tuning, the process of adjusting and optimizing the performance of processes, materials, or activities, is essential in many fields, particularly within making communities. Both novice and experienced makers frequently engage in physical tuning to align their work with design intentions [22]. However, this process is often complicated by constraints related to the human, tools, and materials, such as the inconsistency of the hand, the unanticipated kerf (width) of a blade, or the unpredictable behavior of materials. These factors require makers to iteratively adjust multiple parameters to achieve the desired functionality or aesthetic.

The increasing use of tangible materials, including physical and biomaterials, has elevated the importance of tuning in Human-Computer Interaction (HCI) [20]. In response, interfaces specifically designed for interacting with these materials are being developed [39]. Despite advancements in tuning practices, particularly in areas such as 3D printing, the process continues to rely heavily on trial-and-error [49]. Individuals often adjust parameters and iterate through multiple versions until an optimal solution is reached. While successful outcomes are documented, data from unsuccessful attempts is rarely recorded, resulting in the loss of valuable insights. This leads to a persistent "Goldilocks problem," where finding the 'just right' solution among numerous prototypes is not only frustrating and time-consuming, but also prone to being forgotten and hindered by the high activation energy required to document tuning experiments effectively [29]. In contrast to experimental documentation or characterization that relies heavily on isolating and systematically evaluating numerous variables under controlled conditions, tuning occurs after higher-level design decisions have been resolved. In these stages, the focus shifts to refining a select few parameters, often guided by real-time feedback and opportunistic decision-making. The activation energy, or the initial motivation and effort needed to begin using a tool, makes open-ended spreadsheets and other digital documentation tools impractical for spur-of-the-moment tuning situations. As a result, tuning efforts are rarely formally documented and are instead captured informally through methods like handwritten notes or temporary annotations, underscoring the need for more effective and systematic documentation tools.

Therefore, our work aims to conceptualize and standardize the documentation of diverse tuning situations into a common, usable format that can generalize, record, and share both virtual and physical tuning processes. In this work, we propose a documentation framework informed by best practices from design practice, experimental design, engineering optimization, design methodologies, and material processing. In developing this framework, we recognize the need to support various types of tuning across different contexts, especially in the maker community. To gain deeper insights into how users interact with this framework in real-world settings and to inspire further refinements, we created a tool to operationalize our framework and used it as a design probe to study user behaviors in natural environments and inform design opportunities for supporting tuning workflows. This paper contributes:

- A documentation tool, TuneCatalogs, implemented as a mobile interface that provides a guided and structured approach to documenting tuning experiments through the stages of experimentation, evaluation, and review. While such experiments may involve numerous variables, TuneCatalogs purposefully limits the tuning space to two dimensions to ensure results remain interpretable and accessible, consistent with design practices that often rely on two-dimensional morphological matrices [6] or continuous design maps [17]. The tool instead prioritizes facilitating the exploration of users' tuning decisions and documenting rich annotations that preserve the contextual and exploratory nature of design processes. By logging user interaction data, the tool is used to identify usage patterns and design implications to further refine our framework.
- A user study with 10 participants was conducted to investigate one of the most common fabrication tuning processes – tuning a *mortise-and-tenon joint*. The study examined how users evaluated samples from a large set of prototypes, identified preferred methods for documenting tuning outcomes, and explored how users document and share their tuning process when managing numerous variables. These findings contribute to a deeper understanding of tuning as a concept and its practical applications.
- A 2-week diary study with 5 participants investigated how users interacted with the TuneCatalogs tool during real-world tuning workflows. This study explored unexpected behaviors, usage patterns, and potential challenges associated with documenting tuning processes. Activity logs captured the frequency and stages of tool use, while participant narratives provided insights into their motivations, workflow strategies, and preferences for documenting and evaluating TuneCandidates. A thematic analysis was conducted to identify emergent patterns, revealing diverse tuning approaches, such as all-at-once sprints, gradual refinement, and meta-tuning.

We begin by reviewing and contextualizing related work to understand how designers and engineers approach tuning within crafting and making practices. Then, we analyze different tuning approaches and introduce the tuning framework. We apply the framework in developing the tuning documentation tool. We present the fabrication tuning study, followed by the diary study. We leverage our findings to discuss opportunities and resistances in how tuning practices can be supported, particularly in terms of improving archival methods, fostering or hindering collaboration, and extending their broader applicability within making communities.

2 Related Work

2.1 Understanding Tuning Practices

Tuning is a Tacit Skill. Documentation plays a crucial role in a wide range of activities, providing transparency, enabling knowledge sharing, and supporting informed decision-making. However, the nature of documentation varies significantly across different domains, particularly in tuning practices. These differences stem from the unique goals and contexts in which tuning occurs, ranging from fabrication techniques to material exploration and interaction design. For instance, Kim et al. [22] highlighted the often overlooked challenge of measurement error in 3D printing, revealing the difficulties users face in determining what and how to measure during fabrication. Their study proposes two key strategies to mitigate tuning errors—modular joints for easier iteration and flexible buffers to compensate for small inaccuracies. Similarly, Ramakers et al. [37] categorize tuning strategies in Human-Computer

Interaction (HCI), showing how users leverage domain knowledge, post-processing techniques, and guided manual tasks to address material and machining constraints. Dew et al. [15] argued that successful 3D printing does not result merely from following a checklist; rather, it requires tacit knowledge, manual skills, and improvisational work through a tuning-oriented approach. These studies emphasize the importance of developing and documenting tacit tuning knowledge (knowledge that is difficult to articulate, formalize, or transfer) to enable iterative improvements in design.

Tuning Concerns. Tuning practices are not solely about measurement; they also involve navigating experiential qualities and design motivations. For example, Karana et al. [20] explored how professional interaction designers engage with material qualities on sensorial, interpretive, performative, and affective levels, underscoring the need for documentation that captures these nuanced interactions. In a similar vein, da Rocha et al. [13] identified distinct motivations behind tuning practices, particularly in how designers create, evaluate, and archive their prototypes. Their interviews with designers highlight the dual motivations of communicating work to others and extracting personal insights, which play a central role in how craftsmanship emerges during tuning. These different concerns and motivations illustrate that tuning extends beyond technical adjustments, shaping how designers interact with materials and prototypes to produce meaningful work.

Long-term, iterative interactions with artifacts and materials are essential for developing tuning expertise. Sterman et al. [46] investigated creative practitioners' version control practices, revealing how multiple versions of a design serve as creative tools. Versions function as "palettes" for inquiry, providing confidence through the ability to undo, enhancing variation by omitting certain information, and offering a continuous record of creative evolution over time. In a different context, Moradi et al. [29] conducted a contextual inquiry with expert ceramicists, uncovering lifelong tuning practices that involve trial-and-error, serendipity, and the use of both temporary and rigorous records. These findings demonstrate how longitudinal engagement with materials and processes fosters deeper understanding and mastery, influencing how individuals navigate choices and refine their tuning over time.

Exposing Tuning. Making the tuning process explicit is vital, particularly for learners and novice designers. Moreno et al. [30] illustrated how documenting the tuning journey—such as tracking the marks a drawing machine makes—can scaffold design methods and encourage a tinkering mindset. By exposing adaptable steps and highlighting materials used in tuning, Moreno et al. argued that this practice not only facilitates learning but also democratizes access to the design process by making it more transparent. Such scaffolding supports novice designers in developing their tuning skills, allowing them to understand and engage with the iterative nature of design.

TuneCatalogs builds on this body of work by contributing two complementary studies of tuning practices. In our workshop study, we examine how tuning can be scaffolded through structured interventions, focusing on "one-shot" tuning where adjustments must be made in a limited timeframe or with limited resources. In our diary study, we explore the factors that influence long-term tuning practices, or "lifelong tuning," by documenting how individuals interact with materials and tools over extended periods. These studies provide new insights into how tuning can be supported in both short-term and long-term contexts and offers a comprehensive view of how tuning knowledge is developed, documented, and applied across creative and technical domains.

2.2 Tuning Tools

Proactive Tuning. Proactive tuning techniques aim to embed adjustments within the design or fabrication process itself, anticipating potential issues before they occur. Roumen et al. [40] demonstrated this approach with dynamic mechanical geometries that counteract dimensional errors caused by a cutting tool's kerf, reducing the need for post-fabrication corrections. Liang et al. [25] extended this by using augmented reality to detect measurement ranges in the physical environment, allowing 3D-printed designs to seamlessly integrate with existing objects. Subbaraman et al. [48] emphasized that frequent machine tuning, in the form of maintenance work, is often invisible and undervalued in the design and fabrication process, yet it is essential to integrate it into the workflow rather than relying solely on adjusting a few interface parameters. These approaches highlight how proactive tuning reduces reliance on reactive fixes by engineering solutions that are directly involved in the creation process.

Documentation-centered Tuning. In contrast, other approaches emphasize the importance of documentation during the tuning process. Kaleidoscope [47], designed for HCI courses, revealed how documenting design decisions makes the process visible while also introducing friction between documentation and creation. Toolkits have been shown as effective strategies for scaffolding documentation practices. Camera et al. [9] created a toolkit with physical maps and reference images to guide designers in documenting the experiential qualities of materials. Subbaraman et al. [49] proposed a replayable tuning system that synchronizes video recordings with 3D printing parameters, helping users revisit key moments in the tuning process. Quickpose [38] externalized version control, showing users a spatial map of their design versions with annotations and visual cues. These systems emphasize structured documentation strategies to support iterative tuning without disrupting the design process.

Tuning Interfaces. Interactive tuning interfaces expose parameters for real-time adjustment and allow users to refine their designs on the fly. Risseeuw et al. [39] offered interfaces with sliders that adjust digital models in real-time, enhancing user control. However, these systems often require calibration to address the unique limitations of fabrication tools. Ziegler et al. [58] proposed flow-based programming to externalize the workflow, reducing feedback cycles and improving the tuning process. Matejka et al. [27] introduced a tool that allows designers to explore large-scale generative design datasets, rank 3D models based on customizable criteria, and save their selections for future use. While digital tuning interfaces allow for real-time feedback, physical adjustments like those required in 3D printing are more difficult due to energy inefficiencies and the reliance on tacit knowledge accumulated through repeated interactions with machines [20, 55]. These approaches underscore the challenge of balancing real-time adjustments with the practical limitations of fabrication processes.

TuneCatalogs integrates and isolates the more often overlooking tuning stage within the design process, providing users with guided documentation that captures both functional and aesthetic tuning concerns. Keeping track of positive and negative prototypes prevents documentation sprawl and organizes the tuning process using a grid-based approach. By assessing patterns of use, we demonstrate how tuning support tools can be adapted to diverse user motivations, ensuring it remains flexible and responsive to different tuning needs.

2.3 Facilitating documentation

Many documentation tools leverage structured templates to reduce the activation energy required for documentation. For example, Milara et al. [28] introduced a guided template that allowed users to document reports and tutorials in real-time as they engaged in their makerspace projects. Similarly, Ettehadi et al. [16] automated the documentation process by capturing key information through audio or video recordings and embedding tags onto prototypes, facilitating easier tracking and retrieval of information. While these tools effectively archived comprehensive records of prototyping processes, retrieving specific data often required a time-consuming and manual review of archived materials.

A common method for documentation during prototyping involved capturing images, audio, or video [3, 28, 51]. For instance, Tseng et al. [52] used a turntable system to capture pictures and videos, converting them into 3D animations for enhanced visualization. Similarly, Akter et al. [3] supported documentation in educational settings by providing students with a dedicated booth with a capture system to record photos, audio, and videos of their digital fabrication projects. This approach enabled instructors to provide targeted feedback. However, errors in the documentation process often disrupt workflows and require revalidation of prior steps to maintain consistency and accuracy.

In contrast, TuneCatalogs addresses a different scope of documentation, focusing on capturing the tuning results that are often relegated to memory. Our catalogs are able to minimize the activation energy by structuring the tuning process into a 2D numerical grid accessible through a mobile interface; this allows us to support quick overviews of archived information and easy access to update or create catalog entries. By addressing the tedious and often overlooked tuning process, TuneCatalogs complements the broader ecosystem of documentation tools.

3 Tuning Design Principles

To develop effective tuning support tools, we identified four guiding design principles inspired by related work, each addressing a crucial aspect of the tuning process. These principles aim to improve how makers and practitioners interact with tuning systems, making the process more efficient, insightful, and adaptable. These principles emphasize lowering barriers to entry, fostering continuous learning, and encouraging seamless integration of insights across projects.

3.1 Design Principles

Support Diverse Tuning Workflows. The variety of tuning methods — from physical tuning (e.g., sanding [26], shaving [31], cutting [2, 41, 42], melting [43, 53]) to property tuning (e.g., tolerancing, real-time adjustments in CAD-CAM [39]) — showcases a wide range of workflows. Some of these workflows are systematic (e.g., optimization algorithms with fitness functions [57]), while others rely on trial and error (e.g., calibration using the tugboat print [1] for 3D printers). Tinkering plays a key role, as it allows for improvisation and material-centered exploration [29], while computational optimization introduces structured problem-solving (e.g., fitness functions [57]). By supporting these various workflows, design systems can accommodate both procedural and opportunistic approaches.

Tuning support must accommodate both structured and exploratory workflows to effectively meet diverse user needs and making contexts.

Reduce Activation Energy to Document/Archive. Many of the tuning processes are embodied and single-use (e.g., manual adjustments in physical tuning or human gestures in AR/VR systems [34]). Documenting these processes, especially when they rely on tacit knowledge, is often skipped or overlooked. Calibration prints like the tugboat [1] externalize possible design decisions and reduce activation energy by providing a tangible archive. If we make tuning processes more accessible and integratable into existing workflows (e.g., through flow-based programming [58]), it can improve rigor, archiving, and shareability, especially in opportunistic practices.

Tuning support must lower the barriers to documentation, making it easy to capture, archive, and share tuning insights.

Enhance Longitudinal Sensemaking. Trial and error, such as serendipitous discoveries in tinkering and material exploration [29], uncovers the "positive" and "negative" spaces of the design. This iterative process, driven by human and material tuning, responds to the unpredictable properties of materials, requiring recalibration and reframing of goals [20]. Over time, these adjustments build a deeper understanding of the interaction between materials and machines. For example, Kombucha leather production introduces not only a sustainable material but also opportunities for serendipitous discovery and dynamic goal-setting [4, 5, 54]. By capturing tuning outcomes as sensemaking resources, designers can track iterative discoveries, adjust goals, and recognize evolving patterns.

Tuning support must scaffold sensemaking by enabling flexible goal adjustment and highlighting insights gained through iterative exploration.

Shift Perspectives. Many tuning tasks, such as calibration, are typically tedious, often requiring multiple adjustments and iterations (e.g., manually adjusting 3D printer settings [50]). By designing for enjoyable experiences and acceptance of the unknown, we can shift perspectives about tuning from a chore to an enjoyable exploration. For example, Moradi et al. [29] found that reframing of "incorrect outcomes" in ceramics was part of a co-creative process shows how embracing the unknown can enhance creative exploration. Similarly, interactive tuning processes, like those involving PID controllers and sensor-actuator loops [18], can make typically monotonous adjustments more engaging by providing constant feedback and offering new insights [35].

Tuning support must transform tedious tasks into engaging explorations by fostering creativity and embracing the potential for unexpected outcomes.

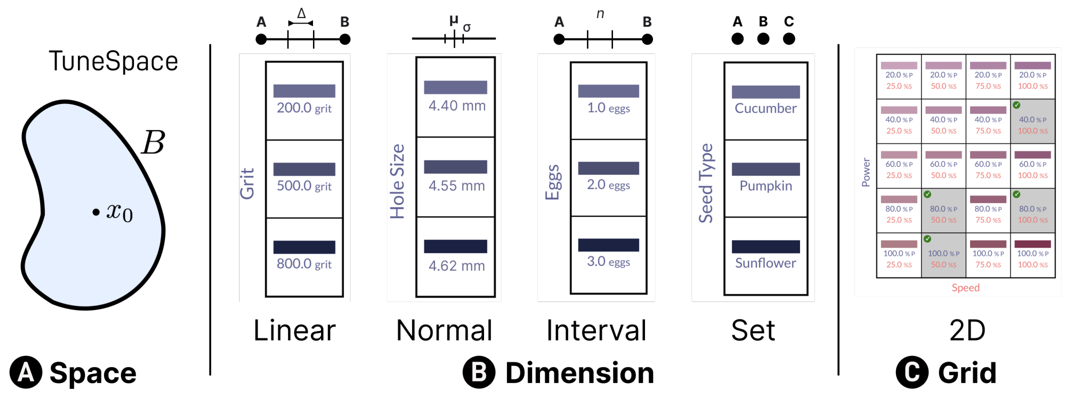

Figure 2: Tuning Definitions. A) TuneSpace B is defined as a space used to represent all possible tuning candidates; B) The TuneSpace can be more ordered using dimensions where TuneCandidates are sampled from linear, normal, interval, or set distributions, depending on the context; C) A two-dimensional search space is formed to sample a TuneSpace systematically.

Guided by these principles, we developed TuneCatalogs, a tool developed to streamline how tuning insights are recorded and shared.

4 TuneCatalog Tool

TuneCatalogs, deployed as a design probe, is a flexible tool designed to guide and document tuning processes across diverse practices. By allowing users to create, track, and share tuning experiments, the system provides a structured tuning process that supports both individual reflection and community knowledge exchange.

4.1 Approach

At the core of our tool is the concept of a *TuneSpace*, a conceptual space where all potential tuning options are mapped (Figure 2). The TuneSpace allows users to visually organize and navigate their tuning experiments, providing a structured and intuitive way to explore and refine parameters. A *TuneCandidate* represents a specific point within the TuneSpace, corresponding to a particular set of tuning parameters. Each TuneCandidate is designed to be transparent and communicate the parameters it represents. TuneCandidates are designed to target and mark strategic locations within the space that merit exploration. These candidates serve as tangible or conceptual outputs that guide users toward their tuning goals. Within the TuneSpace, there lies a subspace we term as the *Goldilocks Zone* – the optimal range where parameters are finely tuned to meet the desired outcome. This zone can vary depending on the context, from being well-defined and static in precise engineering applications to more fluid and dynamic in creative or exploratory workflows.

The *TuneCatalog* tool serves as a tool for exposing the *TuneSpace*, identifying *TuneCandidates*, and documenting the process of searching for the *Goldilocks Zone*. By employing a grid-based strategy, the TuneSpace is simplified into one or two dimensions, with each cell in the grid representing a unique *TuneCandidate*. Grids help organize information systematically, allowing users to concentrate on specific elements without being overwhelmed. This structure was chosen to improve the clarity and accessibility of data and present relationships or changes in a clear and digestible format [12].

Each *TuneCandidate* stores specific tuning criteria, which is externalized as a color value within the grid. These colors collectively form a heatmap, providing a visual representation of tuning outcomes and making the *Goldilocks Zone* easily identifiable. This grid structure is designed to ensure flexibility and clarity, so users can explore and understand their tuning experiments in a navigable format.

Implementation Details. TuneCatalogs was developed as a responsive standalone web-based application using React for the frontend and MongoDB for the backend database, which stores catalogs and user interaction logs. The system supports user accounts, enabling personalization and tracking of individual tuning experiments. To encourage collaboration and knowledge sharing, each catalog is assigned a shareable URL to allow users to distribute and revisit catalogs across teams and projects.

4.2 Interactions

Creating a Catalog. When users create a catalog, they are prompted to define a two-dimensional TuneSpace (Figure 2). Users can specify various parameters, intervals, or distributions (e.g., *sets* [to represent a group or qualitative or non-numerical variable], *linear spreads* [for numerical variables with known ranges], or normal distributions [for numerical variables with known distributions]) depending on the nature of their tune.

In a design workflow, users might specify a linear spread to track subtle changes in material properties, whereas, in an engineering context, a set might be used to measure specific performance metrics across a range of settings. The system is designed to support longitudinal tracking of both positive and negative results so as to preserve all data for future reference. Additionally, users can clone existing catalogs to replicate experiments and build upon prior work.

Specifying Tuning Criteria. TuneCatalogs offers multiple evaluation formats to accommodate diverse needs, including Likert scales, numerical ratings, and open-ended responses. These criteria allow users to adapt their assessments based on the nature of the experiment (Figure 3).

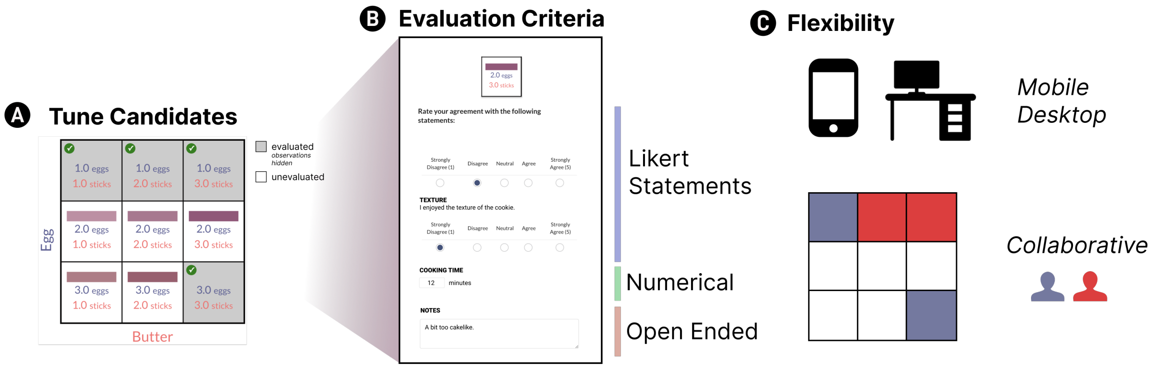

Figure 3: TuneEvaluation. A. Each TuneCandidate is evaluated based on predefined criteria. B. Upon selecting a specific TuneCandidate, a new window opens where the user can further evaluate the respective candidate. The TuneCatalog currently supports Open-Ended questions, Numerical evaluations, and Likert-type evaluations. C. Collaborative evaluations can be conducted on mobile or desktop devices to enhance accessibility and rigor.

In a design workflow, a Likert scale might be used to evaluate subjective properties like aesthetic appeal, while numerical ratings could assess objective metrics such as material strength. Open-ended responses provide space for users to record unexpected observations or deeper insights. This flexibility is designed to enhance longitudinal sensemaking, as users may not know ahead of time which evaluation criteria will be most valuable. Initially, all criteria are weighted equally, but users can later adjust the weights to emphasize or de-emphasize specific aspects as needed.

Recording a Tune. To record a tuning experiment, users open the app and locate a TuneCandidate within the grid. Once selected, they can fill out an evaluation using the specified criteria. TuneCatalogs provides a progress bar during this process, rewarding users with a visual representation of how much of the TuneSpace they have explored. This progress bar is designed to encourage filing out all possible TuneCandidates.

Reviewing a Tuning Experiment. After an experiment has been conducted, users can review the results on a dedicated screen. Here, evaluation criteria are ranked and presented in a heatmap, to more easily identify patterns and trends. Heatmaps were selected due to their approachability, effectiveness in simplifying complex data, and ease of interpretations in drawing quick comparisons across different states [23, 24]. Additionally, heatmaps have been shown to enhance user engagement and support data-driven decision-making, making them rapidly adopted in usability design [14].

The heatmap is generated using nearest-neighbor interpolation, where the criteria for each TuneCandidate are averaged to produce an overall score. For tuning candidates lacking direct evaluations, the method identifies the n-nearest neighbors ($n = 4$) and computes an interpolated score based on the weighted average of their neighbors, with weights normalized by the distance to the candidate being assessed. These scores are then visualized using a divergent color palette (blue to green), to provide an intuitive distinction between positive and negative candidates. We avoid more common red-green palettes to shift perspectives away from "failed" candidates.

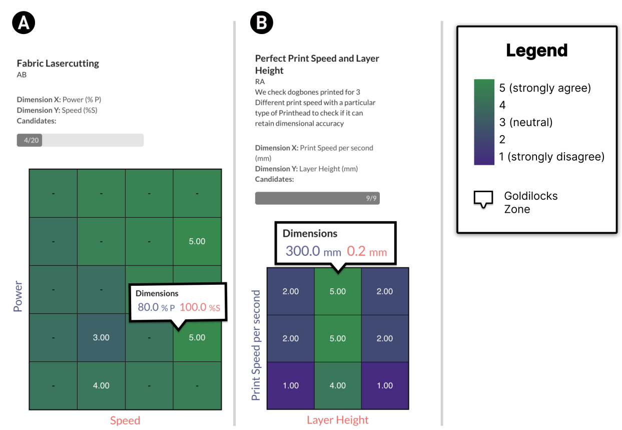

Figure 4: Sample Tune Catalogs. A sample of recorded TuneCatalogs: A) A fabric being laser cut, with laser power and speed tuned. The Goldilocks zone identified 100% speed as the only critical dimension; B) A 3D print of a dogbone tuned for print speed and layer height, where 0.2 mm layer height consistently produced better results. Each catalog summarizes TuneCandidates in a heatmap, with a blue-green gradient used to surface the Goldilocks Zone(s). The grid colors are interpolated, and selecting a grid reveals the criteria and parameters for the associated TuneCandidate.

The heatmap visualization can be used to quickly highlight the *Goldilocks zone* where tuning parameters are optimized, while less successful data is retained for reference (Figure 4). This visual representation is designed to support users to quickly identify which areas of the TuneSpace produced the best results. All tuning experiments are persistently archived and can be accessed at any time, providing a comprehensive record of previous work. This allows users to track their progress over time and refine their approach based on past experiences.

For clarity and flow, we use the terms catalog, space, and candidate to refer to TuneCatalogs, TuneSpaces, and TuneCandidates, respectively.

5 Tuning User Study

The tuning user study (Figure 5) aimed to evaluate the tool's effectiveness in common tuning scenarios, both in digital fabrication and crafting contexts. The tasks explored various aspects of tuning, including adjusting geometries, material properties, and hand-fabrication techniques. We assessed how users documented and evaluated a tuning task with TuneCatalogs, their perception of tuning with and without the tool, and their perceived tuning self-efficacy and agency. The study received approval from our Institutional Review Board (IRB).

5.0.1 Participant Recruitment and Selection. Participants were recruited through university mailing lists; due to the focus on 3D printing, we recruited participants who have some experience in 3D design and printing. A total of 10 participants (4 female, 6 male) took part in the study with an average age of 22 ± 2 years. Our study was conducted in a design studio setting; each participant met with us individually and received a $15 USD compensation for their contributions.

5.0.2 Study Design. The study comprised two distinct tuning tasks, each designed to simulate scenarios where a user adjusts parameters for both digital and physical designs. We designed tasks that incorporated 3D printing with simple geometry to minimize fabrication time, a unique material (conductive PLA) to simulate the challenges of working with unfamiliar materials, and a crafting context using classic fuse bead crafts to explore tuning in a tangible, hands-on setting. Each task required 20 minutes to complete.

5.0.3 Study Setup. The user study was conducted in a controlled lab environment, which included a table and an ergonomic chair for participant comfort (Figure 6). The study instruments included a fuse bead kit along with a multimeter, digital calipers, and an iron. To maximize the workspace for the study activity, an FFF 3D printer was placed on a separate table nearby. A laptop running the TuneCatalogs tool was used both to administer surveys and facilitate study activities.

Prior to the main study tasks, a 5-minute warm-up session was conducted to acquaint the participants with tuning and reduce novelty effects. This introductory phase included exposure to the study materials and an introduction to the TuneCatalogs interface.

Task 1: Fabrication Tune. Crafting with fuse beads requires users to arrange plastic beads on a pegboard. A common issue with these beads is their often oversized inner diameter which can cause them to slip off the pegs during the fusing process. These classic mortise-and-tenon joints highlight a common situation where machine-material tuning is needed to achieve a secure "press fit" – in this case, where the mortise (beads) fits snugly and securely onto the tenon (pegboard).

In this task, participants were provided with an existing catalog that generated a TuneSpace of seven candidates, each with varying inner diameters (Figure 5). Participants were provided a set of printed beads on a sprue frame (akin to how model toy parts are packaged) with corresponding inner diameters (Figure 7). They were tasked with thinking aloud as they filled out the evaluation for each TuneCandidate. The TuneCandidate evaluation included a set of 5-point Likert statements, representing criteria for the most usable press-fit connection:

- *Hold* - The peg can effectively hold the bead
- *Removal* - The bead can be easily removed from the peg.
- *Force* - Removing beads from the pegboard requires significant force

Task 2: Manual Tune. Although most commodity fuse beads are non-conductive, 3D printing bead geometries using conductive filaments allow for the creation of conductive beads. These beads can be fused together to form line connections (rails), similar to those on circuit boards. However, the fusing process is highly variable due to its reliance on manual techniques, introducing inconsistencies. This task was designed to simulate a tuning scenario where participants worked with a novel material and needed to refine their technique through hands-on adjustment and self-guided experimentation.

Participants were provided with a pre-structured catalog, which included three candidates corresponding to varying iron pressures—low, medium, and high (Figure 5). Using an iron, they fused 7 beads into a rail for each candidate (Figure 8). Participants were asked to record the resistance of the fabricated rail as well as evaluate its overall deformation with a Likert statement.

After completing the tasks, participants took part in a semi-structured interview to provide insights into their perceptions of the tuning process and their engagement with the TuneCatalogs tool.

5.1 Thematic Analysis

We delineate four key themes that emerged from the empirical data collected during the user study. The empirical data comprises 20 interview transcripts (totaling 100 minutes of audio recording). We first identify different tuning moments and describe each moment experienced by the participants during the study.

5.1.1 Method. To analyze the data, we reviewed survey responses, observed actions, and interview and think-aloud transcripts. Two authors coded quotes and observations, refining the process iteratively until a consensus was reached. Axial coding was used to organize the data into initial clusters. Through thematic analysis [7, 8, 11], we identified four themes that summarized the findings.

5.1.2 Theme 1: Tuning as Laborius, Wasted, Wasteful but Unavoidable. When prompted about participants' previous tuning experiences, they mentioned a lack of a defined tuning workflow when trying to find an optimal tuning candidate. Nonetheless, the challenges that arose during the actual 3D printing process or subsequent modifications of the digital design prompted many participants to seek assistance from the 3D printing "masters" in various fabrication labs. Unlike other creative practices, unused 3D objects remain wasted when it comes to finding the right candidates. One participant shared:

> **U9**: I tried to change [my design]…and lost track [of what parameter I used], so I went to [TuneCatalog (tool)], and

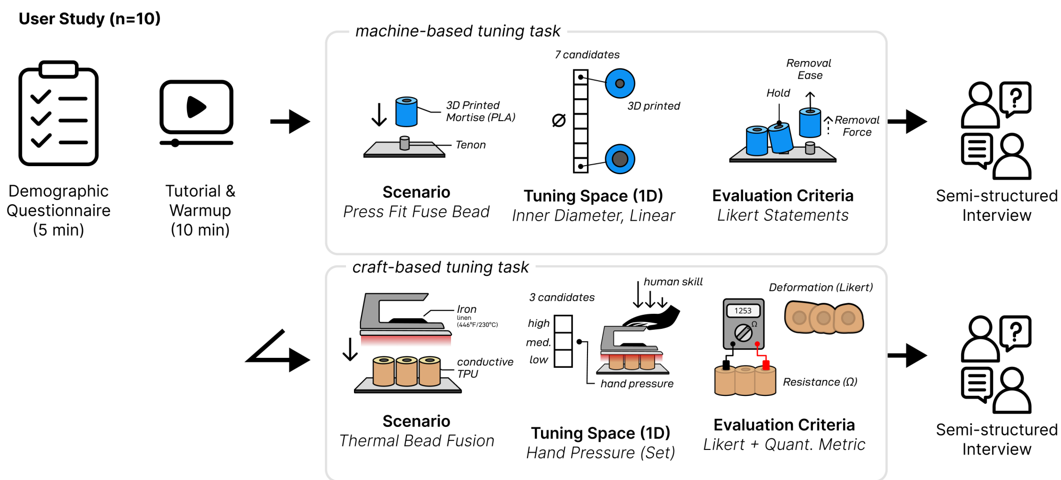

Figure 5: User Study Tasks. The tool was evaluated in a one-hour study combining machine-based and craft-based tuning tasks. Participants tested various bead sizes on a pegboard to achieve a desired fit and thermally fused conductive beads to form conductive connections. A semi-structured interview was conducted after each tuning and documentation activity to gather deeper insights into the tool's applicability.

Figure 6: User Study Setup. The study environment included a laptop running the TuneCatalog app, an ergonomic chair, and a standard table (1 x 1.5 meters). Participants were supplied an electric iron alongside a variety of fuse beads (commercially available, 3D-printed PLA and conductive PLA). A multimeter was provided to measure the resistance of fused conductive beads.

> then they help[ed] me [keep] track [of my adjustments] and print.

Despite being a frustrating trial-and-error process, participants described still engaging in a dynamic and problem-solving mindset, actively analyzing the situation to overcome challenges. A participant shared their experience in 3D printing a memory card holder:

Figure 7: Fabrication Tuning. Fuse beads and pegboards serve as examples of mortise and tenon joints, which require precise fitting for optimal functionality. Since 3D printing can introduce small errors that lead to misfits, the mortise (inner hole) was adjusted to better accommodate the tenon. A TuneSpace consisting of seven linearly spaced candidates, starting from 1 mm, was created and 3D-printed for testing. Participants evaluated each candidate based on three criteria: Hold, Removal, and Force.

> **U2**: It was kind of a trial and error thing for me, frustrating, but I was planning to do it anyway . . .

Despite this uncertainty, tuning was acknowledged as ubiquitous and unavoidable:

> **U9**: Can we actually avoid [printing multiple versions]? I know avoiding them would save a lot of time because it takes literally a day to do.

Participants expressed concerns about the disorganized and sporadic nature of their existing tuning workflows. The participant emphasized that their sampling approach, or how they chose which candidate to fabricate and evaluate, was random often going undocumented. These tuning efforts were viewed as wasted.

5.1.3 Theme 2: TuneCatalogs as a Structured and Contained Experience. Participants enjoyed participating in the tuning process

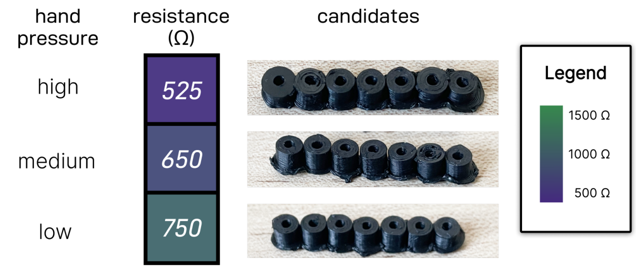

Figure 8: Manual Tuning. Fusing multiple conductive beads can create an electrically conductive line. Participants were asked to fuse seven beads to form line connections under varying pressure levels. A TuneSpace was created with three candidates and distributed in a set pattern. After forming the bead line connections, participants measured the resistance and updated the results in the app.

due to the catalog grid allowing all candidates to be readily visible. The structure of TuneCatalogs facilitated a more manageable and achievable exploration of candidates, even as participants expressed a desire to explore additional options. Participants appreciated the collaborative nature of the tuning experiment that enabled multiple reviewers or evaluators to contribute to the evaluation efforts. The organization of the tool provided clarity and order, improving the overall tuning experience.

> **U9**: I tried all of the samples because I wanted to see how perfect the fit would get.

The availability of all potential candidates increased participants' confidence in the process. While participants had the option to stop evaluating candidates once they found a suitable candidate, they consistently assessed all candidates for greater accuracy and updated their findings in the catalog. This behavior simplified their search strategy for identifying the best candidate. For instance, 4 out of 10 participants began their search at the origin of the TuneSpace. Starting from the origin allowed them to narrow their focus to a smaller region—either the upper or lower area of the TuneSpace—helping them more efficiently identify the optimal candidate. Participants often struggled to adhere strictly to the evaluation criteria, preferring instead to be able to rank candidates or have reference candidates to anchor their criteria.

5.1.4 Theme 3: TuneGoals as Moving Targets. When designing a tuning experiment, the variables that affect tuning are difficult to anticipate. The tuning process elicited from participants a heightened awareness of all the different variables that affect getting the 'right' tune. Participants became more engaged and actively worked to anticipate capturing their tuning moment into something tangible and perceivable. While fusing conductive beads, one participant expressed her tuning moment as follows:

> **U11**: I started out [with the soft pressure candidate] withholding [the iron] barely touching the beads…then I just kept increasing the pressure each time for [testing medium and hard]. I could feel [the line of beads] melting. I could feel them smooshing down.

We observed that participants tried to navigate this unknown dimension and needed to experientially feel out how to move through the TuneSpace. These types of interactions cause other participants to reflect on the variables that were not explicitly in the tuning experiment and their interpretation of the evaluation criteria:

> **U9**: I actually thought that the tighter one [mortise bead] would be the better one, but when I knew that you have to put the beads on the pegboard to form a design [application], that's when I thought that the tighter one [mortise bead] would not be good because it [beads after fusing] would take a lot of time to take off from the peg board.

Especially in the manual tuning task, participants noted other tuning dimensions (e.g. melting time, iron's surface area, human factors) to explore as well as new criteria for the final tuning outcome.

5.1.5 Theme 4: Theory Colliding with Practice. Participants occasionally experienced a mismatch between their mental models and the observed outcomes, leading to skepticism about the reliability of their results. In response, participants became more attentive in subsequent trials, cross-verifying their observations against their existing knowledge. One participant obtained the lowest resistance in soft press conditions, which did not match their expectation:

> **U9**: I was pressing the iron softly but it [the measurement] gave me the lowest resistance!

In situations such as this, participants sought to identify other factors that might influence their surprising outcomes. This trend suggests a reflective attitude among participants, demonstrating a systematic consideration while searching, selecting, and documenting candidates. Even when ideal candidates were identified, participants tended to evaluate all options exhaustively. This behavior suggests they actively questioned and refined their mental models.

6 Diary Study

Tuning is an iterative process where immediate outcomes are typically prioritized, and potential alternatives are often set aside in favor of quick results. To fully understand how TuneCatalogs affect this practice, it is important to capture how these practices develop and adapt over time, especially as users interact with tools and materials in real-world contexts.

We employed a diary study method, effective for collecting in-situ, reflective data on participants' ongoing experiences [19]. This approach allows us to examine the iterative, long-term nature of tuning, enabling continuous documentation without requiring direct researcher involvement [45]. By allowing participants to record their actions and reflections over time, the diary study provides detailed insights into user behaviors and decision-making processes [33], offering a comprehensive view of tuning as it occurs. The study received approval from our Institutional Review Board (IRB).

6.1 Participant Recruitment and Selection

Participants were recruited via university mailing lists, targeting individuals with prior knowledge or experience in tuning processes. A total of five participants (three female, two male) were selected, with an average age of 26 ± 3 years. The diary study was conducted

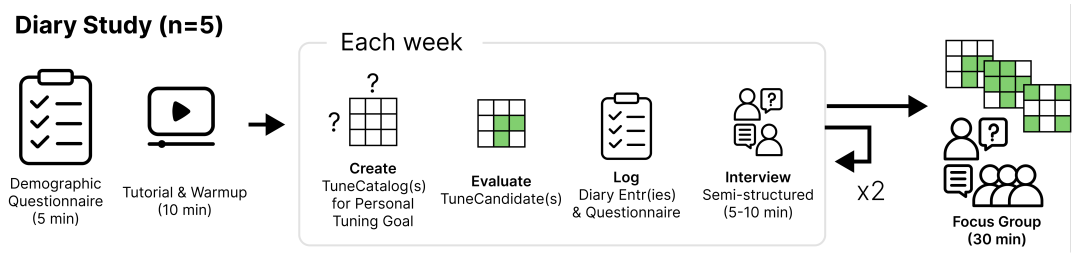

Figure 9: Diary Study. A total of 5 participants (3 males and 2 females) were recruited for a 2-week long diary study. Each week, participants created tune catalogs, evaluated candidates, and filled out diary entries and questionnaires. The study concluded with a focus group discussion.

remotely, and each participant received compensation of $19 USD. Detailed participant backgrounds are provided in Subsection 6.3.1.

6.2 Study Design

The diary study consisted of three stages (illustrated in Figure 9):

(1) **Preparation Stage**: Participants were introduced to the tool via a short instructional video that provided guidance on its navigation and features. Prior to this session, participants completed a demographic questionnaire, which also gathered their initial perceptions of fabrication and tuning processes.

(2) **Weekly Tune & Diary-Keeping Stage**: Each participant was encouraged to interact with the TuneCatalog interface and document at least two catalogs during the two-week study period. Participants were encouraged to create catalogs that fit into their daily activities or work, or catalogs that they would use for future reference.
Each week, participants documented their weekly experiences and challenges with the tool through written notes. Participants also engaged in brief, semi-structured interviews each week. These interviews aimed to capture detailed feedback on the tool's usability, any challenges they encountered, and their thoughts on potential applications. This process also monitored participants' evolving understanding of the tool over time.

(3) **Focus Group Discussion**: After two weeks of diary study sessions, participants participated in a focus group discussion. A moderator conducted the semi-structured discussion, which was audio-recorded and later transcribed for thematic analysis. The discussion aimed to explore shared insights, challenges, and experiences with the tool, helping to identify recurring themes and areas for improvement.

6.3 Data

Our final dataset included 10 weekly questionnaires with diary entries, 10 post-study questionnaires, 10 interview transcripts (totaling 50 minutes), 30-minute transcripts from the focus group discussion, 10 catalogs with 101 tune candidates with a 76% evaluation rate, and 613 events recorded in the activity logs. To ensure consistency between self-reported and observed behaviors, we triangulated data from these sources.

6.3.1 Participant Profiles and TuneCatalogs. To protect the privacy of participants, pseudonyms are used throughout this section. The study involved participants from diverse academic and professional backgrounds, each bringing unique expertise and goals to the tuning tasks. Participants included graduate and undergraduate students with varying levels of experience in 3D printing, laser processing, and materials research. Although many participants had mechanical engineering backgrounds, they incorporated a wide range of materials and manual/digital fabrication processes for their respective projects and hobbies. Samples of their respective catalogs are depicted in Figure 11.

(1) **Jackson** is a graduate student in Industrial Engineering with 3D printing experience. For this study, he tuned the ratio of powders used in sintering 3D printing processes to improve the surface quality and strength of drone blades.

(2) **Paul** is an undergraduate student in Naval Architecture and taught himself 3D printing during his studies. He regularly fine-tunes 3D printing settings and develops multiple prototypes to achieve specific functional goals. Recently, he started working with PEEK, a high-strength filament. During the study, he focused on optimizing the printing temperature to enhance the quality of his PEEK dogbone specimens (a standard geometry used for mechanical characterization), which were evaluated using a tensile strength tester.

(3) **Maryam** is a graduate student in Mechanical Engineering. She frequently works with 3D printers and laser cutters. Her projects focus on developing protective gear, where she tunes laser processing to improve the durability of different materials. She also is a hobbyist painter and tuned different paint compositions.

(4) **Olivia** is a graduate student in Mechanical Engineering and specializes in working with soft and flexible materials. Her recent projects focused on integrating conductive materials into soft materials. She conducted tuning experiments to explore material behavior under different heat conditions.

(5) **Mark** is a graduate student in Mechanical Engineering and works regularly with digital fabrication machines. His recent projects focus on identifying suitable 3D printing nozzles for different 3D printing applications. He tuned the nozzle sizes to improve product quality and print time.

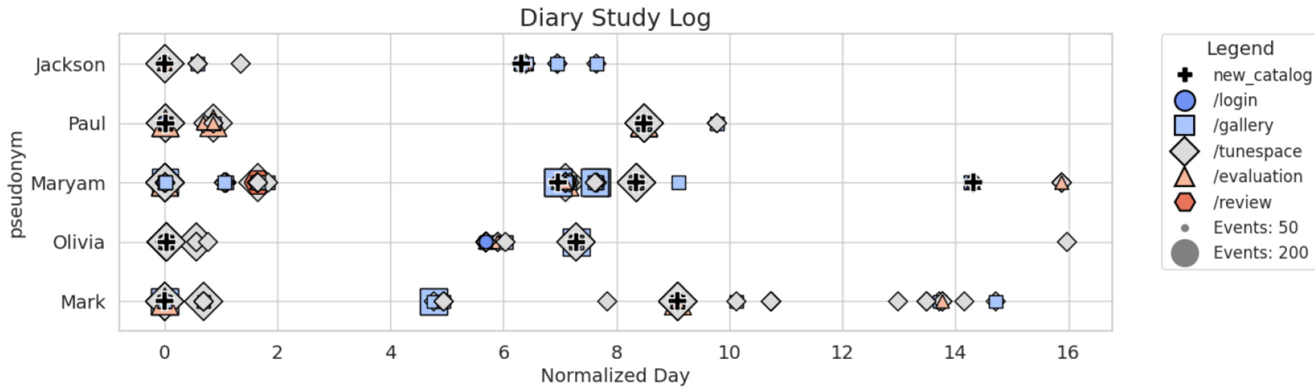

Figure 10: Diary Study Activity Log A scatterplot timeline illustrates participant activities over the two-week study (normalized to the participant's start date) from system logs (n=613). Each marker represents an event, with size proportional to event density, indicating the number of events within a given time period. */login* events mark when a user entered the application, */gallery* denotes viewing or searching for catalogs, */tunespace* represents viewing a specific catalog, */evaluation* indicates assessing a tune candidate, and */review* corresponds to accessing the heatmap summary visualization.

7 Results

7.1 Activity Log Patterns

Activity patterns from the activity log are illustrated in Figure 10. Each log entry includes details such as the catalog being observed, the candidate being evaluated or reviewed (if applicable), the catalog author, and the viewer. During Week 1, the timeline reveals a consistent pattern of engagement following the initial tuning task, with all participants completing the task within two days. Most participants evaluated tune candidates in a single sitting during this phase. Mark leveraged existing data from prior presentations, organizing it into a catalog for easier access and reference. Meanwhile, Maryam spent time reviewing catalogs created by other participants before designing the dimensions of her own catalog.

In Week 2, activity patterns diverged as participants explored different tunes. Mark, who was focused on optimizing printhead nozzle sizes, dedicated six days to refining a single catalog, demonstrating a more gradual and thorough tuning workflow. In contrast, other participants exhibited shorter, yet distributed tuning sessions, typically spanning two to three days. These variations highlight the individualized strategies and pacing participants adopted tuning workflows, reflecting differences in their goals and approaches to problem-solving.

7.2 Thematic Analysis

Two researchers with experience in fabrication, scientific experimentation, and artistic exploration conducted the thematic analysis [10]. Transcripts, catalogs, and activity logs were independently coded using a combined deductive and inductive coding approach to develop the coding framework. Deductive codes were informed by tuning design principles (Section 3) to understand how design decisions and interactions within TuneCatalog affect the tuning experience. Inductive codes emerged from iterative clustering, capturing new insights into tuning workflows. Axial coding was applied to refine and connect codes, confirming and expanding theories about how TuneCatalog influences opportunistic tuning. The resulting themes offer a detailed account of participants' strategies and the broader dynamics of their decision-making processes.

7.2.1 Theme 1: Tuning Workflows. The patterns from the activity log (Figure 10) revealed that tuning behaviors are dynamic rather than static, showing that users adapt their strategies based on the context rather than following a single, fixed approach. Within these patterns, we identified two distinct tuning workflows among participants. The first workflow was characterized by participants working in isolated **all-at-once tuning sessions**. The all-at-once tuning workflow represents a strategy for immediate optimization, where participants leverage side-by-side comparisons to rapidly adapt and refine criteria.

As shown in the activity log (Figure 10), all participants engaged in this type of tuning in 1-day tuning sprints during Week 1. We associate this with participants familiarizing themselves with the catalog process; in the second week, this tuning workflow was less common and became tied to situations where tuning candidates could be rapidly created or in instances where the evaluation was relational.

For example, Maryam's turquoise tuning (Figure 11) required her to see all the shades of four different blue-green color combinations before she could rate which was the most turquoise of them all. Other participants described conducting tuning evaluations simultaneously as a way to quickly morph and adjust the criteria and still be able to apply it to all candidates.

> **Mark**: I think documenting everything together helped me because I could add all my thoughts and questions at once. Sometimes, you face different issues in different experiments. By documenting everything together, I could reflect on everything at once.

This approach helped Mark to engage in a **meta-tuning process** (i.e., tuning the tune). Meta-tuning went beyond tuning individual candidates, focusing instead on iterating the evaluation criteria, descriptions, or documentation standards themselves. This reflexive

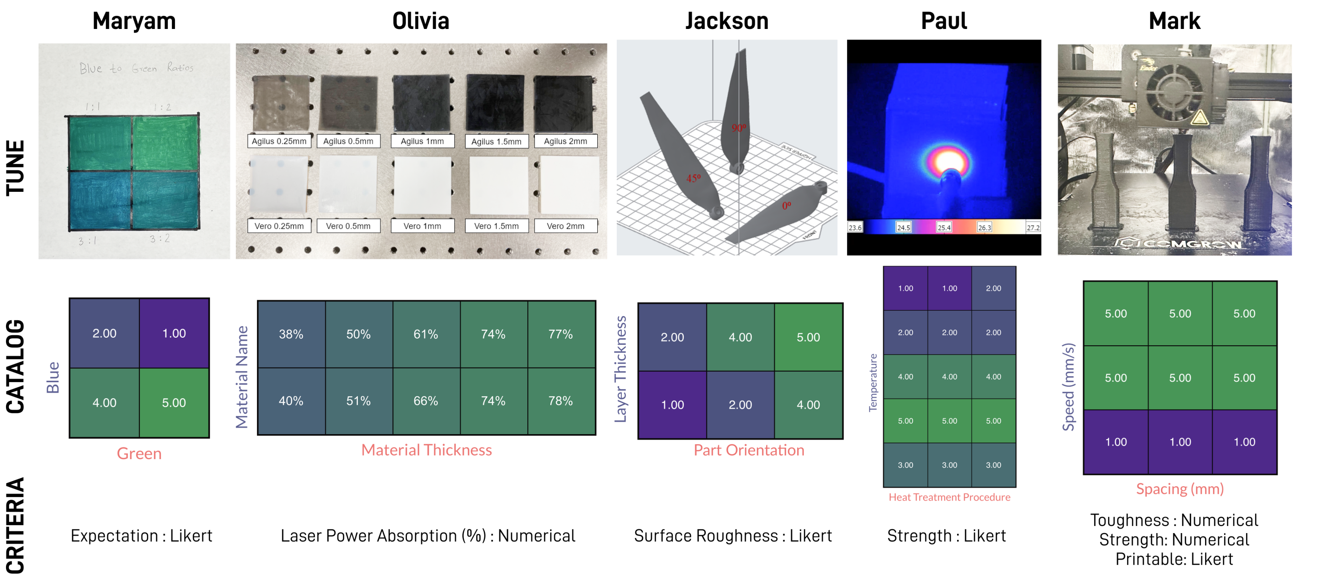

Figure 11: Participants' TuneCatalogs. Each column shows each participant's tuning candidates, the final tune catalog, and the tune criteria used to compute a candidate's score. *Maryam* tuned for the color turquoise from blue-green crayons combinations, *Olivia* tuned material thickness and type for increasing power absorption, *Jackson* tuned layer thickness and orientation to reduce surface roughness in 3D prints, *Paul* tuned the heat treatment of the PEEK filament to improve strength, and *Mark* tuned print speed and spacing for a novel nozzlehead.

process enabled participants to fine-tune not just outcomes but the very mechanisms of their workflows. The all-at-once approach also facilitated **retrospective tunes**, or tunes that captured prior experiences from memory or records. Paul, for example, retrieved data from a prior presentation and used the catalog to curate the results in the "intuitive" standardized format rendered by the tool.

Not all tuning candidate creation techniques supported the opportunistic practices of the all-at-once tuning strategy. Some catalogs revealed a **gradual tuning workflow** that required significant diligence and sustained effort which unfolded over many days. Participants recognized the value in explicitly documenting tunes they might not have otherwise recorded, allowing for more comprehensive tracking and reflection throughout the process. They used this workflow to address complex, evolving criteria, as in experiments requiring sustained observation.

> **Mark**: I think it's better to use it [gradually]. This way, when we perform experiments, we can add our insights to the evaluation section and review them later to understand what happened at that time. When I conducted the experiments last time, I didn't retain everything in my mind, so it would be better to capture it as I go along.

Mark's activity log reflected this gradual approach, showing that evaluation occurred over time in the second experiment. Participants found this gradual tuning process particularly useful for longitudinal experiments, where they stated the catalogs provided the needed organization and flexibility to capture. Beyond tuning in fabrication, they suggested applications such as tracking plant growth (Paul), monitoring plant fertilizer ratios (Olivia), and recording recipes (Jackson), indicating that the catalogs could support extended periods of experimentation beyond the scope of the study.

> **Olivia**: I have a lot of plants, so if I had more time [than the diary study], I could track plant growth over time and look at how different types of soil or water intake affect the plants.

Regardless of whether the tuning process adopted an all-at-once or gradual approach, participants noted that certain tune candidates were often excluded from evaluation and documentation. These exclusions typically fell into one of two categories: candidates that were evidently and unlikely to yield positive results and those rendered unnecessary by the identification of a "good enough" alternative.

7.2.2 Theme 2: Reward & Motivation . Tuning and documentation setup, along with continuous updates, often require significant activation from users. However, the structured process motivated participants by reducing initial startup friction and providing a sense of accomplishment as they reached their desired outcomes; many viewed the structured TuneSpace as inducing a "progress bar" effect, motivating them to complete evaluation for all tuning candidates. This motivation was further reinforced by the tool's ability to offer glanceable interpretations of results. Across both weeks, participants frequently highlighted the straightforward setup procedure and the flexibility to define their own evaluation criteria while setting up.

> **Paul**: I think the interface is more intuitive. If you have a quick look at the charts, the interface allows you to see

> different sets of variables assigned scores, like "5 out of 5" ...
>
> **Olivia**: I felt satisfied with the results I got and with the experience in recording the data. Especially the second time because my parameters were much more distinct, so it was easier to figure out the experimental process and what I needed to record and work on next.

When asked about other recording modalities, participants showed mixed reactions. While some expressed curiosity about video recordings as a less intrusive alternative, most remained hesitant to adopt them, citing concerns about the effort required to organize and review such formats. This reflects a broader trend, where participants found transitioning from informal note-taking to richer documentation formats overly tedious and time-consuming. These observations highlight a key challenge: the additional effort required for more comprehensive recording methods often outweighs their perceived benefits.

Participants highlighted that archived catalogs in galleries could serve as a valuable resource for improving literacy in specific areas and offering setup guidance for unfamiliar tuning experiments. This indicates participants' willingness to gain value from their efforts by informing and sharing their knowledge with others, emphasizing the collaborative and educational potential of well-documented catalogs.

7.2.3 Theme 3: Tunes in Conversation. Tunes were often ideated or created based on previous work, highlighting the iterative and conversational nature of the tuning process. Participants frequently engaged in **self-reflective tuning**, building on their personal experiences with earlier tunes, informing and refining subsequent settings.

> **Jackson**: Yeah, I think I can use these documented settings for my other experiments as well.

Participants often used a cloned tune as a starting point, reducing the activation energy to structure a TuneSpace. For example, the TuneSpace for tuning laser cutter settings was readily reused to cut fabric or etch glass, since most situations required adjusting laser power and speed.

Participants noted that having access to others' formatted tune designs was highly valuable for inspiration. These designs provided a structured reference that facilitated ideation and encouraged the exploration of new tuning possibilities. Additionally, all participants emphasized the tool's simplicity across different stages of use, including learning, reporting, setup, and interpreting recorded data. This simplicity increased participants' preference for the tool over spreadsheets or similar alternatives. Activity logs further revealed that participants, such as Mark and Maryam, particularly appreciated browsing others' catalogs, which they used to guide their own tuning efforts and expand their experimental approaches.

> **Maryam**: It's also easier for others to look at your results this [formatted] way, rather than going through a spreadsheet full of numbers or reading through a paragraph of a questionnaire. It's much more engaging and easier for others to understand your data.

However, they also noted that incomplete or unfinished catalogs lacking detailed documentation might undermine trust when sharing catalogs with others, limiting their perceived reliability and usefulness.

> **Paul**: Yes, [the catalogs] can definitely help others. But ... people need to be careful with the data they're trusting. If everyone inputs realistic and honest data, then it could be really helpful.
>
> **Maryam**: I think it should be much easier and faster to replicate the experiments for someone else. You can already see the results that the original person put in and just start with their ideal case, then work from there, so you can get there faster.

To enhance the robustness of catalogs for reusability and validity, several mechanisms emerged as valuable. Participants such as Olivia, Mark, and Paul emphasized the importance of open-ended responses and detailed descriptions of tuning experiment setups. Additionally, some participants highlighted the need for tools that allowed tuning more than two parameters simultaneously or being more explicit about which potential dimensions were held constant or randomized. These insights underscore the need for catalogs to prioritize transparency in documenting factors, thought processes, and evaluation strategies, enabling users to better understand the rationale behind experimental decisions and effectively adapt or build upon previous work.

7.2.4 Theme 4: Reference Catalogs formed from Meta-tuning. Participants consistently emphasized that archiving supports future sense-making, highlighting the importance of accessible catalogs for longitudinal work. The ability to revisit and interact with catalogs over time was viewed as a valuable feature, enabling users to reflect on their processes and outcomes. Rather than perceiving the catalog as merely a numerical summary or heatmap, participants described its potential to narrate a story, offering context and continuity to their work. For example, Maryam wanted to create a tune that would be useful over time as a reference (as opposed to a scientific experiment).

> **Maryam**: I can definitely use my experiment results in the future. If I ever need to recreate that color or make it again, I'll know exactly what ratios to use to get the same result, instead of just eyeballing it.
>
> **Mark**: I think it would be helpful for researchers conducting experimental studies over a few months. It would allow them to track their work and easily recall what they did three months back, just by checking a few notes on the interface.

A reference catalog, even if incomplete, can provide a quick estimation or baseline for tuning experiments, offering users a starting point for their work.

> **Paul**: You can use it [catalog] as a reference. It might be slightly easier to interpret than a spreadsheet, so next time you can get a quick idea of what your starting points or reference points should be for your experiments.
>
> **Olivia**: From these results, I could learn to use different materials or change my experimental technique rather than continuing the experiment in the same way.

However, in longitudinal tuning applications, both evaluation criteria and the associated TuneSpace may evolve over time, requiring the catalog to adapt dynamically to remain relevant and useful. This highlights the need for flexible documentation tools that can accommodate changes (meta-tuning) while maintaining coherence in the archived data. We observed meta-tuning as the primary way reference tunes were developed.

8 Discussion

A summary of findings across the two studies is shown in Table 1. We discuss these findings and their implications for tuning support tools.

8.1 Scaling to High-Dimensional Tuning

While TuneCatalog focuses on 2D tuning spaces to ensure interpretability and accessibility, our diary study revealed insights that could inform scaling to high-dimensional tuning. Participants found catalogs to be inherently conversational, where one tuning process often informed and refined subsequent explorations. This suggests that supporting high-dimensional tuning could involve interconnecting multiple catalogs, preserving interpretability by capturing the iterative and relational nature of tuning as a linked, dynamic process.

High-dimensional tuning is particularly valuable in contexts requiring complex multi-factorial analyses or randomized controlled experiments. While the TuneSpace can be represented as a higher-dimensional structure, effectively navigating and visualizing it requires strategies to structure the exploration. For example, identifying top candidates that explain or influence the greatest number of dimensions can help participants focus their efforts and make sense of the data. Crowdwork approaches could also enhance high-dimensional tuning by enabling multiple contributors to collaboratively explore a shared tuning space. Assigning compartmentalized regions within the TuneSpace could replicate the progress bar effect observed in participants aiming to exhaustively complete their tuning grids. This method could encourage broader community engagement and contribution. Similar to citizen science initiatives, this approach distributes the workload and benefits from diverse perspectives. However, our findings emphasize the importance of transparent documentation practices to establish trust and ensure rigor in community contributions.

8.2 Supporting Archive and Re-examination

TuneCatalog effectively fostered an environment that supported trial-and-error by reframing the negative result; in candidates contributing to a holistic understanding of how dimensions affected the tuning goal. Participants actively planned and explored unknown variables, while also identifying new criteria to consider during the tuning process. This type of activity has value as a learning strategy that has a positive growth mindset and causes learners to more actively consider the factors that influence design artifacts or engineering systems, similar to how current work on unmaking and deconstructive activities make salient how things work [32].

Public tuning catalogs were identified as valuable sources of social inspiration and guidance, particularly when participants were designing their own tunes. Certain TuneSpaces, such as the speed-power TuneSpace for determining optimal laser cutter settings for specific materials, demonstrated exceptional utility for reuse. We envision such template catalogs becoming integral components of material toolkits, enhancing literacy in working with materials, machines, and processes to achieve specific goals while supporting documentation practices. For instance, working with shape memory alloys often requires iterative tuning to achieve a desired shape programmed at a specific temperature [21] or categorizing the behavior of thermoplastic materials at varying kiln temperatures [36]. Similarly, circuit construction-based educational toolkits enable users to iteratively adjust electrical components until the desired conductivity or performance is achieved [44].

8.3 Supporting Longitudinal Tuning

Our tuning framework prioritized supporting diverse tuning workflows by allowing various types of tuning goals to be expressed in a one- or two-dimensional search space. While this approach facilitated common all-at-once tuning, it also provided opportunities for more gradual tuning workflows. Tuning biomaterials presents a particular challenge, especially given the long periods required to produce a single tuning candidate. Although systems designed to capture and document slow material changes through time-lapse have proven effective [39], our study highlighted a more practical challenge: understanding what to look for and what to tune.

We propose **wanderlust** as a factor to consider when evaluating tuning support tools. We use wanderlust to refer to the extent to which users are drawn to explore beyond what is strictly necessary to achieve their goals. In our study, this was induced through a progress bar that encouraged users to investigate every candidate, not out of necessity, but out of curiosity and a desire for completeness. High wanderlust suggests that the tool fosters curiosity, engagement, and a sense of discovery—framing tuning as a creative or sensemaking activity rather than a chore. In contrast, low wanderlust may indicate friction, fatigue, or a lack of perceived value in exploration. Designing for wanderlust involves creating interactions that reward investigation, lower the cost of trying alternatives, and visually signal the richness of the design space. As such, wanderlust offers a valuable lens for understanding how tools can transform optimization into a more exploratory and rewarding experience.

8.4 Searching through Candidates

In our studies, participants self-determined the order in which candidates would be evaluated. Some participants uniformly sampled and evaluated the candidates in their TuneSpace, while others used greedy or exhaustive strategies. For more complex TuneSpaces, such as tuning parameters for a digital art piece that involves multiple dimensions and many candidates, guiding the order of candidate evaluation or introducing computational evaluation techniques (e.g., via LLMs) can be particularly beneficial in reducing material waste and costs (e.g., randomizing which candidates to evaluate). Participants generally responded positively to public catalogs and the standardized catalog format, though there was some distrust in using results from others due to a perceived lack of rigor in candidate

Design Principles	Interactions	Results
Support diverse tuning workflows	Structured TuneSpace setup; multiple criteria types.	+ Workflows: all-at-once tuning; gradual tuning; meta-tuning; catalogs generated beyond fabrication. Δ Evaluation criteria is a moving target.
Reduce activation energy to document/archive	Structured grid; mobile evaluation; cloning from gallery	+ Progress bar effect (wanderlust); feelings of agency and organization; structured and contained experience; tune spaces constructed from prior catalogs. Δ "good enough" candidates limit tuning against all candidates
Enhance longitudinal sensemaking	Archived catalogs; heatmap interpolation	+ Catalogs used as references; glanceable interpretation; gradual tuning observed. Catalogs are conversational, building on each other (criteria evolution). Δ Desire for more data sensemaking mechanisms
Shift perspectives	Public catalogs; all possible candidates displayed;	+ Viewing others' catalogs as social inspiration and guidance; exhaustive evaluation of all candidates showed engagement and confidence. Δ Lack of trust in others catalogs; insufficient notes for generating candidates from others' catalogs

Table 1: Summary of findings from the studies are mapped to each TuneCatalog design principle. This summary offers insights for future enhancements and the development of tuning support tools. Positive outcomes (+) demonstrate observed successes, while challenges (Δ) indicate areas for improvement.

descriptions. However, participants felt they had more agency, especially with the progress bar effect of 'filling in all the candidates.' Crowd tuning, where multiple participants contribute to exploring a common TuneSpace, could be a way to distribute the tedium of tuning, improve rigor through multiple independent evaluations of candidates, and generate more comprehensive knowledge of a machine, material, or process.

8.5 Evaluation and Visualization

Tuning processes often face challenges due to a lack of transparency in the evaluation and insufficient visualization methods. In our study, we primarily used self-reported techniques, such as Likert scales and numerical entries, along with heatmaps for data visualization. However, participants indicated that broader evaluation and visualization strategies would better support the documentation of tuning workflows. While previous tools have used open-ended formats like video or audio recordings for documentation [3], our diary study showed that participants were reluctant to adopt these methods. We found that the activation energy for initiating tuning remained at the level of handwritten notes. While mobile device access facilitated documentation, increasing information required effective curation for critical glanceability.

As goals, environments, or constraints change, so too does the interpretation of what constitutes a "good" solution. This highlights the value of experiential knowledge gained through hand-tuning. For example, participants in our studies frequently changed their target samples after encountering a wide range of unknown variables. We use **criteria evolution and drift** to refer to the tendency of users to introduce new or revised standards over time, often in response to emerging considerations about how a tuned outcome will be used.

This dynamic presents an opportunity for tuning support tools to surface and scaffold tacit knowledge. For instance, tools could support glanceable representations—through notes, tags, or visual highlights—that help users navigate shifting targets while preserving a sense of continuity. Maintaining consistent evaluative anchors is particularly important for identifying a "Goldilocks Zone" of solutions that remain interpretable and comparable across users.

Such consistency also facilitates downstream benefits, including statistical inference, crowdsourced aggregation, and provenance tracking. Importantly, even incomplete records or "holes" in the tuning process can offer meaningful insights into how discovery and interpretation unfold. We argue that future tuning environments should not only capture parameters and criteria but also support re-engagement with past candidates—enabling comparison, ranking, and reflection as users' standards evolve.

To enhance documentation practices in the maker community, we suggest enabling free-form evaluations and the uploading of rich content, but only if users can quickly get a glanceable review of archived data. Techniques such as video digests, large language model (LLM) summarization, and other condensation methods could help scale the variety of data captured, improving both accessibility and efficiency in evaluating and visualizing the collected tuning data.

8.6 Limitations and Future Work

Archivability. Many people often tune the same systems or materials, and catalogs showed promise in making these efforts reusable. However, they remained prone to error, particularly when experimental conditions needed to be precisely replicated. Similarly, documenting some tuning processes through catalogs requires domain-specific knowledge, which may limit accessibility for those unfamiliar with certain fabrication or experimental techniques.

Study Population. While our user studies had a strong focus on 3D printing fabrication, tuning insights would have been strengthened by incorporating a broader range of fabrication practices such as practitioners with primarily art or design backgrounds. Individuals with a design-oriented mindset may approach tuning as a creative and exploratory process rather than one focused purely on optimization [20].

Beyond 2D tuning. The current 2D tuning space is effective for well-defined scenarios; however, future iterations should support more complex, high-dimensional tasks involving multiple interdependent parameters. In such cases, the relevant tuning dimensions may not be known in advance, creating opportunities for tools to support exploratory feature analysis, statistical testing (e.g., ANOVA), or even material conversation workflows to surface meaningful variables to guide the tuning process.

LLM Tuning. Tuning, whether in material experiments or algorithmic prompts like those in LLMs, faces common challenges such as untrackable iterations, lack of sharing, and insufficient long-term sensemaking. A structured approach, similar to TuneCatalog, can benefit those working on fine-tuning LLMs by storing and organizing various tuning data, which facilitates quick evaluation and review. Evaluation metrics proposed by Zheng et al., such as standardized metrics [56] or a grammatical lexicon, could further support users by documenting their prompt-tuning strategies and highlighting the benefits of shared exploration. This approach mirrors how tuning materials enhances understanding of material-machine interactions.

9 Conclusion

We developed and introduced TuneCatalog, a documentation tool designed to support the effective tuning of materials, machines, and processes. We deployed our system as a design probe to gain empirical insights into tuning within common fabrication tasks and longitudinal scenarios. Our analysis showed that structuring the tuning process by defining a finite set of candidates created a contained and curated tuning experience. This reframed participants' view of tuning from a tedious task to one of curiosity and exploration – a behavior we characterized as inducing *wanderlust*. The studies reinforced that tuning is situational, requiring support for workflows that occur either in a single sitting or over time. Tuning behaviors also revealed that effective support must accommodate *criteria evolution and drift*. Lastly, archived catalogs proved valuable not only as glanceable references for tuned data, but more importantly, as windows into the tacit strategies other practitioners use to fine-tune their materials, tools, and techniques to get them "just right".

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References

[1] 2023. *Printing Tugboat.* https://www.thingiverse.com/thing:763622

[2] Muhammad Abdullah, Romeo Sommerfeld, Laurenz Seidel, Jonas Noack, Ran Zhang, Thijs Roumen, and Patrick Baudisch. 2021. Roadkill: Nesting laser-cut objects for fast assembly. In *The 34th Annual ACM Symposium on User Interface Software and Technology.* 972–984.

[3] Nasrin Akter, Nijar Hossain, Iván Sánchez Milara, and Georgi V Georgiev. 2021. Supporting Documentation and Evaluation of Student Progress in Digital Fabrication. *Blucher Design Proceedings. Editora Blucher, UK* (2021), 98–109.

[4] Fiona Bell, Derrek Chow, Hyelin Choi, and Mirela Alistar. 2023. SCOBY Breastplate: Slowly Growing a Microbial Interface. In *Proceedings of the Seventeenth International Conference on Tangible, Embedded, and Embodied Interaction.* 1–15.

[5] Fiona Bell, Derrek Chow, Eldy S Lazaro Vasquez, Laura Devendorf, and Mirela Alistar. 2023. Designing Interactions with Kombucha SCOBY. In *Proceedings of the Seventeenth International Conference on Tangible, Embedded, and Embodied Interaction.* 1–5.

[6] Michael Mose Biskjaer, Peter Dalsgaard, and Kim Halskov. 2014. A constraint-based understanding of design spaces. In *Proceedings of the 2014 Conference on Designing Interactive Systems* (Vancouver, BC, Canada) *(DIS '14).* Association for Computing Machinery, New York, NY, USA, 453–462. doi:10.1145/2598510.2598533

[7] V Braun and V Clarke. 2014. Thematic analysis in encyclopedia of critical psychology.

[8] Virginia Braun and Victoria Clarke. 2021. Thematic analysis. Analysing qualitative data in psychology.

[9] Serena Camera and Elvin Karana. 2018. Experiential characterization of materials: Toward a toolkit. In *Proceedings of the DRS International Conference 2018.*

[10] Victoria Clarke and Virginia Braun. 2017. Thematic analysis. *The journal of positive psychology* 12, 3 (2017), 297–298.

[11] Victoria Clarke, Virginia Braun, and Nikki Hayfield. 2015. Thematic analysis. *Qualitative psychology: A practical guide to research methods* 222, 2015 (2015), 248.

[12] Aaron Mosiah Curtis, Taylor Michael Wells, Trevor Higbee, and Paul Benjamin Lowry. 2008. An overview and tutorial of the repertory grid technique in information systems research. *Communications of the Association for Information Systems (CAIS)* 23, 3 (2008), 37–62.

[13] Bruna Goveia da Rocha, Janne Spork, and Kristina Andersen. 2022. Making Matters: Samples and Documentation in Digital Craftsmanship.. In *TEI.* 37–1.

[14] Fabricio Davila, Freddy Paz, and Arturo Moquillaza. 2023. Usage and Application of Heatmap Visualizations on Usability User Testing: A Systematic Literature Review. In *International Conference on Human-Computer Interaction.* Springer, 3–17.

[15] Kristin N Dew, Sophie Landwehr-Sydow, Daniela K Rosner, Alex Thayer, and Martin Jonsson. 2019. Producing printability: Articulation work and alignment in 3d printing. *Human–Computer Interaction* 34, 5-6 (2019), 433–469.

[16] Omid Ettehadi, Fraser Anderson, Adam Tindale, and Sowmya Somanath. 2021. Documented: Embedding information onto and retrieving information from 3D printed objects. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems.* 1–11.

[17] Kim Halskov and Caroline Lundqvist. 2021. Filtering and Informing the Design Space: Towards Design-Space Thinking. *ACM Trans. Comput.-Hum. Interact.* 28, 1, Article 8 (Jan. 2021), 28 pages. doi:10.1145/3434462

[18] Takeru Hashimoto, Shigeo Yoshida, and Takuji Narumi. 2022. MetamorphX: An Ungrounded 3-DoF Moment Display that Changes its Physical Properties through Rotational Impedance Control. In *Proceedings of the 35th Annual ACM Symposium on User Interface Software and Technology.* 1–14.

[19] Tero Jokela, Jarno Ojala, and Thomas Olsson. 2015. A diary study on combining multiple information devices in everyday activities and tasks. In *Proceedings of the 33rd annual ACM conference on human factors in computing systems.* 3903–3912.

[20] Elvin Karana, Elisa Giaccardi, Niels Stamhuis, and Jasper Goossensen. 2016. The tuning of materials: a designer's journey. In *Proceedings of the 2016 ACM conference on designing interactive systems.* 619–631.

[21] Hyunyoung Kim, Aluna Everitt, Carlos Tejada, Mengyu Zhong, and Daniel Ashbrook. 2021. Morpheesplug: A toolkit for prototyping shape-changing interfaces. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems.* 1–13.

[22] Jeeeun Kim, Anhong Guo, Tom Yeh, Scott E Hudson, and Jennifer Mankoff. 2017. Understanding uncertainty in measurement and accommodating its impact in 3D modeling and printing. In *Proceedings of the 2017 conference on designing interactive systems.* 1067–1078.

[23] David Krakov and Dror G Feitelson. 2013. Comparing performance heatmaps. In *Workshop on Job Scheduling Strategies for Parallel Processing.* Springer, 42–61.

[24] Matthias Kraus, Katrin Angerbauer, Juri Buchmüller, Daniel Schweitzer, Daniel A Keim, Michael Sedlmair, and Johannes Fuchs. 2020. Assessing 2d and 3d heatmaps for comparative analysis: An empirical study. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems.* 1–14.

[25] Chen Liang, Anhong Guo, and Jeeeun Kim. 2022. CustomizAR: Facilitating Interactive Exploration and Measurement of Adaptive 3D Designs. In *Proceedings of the 2022 ACM Designing Interactive Systems Conference.* 898–912.

[26] Bruno Maric, Alan Mutka, and Matko Orsag. 2020. Collaborative human-robot framework for delicate sanding of complex shape surfaces. *IEEE Robotics and Automation Letters* 5, 2 (2020), 2848–2855.

[27] Justin Matejka, Michael Glueck, Erin Bradner, Ali Hashemi, Tovi Grossman, and George Fitzmaurice. 2018. Dream lens: Exploration and visualization of large-scale generative design datasets. In *Proceedings of the 2018 CHI conference on human factors in computing systems*. 1–12.

[28] Iván Sánchez Milara, Georgi V Georgiev, Jani Ylioja, Onnur Özüduru, and Jukka Riekki. 2019. " Document-while-doing": a documentation tool for Fab Lab environments. *The Design Journal* 22, sup1 (2019), 2019–2030.

[29] Hedieh Moradi, Long N Nguyen, Quyen-Anh Valentina Nguyen, and Cesar Torres. 2022. Glaze Epochs: Understanding Lifelong Material Relationships within Ceramics Studios. In *Sixteenth International Conference on Tangible, Embedded, and Embodied Interaction*. 1–13.

[30] Celeste Moreno and Ricarose Roque. 2023. Revealing the Tuning Practices of Creative Learning Experience Designers. In *Proceedings of the 15th Conference on Creativity and Cognition*. 529–540.

[31] Stefanie Mueller, Martin Fritzsche, Jan Kossmann, Maximilian Schneider, Jonathan Striebel, and Patrick Baudisch. 2015. Scotty: Relocating physical objects across distances using destructive scanning, encryption, and 3D printing. In *Proceedings of the Ninth International Conference on Tangible, Embedded, and Embodied Interaction*. 233–240.

[32] Martin Murer. 2018. Making things apart: gaining material understanding. In *Proceedings of the 2018 Designing Interactive Systems Conference*. 497–509.

[33] Nathalie Overdevest, Rakesh Patibanda, Aryan Saini, Elise Van Den Hoven, and Florian 'Floyd' Mueller. 2023. Towards Designing for Everyday Embodied Remembering: Findings from a Diary Study. In *Proceedings of the 2023 ACM Designing Interactive Systems Conference*. 2611–2624.

[34] Ivan Poupyrev, Zhiquan Yeo, Joshua D Griffin, and Scott Hudson. 2010. Sensing human activities with resonant tuning. In *CHI'10 Extended Abstracts on Human Factors in Computing Systems*. 4135–4140.

[35] Mattia Racca, Ville Kyrki, and Maya Cakmak. 2020. Interactive tuning of robot program parameters via expected divergence maximization. In *Proceedings of the 2020 ACM/IEEE International Conference on Human-Robot Interaction*. 629–638.

[36] Mohammad Abu Nasir Rakib, Jeremy Scidmore, Justin Ginsberg, and Cesar Torres. 2023. Thermoplastic Kilnforms: Extending Glass Kilnforming Techniques to Thermoplastic Materials using Ontology-Driven Design. In *Proceedings of the 2023 ACM Designing Interactive Systems Conference*. 263–281.

[37] Raf Ramakers, Danny Leen, Jeeeun Kim, Kris Luyten, Steven Houben, and Tom Veuskens. 2023. Measurement Patterns: User-Oriented Strategies for Dealing with Measurements and Dimensions in Making Processes. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems*. 1–17.

[38] Eric Rawn, Jingyi Li, Eric Paulos, and Sarah E Chasins. 2023. Understanding Version Control as Material Interaction with Quickpose. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems*. 1–18.

[39] Clarice Risseeuw, Jose Francisco Martinez Castro, Pascal Barla, and Elvin Karana. 2023. FlavoMetrics: Towards a Digital Tool to Understand and Tune Living Aesthetics of Flavobacteria. In *Proceedings of the 2023 ACM Designing Interactive Systems Conference*. 2079–2092.

[40] Thijs Roumen, Ingo Apel, Jotaro Shigeyama, Abdullah Muhammad, and Patrick Baudisch. 2020. Kerf-canceling mechanisms: making laser-cut mechanisms operate across different laser cutters. In *Proceedings of the 33rd Annual ACM Symposium on User Interface Software and Technology*. 293–303.

[41] Thijs Roumen, Yannis Kommana, Ingo Apel, Conrad Lempert, Markus Brand, Erik Brendel, Laurenz Seidel, Lukas Rambold, Carl Goedecken, Pascal Crenzin, et al. 2021. Assembler3: 3d reconstruction of laser-cut models. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems*. 1–11.

[42] Thijs Roumen, Conrad Lempert, Lukas Rambold, Muhammad Abdullah, and Patrick Baudisch. 2022. Demonstrating 3D Reconstruction to Modify 2D Laser Cutting Plans. In *CHI Conference on Human Factors in Computing Systems Extended Abstracts*. 1–3.

[43] Andrew O Sageman-Furnas, Nobuyuki Umetani, and Ryan Schmidt. 2015. Meltables: fabrication of complex 3d curves by melting. In *SIGGRAPH Asia 2015 Technical Briefs*. 1–4.

[44] Laura Scheepmaker, Kay Kender, Christopher Frauenberger, and Geraldine Fitzpatrick. 2021. Leaving the field: Designing a socio-material toolkit for teachers to continue to design technology with children. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems*. 1–14.

[45] Anjeli Singh and Sareeka Malhotra. 2013. A researcher's guide to running diary studies. In *Proceedings of the 11th Asia Pacific Conference on Computer Human Interaction*. 296–300.

[46] Sarah Sterman, Molly Jane Nicholas, and Eric Paulos. 2022. Towards Creative Version Control. *Proceedings of the ACM on Human-Computer Interaction* 6, CSCW2 (2022), 1–25.

[47] Sarah Sterman, Molly Jane Nicholas, Janaki Vivrekar, Jessica R Mindel, and Eric Paulos. 2023. Kaleidoscope: A reflective documentation tool for a user interface design course. In *Proceedings of the 2023 CHI conference on human factors in computing systems*. 1–19.

[48] Blair Subbaraman and Nadya Peek. 2023. 3D printers don't fix themselves: how maintenance is part of digital fabrication. In *Proceedings of the 2023 ACM designing interactive systems conference*. 2050–2065.

[49] Blair Subbaraman and Nadya Peek. 2024. Playing the Print: MIDI-Based Fabrication Interfaces to Explore and Document Material Behavior. In *Extended Abstracts of the CHI Conference on Human Factors in Computing Systems*. 1–8.

[50] Haruki Takahashi and Homei Miyashita. 2017. Expressive fused deposition modeling by controlling extruder height and extrusion amount. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems*. 5065–5074.

[51] Tiffany Tseng. 2015. Making make-throughs: Supporting young makers sharing design process. In *Conference on Creativity and Fabrication in Education-Fablearn*, Vol. 15.

[52] Tiffany Tseng. 2015. Spin: a photography turntable system for creating animated documentation. In *Proceedings of the 14th International Conference on Interaction Design and Children*. 422–425.

[53] Udayan Umapathi, Hsiang-Ting Chen, Stefanie Mueller, Ludwig Wall, Anna Seufert, and Patrick Baudisch. 2015. LaserStacker: Fabricating 3D objects by laser cutting and welding. In *Proceedings of the 28th Annual ACM Symposium on User Interface Software & Technology*. 575–582.

[54] Eldy S Lazaro Vasquez and Katia Vega. 2019. Myco-accessories: sustainable wearables with biodegradable materials. In *Proceedings of the 2019 ACM International Symposium on Wearable Computers*. 306–311.

[55] Shota Yamanaka and Hiroki Usuba. 2023. Tuning Endpoint-variability Parameters by Observed Error Rates to Obtain Better Prediction Accuracy of Pointing Misses. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems*. 1–18.

[56] Xingchen Zeng, Ziyao Gao, Yilin Ye, and Wei Zeng. 2024. IntentTuner: An Interactive Framework for Integrating Human Intentions in Fine-tuning Text-to-Image Generative Models. In *Proceedings of the CHI Conference on Human Factors in Computing Systems*. 1–18.

[57] Zheng-Yu Zhao, Mo Li, Zheng Zhang, Qing Fang, Ligang Liu, and Xiao-Ming Fu. 2023. Evolutionary Piecewise Developable Approximations. *ACM Transactions on Graphics (TOG)* 42, 4 (2023), 1–14.

[58] Matthew M Ziegler, Lakshmi N Reddy, and Robert L Franch. 2022. Design flow parameter optimization with multi-phase positive nondeterministic tuning. In *Proceedings of the 2022 International Symposium on Physical Design*. 29–37.