Process-Sensitive Creativity Support Tools

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Process-Sensitive Creativity Support Tools

by

Sarah Gimbert Sterman

A dissertation submitted in partial satisfaction of the

requirements for the degree of

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in

Computer Science

and the Designated Emphasis

in

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of the

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Committee in charge:

Professor Eric Paulos, Chair
Professor Abigail De Kosnik
Professor Björn Hartmann

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Abstract

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Technology is deeply entwined with creativity. In creative work today, computational tools provide unique capabilities, new materials, and shape how we perform tasks. Yet many modern computer systems have roots in productivity and industrial contexts, the needs and values of which do not always align with those of creative work. In this dissertation, I seek to understand the values of creative process, and how these values can inform the design of creativity support tools that embrace the messy, complicated, and human aspects of creative work.

This dissertation contributes two concepts for organizing our approach to creative process. *Value inversions* define moments when the values in creative process seem at odds with traditional computational values; these inversions reveal opportunities for changing our expectations of the role of tools in our work and perceptions about effective workflows. *Process-sensitive creativity support tools* embrace the values of creative process, foregrounding the actions and mindsets necessary to creative work rather than solely focusing on output. To develop these concepts, this dissertation combines qualitative research on professional creative practice with the design and evaluation of novel computational tools in the areas of creative writing, documentation tools, and design education.

As we integrate existing tools into our workflows and develop novel creativity support tools, it is important to consider how these tools are shaping our process and workflows. The expectations and values embedded in our tools have concrete effects on how we work, how we evaluate success, and how we learn and grow as creative practitioners.

To my family, who taught me the beauty of both words and numbers.

And to all the young writers, scientists, artists, and engineers who are ‘all of the above.’

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Chapter 1

Introduction

Creativity is an essential part of human progress, expression, and flourishing. Whether the day-to-day creativity we all perform, or works that change entire fields, engaging in creative activity allows us to express our perspectives, solve problems, provoke questions, and bring new forms into being. You likely use creativity in your life: perhaps you create new recipes when you cook, paint in your free time, do scientific research or media art, or figure out clever fixes to broken objects. However creativity manifests in your life, I invite to you to consider your own creative process as you read this dissertation. Perhaps some techniques we explore will resonate with your own experiences; perhaps some will spark something new.

Often when we discuss creativity, we think of outputs – objects or ideas that are novel and useful in their context. A piece of art that makes us realize something unexpected might be creative, or an algorithm that solves a problem in a radically new way. But we can also think about *creative process*, or how we do the work that leads to these creative outputs. Discussing process centers the actions taken to do creative work and the context they occur in – environment, mindsets, and external pressures – and suggests that to increase creativity, we should consider the experience of performing creative work. Focusing on the experience of work also foregrounds human expression and flourishing as important outcomes: *doing* creative work can be as valuable as producing a creative *output*. At the same time, understanding and improving process increases the quality of creative outputs.

Yet despite the importance of process in understanding and supporting creative work, process is harder to study and define than outputs (Amabile 2018). While we can evaluate particular aspects of process, we lack a comprehensive understanding of creative process and the role of tools within it. **This dissertation seeks to contribute to understanding creative process through an investigation of the values practitioners hold in creative process, and how these values can inform the design of creativity support tools.**

Every tool designed by a human being is influenced by what the creator values. These values are expressed in the tool's capabilities, underlying structures, and presentation, as well as through the metrics we use to evaluate the tool. Today, computers are increasingly at the heart of modern work, whether in engineering, business, art, or design, and how we do creative work is becoming in large part dependent on how we use computational systems, drawing capabilities, values, and assumptions about ways of working from technological norms. Yet the histories that have led to the design of current technologies do not always align with the needs of creative work. In thinking about "creativity support tools" instead of "productivity support tools" (Shneiderman 2007), we must think not only about a new set of tasks that must be supported, but a new set of values. A spreadsheet can be a productivity tool, and it can be a creativity tool, allowing a user to flexibly explore scenarios. But simply using a tool in a new context does not mean that the values it was designed with are necessarily matched to the new needs.

For example, the design of digital fabrication tools grew from the history of mass manufacturing and industrial production. Despite a promise of flexible creativity, personal fabrication, and democratization of design, the tools and workflows of digital fabrication drew from the values of mass manufacturing: for example, precision, repeatability, and amortization of effort. While important and appropriate to manufacturing, these values can stand in the way of certain kinds of creativity. For example, CAD workflows developed for industrial contexts introduce significant overhead when used by hobbyists to create a one-of-a-kind objects. Challenging these value assumptions create opportunities for new ways of working, expanded participation, and greater creativity to flourish. For example, Tian draws values from manual craft practices like woodworking to expand the range of digital fabrication workflows (Tian et al. 2018; Tian 2021).

When then, does designing with computational values at the forefront limit our conceptual framing of what the role of digital tools should be in creative process? Do we need to change how we think about values in the design of computational tools?

To better support creative process with digital tools, we must understand where the values and assumptions about our systems come from, and question whether they are aligned with the needs of process, not just outputs or prior system values. In this dissertation, I present the concept of *process-sensitive* creativity support tools:

> **Process-Sensitive Creativity Support Tool:** A computational tool whose values are guided by the experience of performing creative tasks, rather than enabling specific outputs.

Process-sensitive creativity support tools foreground how people work and what they value in their creative work: not just outputs, but ways of working, mindsets, and creative growth. These creative processes can be full of fits and starts, redos, failures, mistakes, moments of euphoria – this winding journey can seem unstructured, but there are many strategies, techniques, and values that underlie it. The diversity of approaches can make creativity seem messy and hard to pin down. Yet when we resist the temptation to 'organize' or 'fix' our creative process with the metrics of productivity, we gain opportunities for understanding and supporting creativity more deeply.

By engaging with process as a lens for tool design, this dissertation seeks to align the

Figure 1.1: Messy creative workshops. Studios and workshops are familiar examples of creative mess, such as this violin maker's studio (left) and ceramicist's workshop (right), where tools, materials, inspirations, references, works-in-progress, completed pieces, and others share space.

values embedded in our digital tools with how we perform effective, fulfilling, and enriching creative work. Such explicit engagement with values allows us to more clearly identify when assumptions inherited from other historical roots are in fact at odds with the needs of creative process, what we will call *value inversions*:

Value Inversion: When a value found in creative process is contradictory to a value embedded in a tool's design or assumed from another context to be appropriate.

For example, "organization" is often a core value of computational systems; we can see this in the way many tools are built with file system metaphors, and present information in neat grids and lists. Yet creative spaces are often messy — studios or workshops are familiar examples of creative mess. Instead of neat lists or menus that separate tools from content, a violin maker's studio is a mix of old pieces, in-progress work, materials, tools, and references (Figure 1.1). Psychology research has found that there are benefits to mess, showing that messy environments encourage creativity and a preference for novelty (Vohs et al. 2013, Figure 1.2). A set of value inversions explored in this thesis are listed in Table 1.1.

We can think of these values as a form of *process mess*: they are not always helpful, they can be uncomfortable, they can chafe against our expectations for what a "good system" or an "effective system" should do. We might wish to clean them up, to bring consistency and organization to our creative process. In this thesis, I hope to demonstrate the importance of process mess, of embracing the benefits that process values can bring to our creative

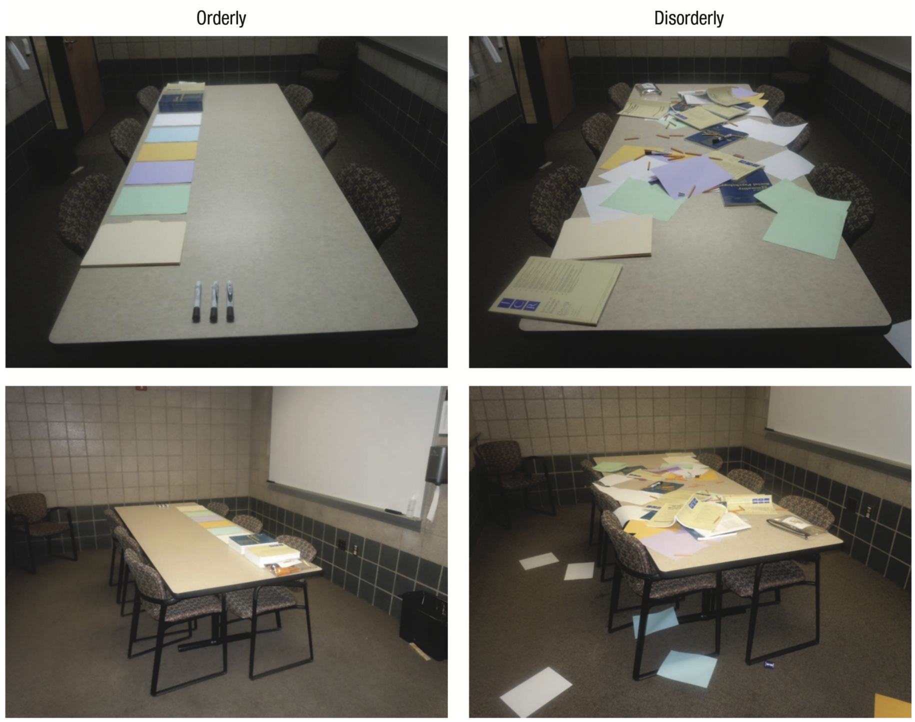

Figure 1.2: Mess encourages novelty. Vohs et al. demonstrated that messy spaces can encourage creativity and a preference for novelty (Figure from Vohs et al. 2013).

outputs and experiences. Submitting to the desire to allow computational values to define our creative lives for the sake of ease and organization would be a disservice to the richness and complexity of human creativity.

Designing process-sensitive software tools requires us to identify what creative practitioners value, understand how creative practitioners structure their process, and integrate the inherently messy, complicated, and human aspects of creative process with the capabilities of computer tools. To do this, I integrate qualitative methods and design approaches to generate conceptual frameworks of creative process and build new tools to support process.

I address three primary research questions in this dissertation:

R1: What process values are present in existing creative practices?

It is important to understand first what values relating to process are successful and desirable in how creative work is performed. Some of these may be specific to particular tasks or domains; some may be shared across contexts. This research question requires studies in multiple domains and practices, where empirical research on existing contexts and behaviors by practitioners can provide a structured understanding of the breadth of creative

Computational Value	**Creative Process Value**	**Introduced in Chapter**
Accuracy	Uncertainty	Chapter 3
Categorization	Interpretation	Chapter 3
Ease	Friction	Chapter 4
Retention	Forgetting	Chapter 4, 5
Precision	Imprecision	Chapter 5
Replication	Adaptability	Chapter 5

Table 1.1: Value inversions in this dissertation. This dissertation presents a selection of computational values inverted by expert practitioners in their creative processes. Specific workflows and strategies instantiate these values at different points in the process. These values can be incorporated into tool designs, or resisted by them.

process and lay the groundwork for the next questions.

R2: How do creative practitioners instantiate these values in specific strategies and behaviors? How do tools, computational and otherwise, support or inhibit these strategies?

Part of how we understand values is by observing what practitioners do. The specific strategies and behaviors of creative practitioners as they structure their work give insight into what they value, as well as bringing those values to life. These strategies and behaviors help us understand how to support process values by enabling particular ways of working. Tools play an essential role, shaping what is possible to do, and how easy it is to achieve. Therefore it is important to understand what existing tools practitioners choose to use or not use, and how they integrate into practitioners' processes.

R3: How can creativity support tool designers leverage process values and techniques to create computational tools that support process as well as output?

Studying existing practice is valuable for a deeper understanding of creativity and creative work. The final question of this thesis is how to take that understanding to design better computational creativity support tools. Tools that center process in their design might help teach skills, improve wellbeing, and expand the ways that we imagine using and designing computational tools. To create such tools, this dissertation explores how to use value inversions and creative techniques to guide tool design for novel computational experiences to further creativity.

1.1 Contribution Summary

This dissertation contributes to the field of creativity support by introducing the concept of process-sensitive tools and exploring how explicit engagement with process and values can enrich the roles of creativity support tools. I do so through two complementary types of work: insights into the role of tools in creative process derived from interviews with expert practitioners, and novel system designs for process-sensitive tools.

1.1.1 Insights about Process

Interviews with expert practitioners reveal strategies and values that shape effective creative process, through managing motivation, encouraging positive affect and growth mindsets, and supporting ideation, revision, and reflection. This work presents thematic analyses of semi-structured interviews with expert practitioners across a variety of domains, grounded in their workplaces and tools, to help us understand creative process and guide the design of tools that engage explicitly with creative process.

Chapter 4 presents four expert strategies for structuring creative process and motivation: strategic forgetting, mode switching, embodying process, and aestheticizing. These strategies reveal value inversions including retention/forgetting and ease/friction.

Chapter 5 presents four considerations for version control tools in creative process: using versions as a palette of materials, gaining confidence and freedom to explore through reversion, deconstruction, and recreation, supporting variation through low-fidelity records, and using versions across long lifetimes. These considerations address value inversions including replication/adaptability, precision/imprecision, and retention/forgetting.

1.1.2 Novel System Designs

Designing novel systems allows us to instantiate and study the effect of process-sensitive creativity support tools. This dissertation presents two interactive computational systems: Style Interfaces (Chapter 3) and Kaleidoscope (Chapter 6).

To design the Style Interfaces, I explored how readers and writers work with style, and how value inversions including accuracy/uncertainty and categorization/interpretation can support these processes. The design of the Style Interfaces draws from these insights and values. The interfaces include two interactive visualizations, a *style space* and *style barcodes* to support close reading and distant reading analyses of style, and to support creative writing and style-based browsing.

Kaleidoscope is a documentation tool for online group collaboration in a design course, using multimedia artifacts and a shared visual history to help students collect and reflect on the history of their creative process. Kaleidoscope draws key design goals from the themes of Chapters 4 and 5, including embodying process, aestheticizing, and using history as a palette of materials.

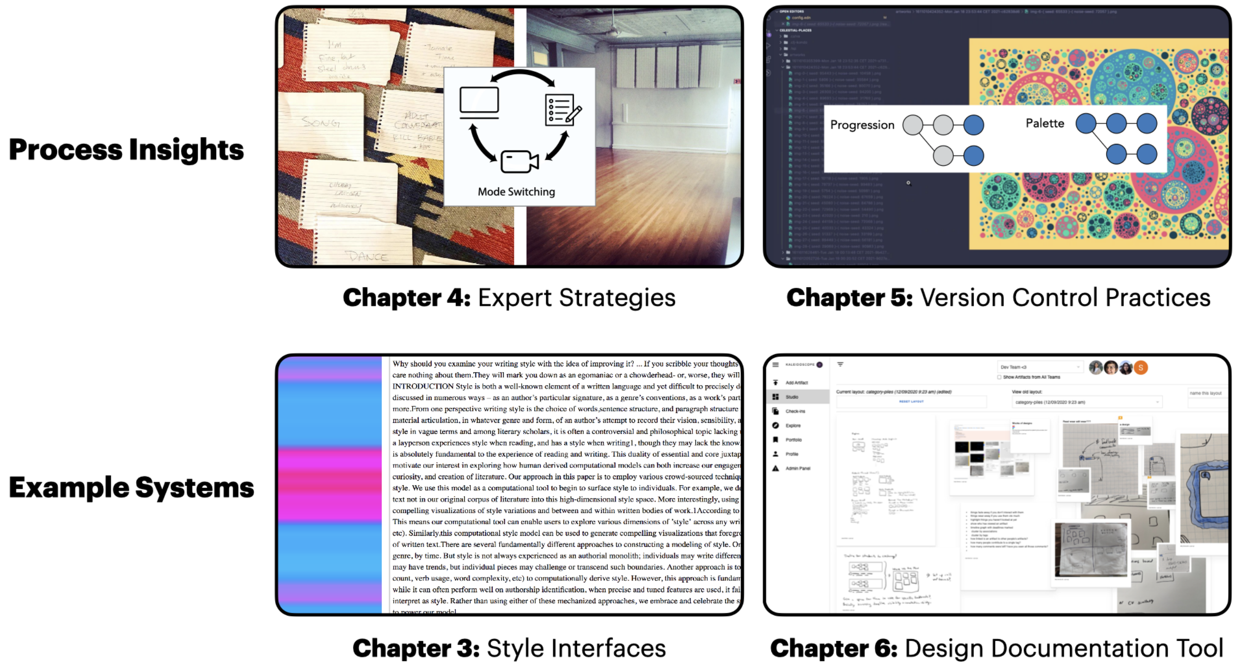

Figure 1.3: Dissertation outline. This thesis includes two types of contributions: Chapters 4 and 5 primarily present insights on creative process, including themes and strategies drawn from qualitative interviews with expert creative practitioners (Nicholas et al. 2022; Sterman, Nicholas, et al. 2022). Chapters 3 and 6 primarily present novel designs of process-sensitive creativity support tools, including interfaces for literary style (Sterman, E. Huang, et al. 2020) and for documentation in a design course.

1.2 Structure

This dissertation explores *process-sensitive creativity support tools* and *value inversions* as frameworks for creativity support tool analysis and design through four examples.

In Chapter 2, I review prior work on creativity theory and creativity support tools. I present key definitions for terms used in the remainder of the dissertation, and argue for the need for a process-centric perspective on tool design.

Chapter 3 discusses how process-sensitive design approaches can inform novel creative writing tools. I present interfaces for literary style to explore how the values in prior computational systems for style analysis, including machine learning and stylometry, are at odds with the process values of readers and writers. I explore how a process-sensitive tool opens up new opportunities for reflection, analysis, and creative work.

Chapters 4 and 5 present an analysis of history and documentation tools in creative domains. Through a series of 18 interviews with expert creative practitioners, these chapters explore how creative process and documentation tools mutually shape each other. Chapter 4 focuses on creative strategies, identifying specific behaviors around history and documentation that practitioners use to structure motivation, affect, inspiration, and revision. Chapter 5 explores the relationship between the values held by expert practitioners for creative process and the values embedded in computational version control systems.

Chapter 6 brings the prior chapters together, applying the framework of process-sensitive design and the qualitative insights on process from expert practitioner interviews to the design of Kaleidoscope, a process-sensitive tool for remote collaboration in a user interface design course.

Finally, Chapter 7 reflects on the concept of process-sensitive creativity support tools and value inversions in broader contexts, and discusses limitations and future work in the space of tools for creative process.

1.3 Statement of multiple authorship and prior publication

This dissertation draws upon work that was previously published at the ACM CHI 2020 conference (*Interacting with Literary Style*, Sterman, E. Huang, et al. 2020), the ACM C&C 2022 conference (*Creative and Motivational Strategies of Expert Practitioners*, Nicholas et al. 2022), and the ACM CSCW 2022 conference (*Towards Creative Version Control*, Sterman, Nicholas, et al. 2022). Although I served as first author or co-first author and led the research and writing behind each work, each piece of work was deeply collaborative. *Creative and Motivational Strategies* and *Towards Creative Version Control* were co-authored with Molly Nicholas, who interviewed participants, collaboratively analyzed data, and co-wrote the papers with me. Janaki Vivrekar, Molly Nicholas, and Jessie Mindel developed code for the Kaleidoscope system, and assisted in data collection and analysis. Vivian Liu and Evey Huang provided invaluable brainstorming and prototyping to the literary style analysis tools. Members of the Hybrid Ecologies Lab – Rundong Tian, Christie Dierk, Cesar Torres, Katherine Song, Janaki Vivrekar, Eric Rawn, and Chris Myers – inspired, critiqued, and shaped all the works in this thesis. My advisor Eric Paulos provided essential feedback, inspiration, and support to my research.

Chapter 2

Background and Related Work

This chapter situates our discussion of process in creative work in the context of research on creativity, tool design, and creativity support tools. Each of these topics is an extensive domain, crossing multiple disciplinary bounds; here, I highlight a selection of key theories and prior work that ground and contextualize the ideas explored in this thesis. Work related to specific domains of practice are discussed in more detail in individual chapters, including creative writing and literary style (Chapter 3), documentation and history-keeping (Chapter 4), version control (Chapter 5), and design education (Chapter 6).

2.1 Theories of Creativity

Many definitions of creativity have been proposed over time, as researchers attempt to understand what "creativity" means, and what affects it. The common thread of currently accepted definitions require *originality* and *effectiveness* (Plucker et al. 2004; Runco et al. 2012; Barron 1955; Stein 1953; Amabile 2018; Kaufman et al. 2009; Frich, Biskjaer, MacDonald Vermeulen, et al. 2019; Csikszentmihalyi 2015). These definitions typically take creativity to be a feature of an *output*, where we evaluate an artifact – be it an invention, design, piece of art, or idea – in terms of its relation to prior artifacts and its ability to fulfill the task or goal it addresses.

Teresa Amabile argues for the necessity of an output-focused definition as follows: "Given the current state of psychological theory and research methodology, a definition based on process is not feasible...the identification of a thought process or subprocess as creative must finally depend upon the fruit of that process – a product or response" (Amabile 2018). One can examine an output, compare it to other outputs, and define its usefulness and novelty. However, she also proposes an underlying conceptual definition of creativity, that addresses creative process:

> A product or response will be judged as creative to the extent that (a) it is both a novel and appropriate, useful, correct or valuable response to the task at hand, and (b) the task is heuristic rather than algorithmic. (Amabile 2018)

The requirement that the task be heuristic rather than algorithmic addresses *how* the creative work is performed, not just features of its final state. This definition uses a quality of process (being heuristic) as a necessary, but not sufficient, component of the definition of creativity; not every heuristic action results in a creative output, as the output must also be novel and appropriate.

In investigating creative process, this dissertation draws from a social constructivist (Von Glasersfeld 2012) perspective, which embraces a broad understanding of the ways in which people, environments, and tools combine to shape both process and outcome (Dalsgaard 2014; James Hollan et al. 2000; Latour 1996; Suchman and Jordan 1990; Von Glasersfeld 2012; Plucker et al. 2004; Dalsgaard 2017). Plucker et al. articulate such a vision of creativity research, focusing on the interaction between "aptitude, process, and environment" (Plucker et al. 2004). Amabile's Componential Model of creativity is an influential framing that takes into account both aptitude and process, emphasizing three core aspects of creativity: domain-relevant skills, creativity-relevant processes, and task motivation (especially intrinsic motivation) (Amabile and Pillemer 2012). Creative work is done in a particular social and environmental context, and creative work can be intentionally or implicitly shaped by this context.

In this dissertation, I am primarily concerned with the question of process. To investigate process in creative contexts, I draw from the common requirement of originality and effectiveness (or "novel[ty]" and "appropriate[ness]" as Amabile puts it) to motivate selection of domains and practitioners: I seek contexts where the goal is creative output. I will consider a *creative domain* to be any domain in which the practitioner's goal is a creative output, and the practitioner engages in a process involving open-ended problem solving and heuristic approaches to task completion (Amabile 2018). A *creative practitioner* is an individual engaged in this type of problem solving or heuristic task. The outputs of expert and professional creative practitioners have been validated by their peers and prior work as creative; therefore we can consider the way they perform that work as an example of creative process.

Kaufman and Beghetto define a range of types of creativity, from "creative genius" to how children learn (Kaufman et al. 2009). In addition to eminent creativity or "Big-C" creativity and "little-c" creativity of everyday innovation, they present "Pro-c" and "mini-c" creativity. This "Four C" model recognizes the possibility for learning and developing creativity, and for transitioning between types of creativity over a practitioner's lifetime (Figure 2.1). In this dissertation, Chapters 4 and 5 primarily investigate Pro-c creativity, looking at the ways that professional creative practitioners perform their work to characterize specific techniques and values of creative process. Chapter 6 explores how a process-focused tool in an educational context might assist in the transitions from mini-c and little-c creativity to Pro-c behaviors and mindsets. Designing to support learning and improving creative process embraces a focus on dynamic, mutable aptitudes rather than on the study of static, immutable personality traits (Amabile 2018; Plucker et al. 2004; Glăveanu et al. 2021; Diakidoy et al. 2001).

Kaufman and Beghetto also emphasize that creativity can be used to express oneself or enrich a personal life: "Creativity for its own sake is a worthy end goal, regardless of how a creative product may be reviewed or received by a larger population" (Kaufman et al.

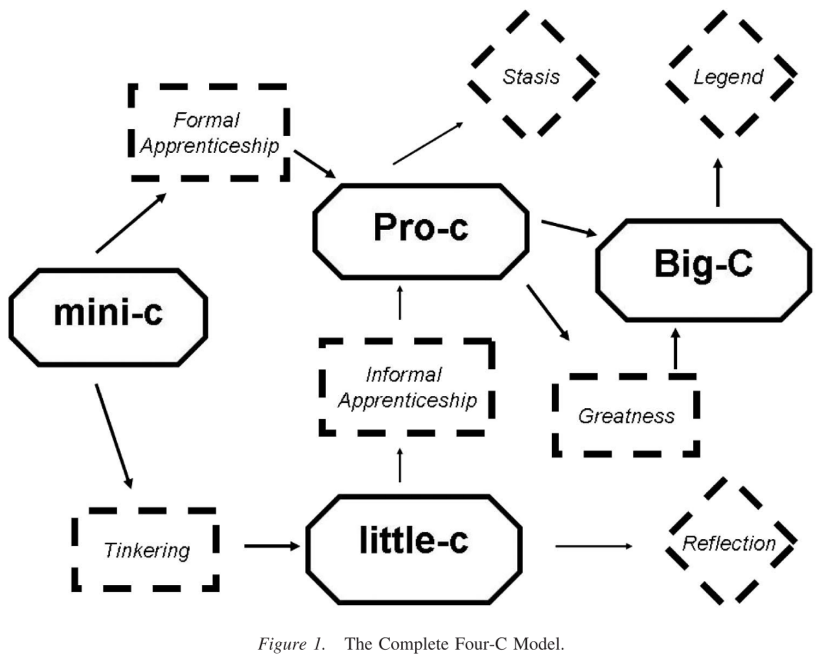

Figure 2.1: "Four C" model of creativity. Kaufman and Beghetto demonstrate how a practitioner might move through four different types of creativity over the course of their lifetime of work (Figure from Kaufman et al. 2009).

2009). This dissertation embraces this perspective as well. Regardless of the "quality" of the output, the act of creative work and expression has value for the full expression and flourishing of human experience. Creativity can be learned, practiced, and improved, and studying creativity at many levels can help us understand how tools can support people in learning, practicing, and improving.

2.2 Creative Process

If creativity is the act of working towards original and effective outputs, and anyone can be creative, we might ask what goes into doing creative work. How do we perform creative work? What is creative process? It is useful first to clarify several levels of detail with which we can discuss creative process: frameworks, tasks, and strategies (Figure 2.2).

2.2.1 Frameworks

At the highest level, we can consider "process" through the lens of high-level models, made up of stages which describe the entire cycle of creative work from problem to output (Figure 2.3). For example, structuralist approaches describe key stages to creative process, which if

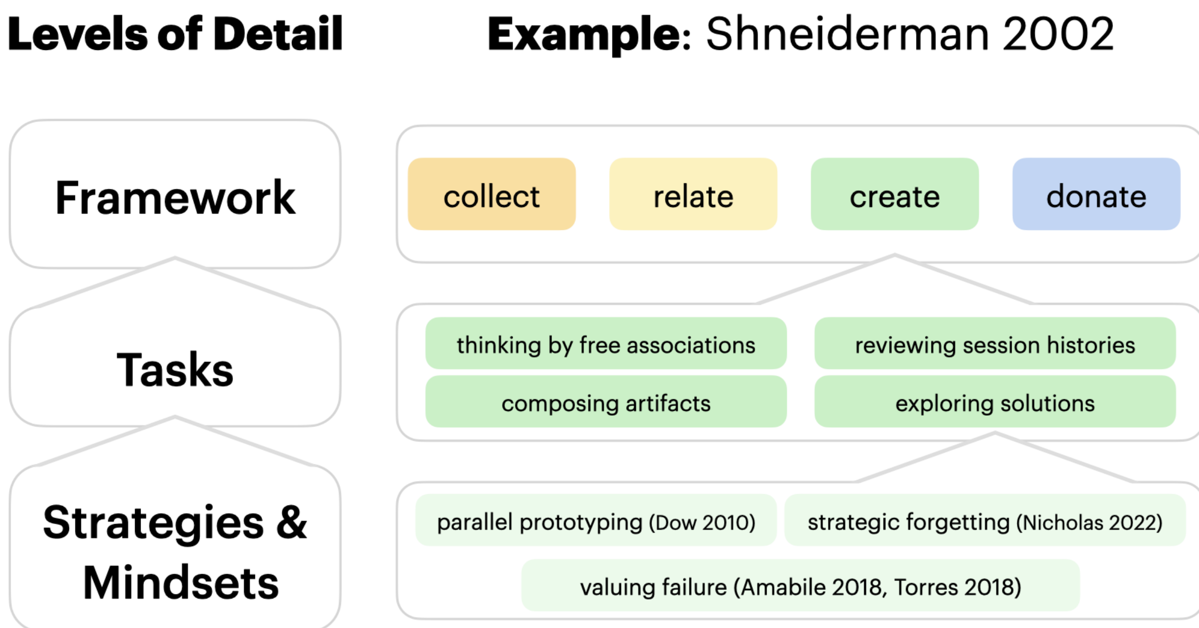

Figure 2.2: Levels of detail in creative process. I organize our discussion of creative process through three levels of detail: models or frameworks of creativity that describe the entire cycle of creative work; tasks that occur within the stages of these frameworks; or strategies and mindsets that can support particular tasks. The right column of the figure demonstrates these levels with Shneiderman's framework of *collect, relate, create, donate*, where the *create* stage contains tasks such as *thinking, reviewing, composing* and *exploring* (Shneiderman 2002), which can be supported by strategies and mindsets such as parallel prototyping (Dow et al. 2010), strategic forgetting (Nicholas et al. 2022), and valuing failure (Amabile 2018; Torres, Sterman, et al. 2018).

followed, can produce creative output. In 1945, Hadamard proposed four key stages: *preparation, incubation, illumination*, and *verification* (Hadamard 1945). These stages happen mainly in order, and each rely on the prior. This type of model of creativity has been consistent and influential in creativity research. For example, Amabile's model involves cycles among *problem or task identification, preparation, response generation,* and *response validation* (Amabile 2018), and Shneiderman proposed the stages of *collect, relate, create, donate* (Shneiderman 2002) (Figure 2.3). These models of process have found adoption in practice, as roadmaps for performing creative work. For example, the IDEO design thinking process is a model for how to perform creative design that has been influential in teaching design thinking and in design consultancies around the world. In 1995, soon after IDEO's founding, IDEO's framework consisted of five stages, *understand, observe, visualize and predict, evaluate and refine*, and *implement* (Spreenberg et al. 1995). The Stanford d.school teaches a design thinking process adapted from this model, consisting of *empathize, define, ideate, prototype*, and *test* (Figure 2.3). While these stages are modeled as discrete and sequential, many of these models include the idea of cycling between stages. For instance, one might prepare, then generate a response, then cycle back to additional preparation before finishing response generation in Amabile's Componential Model. Real-world creative work is fluid and cyclic, often with messy overlap between stages.

2.2.2 Tasks

Frameworks might suggest tasks or actions that can be performed inside each stage, for example, in the first stage of the d.school design thinking framework, one might perform interviews or shadow potential users to understand their context and needs. Hadamard emphasizes the importance of walking away from the problem during the "incubation" stage, allowing oneself to forget unsuccessful attempts and find inspiration from other inputs (Hadamard 1945). Shneiderman proposes eight specific tasks that help people be creative during his stages of creative work: searching, visualizing, relating, thinking, exploring, composing, reviewing, and disseminating, and proposes specific types of tools that support these tasks, for example how simulation enables broad exploration (Shneiderman 2002). Schleith et al. present a method for identifying what tasks might be useful in a given stage in order to effectively structure creative work (Schleith et al. 2022).

2.2.3 Strategies

Practitioners can structure tasks and actions using particular strategies and behaviors. In Amabile's Componential Model, each stage of her structural model is influenced by three key components: task motivation, domain-relevant skills, and creativity-relevant processes. Rather than framing these exclusively as required tasks, the components include internal mindsets (for instance, the individual's perspective on why they are performing the task, or how they respond to a failed direction), background knowledge, and knowledge of useful actions to take (effective heuristics) (Amabile 2018). Each of these supports and shapes the tasks that will occur during creative work, and is an essential part of understanding creative process.

For example, we might consider how perspectives on failure affect creative process. Amabile considers "recognition that failure in work can provide valuable information" as a social-environmental influence on creativity (Amabile 2018). This perspective on the role of mindset in creativity relates to Carol Dweck's work on mindsets in learning, where *growth mindset* is "the belief that human capacities are not fixed but can be developed over time" (Dweck 2008), and failure is a chance to learn new strategies and approaches rather than an indication of innate incompetence. In *Guardians of Practice*, Torres et al. and I explored how creative practitioners build failure into their processes in productive ways, both with mindsets and concrete strategies (Torres, Sterman, et al. 2018). For example, a creative writer uses "amputations" of chunks of writing to reduce the pressure to have a singular, successful piece of work; having multiple small documents that may or may not be included in the final manuscript allows her to be flexible, creative, and reduce the feeling that any particular piece of writing is "finalized" or "official" (Torres, Sterman, et al. 2018). In this example, we see how a particular behavior (writing in multiple documents), mediated by par-

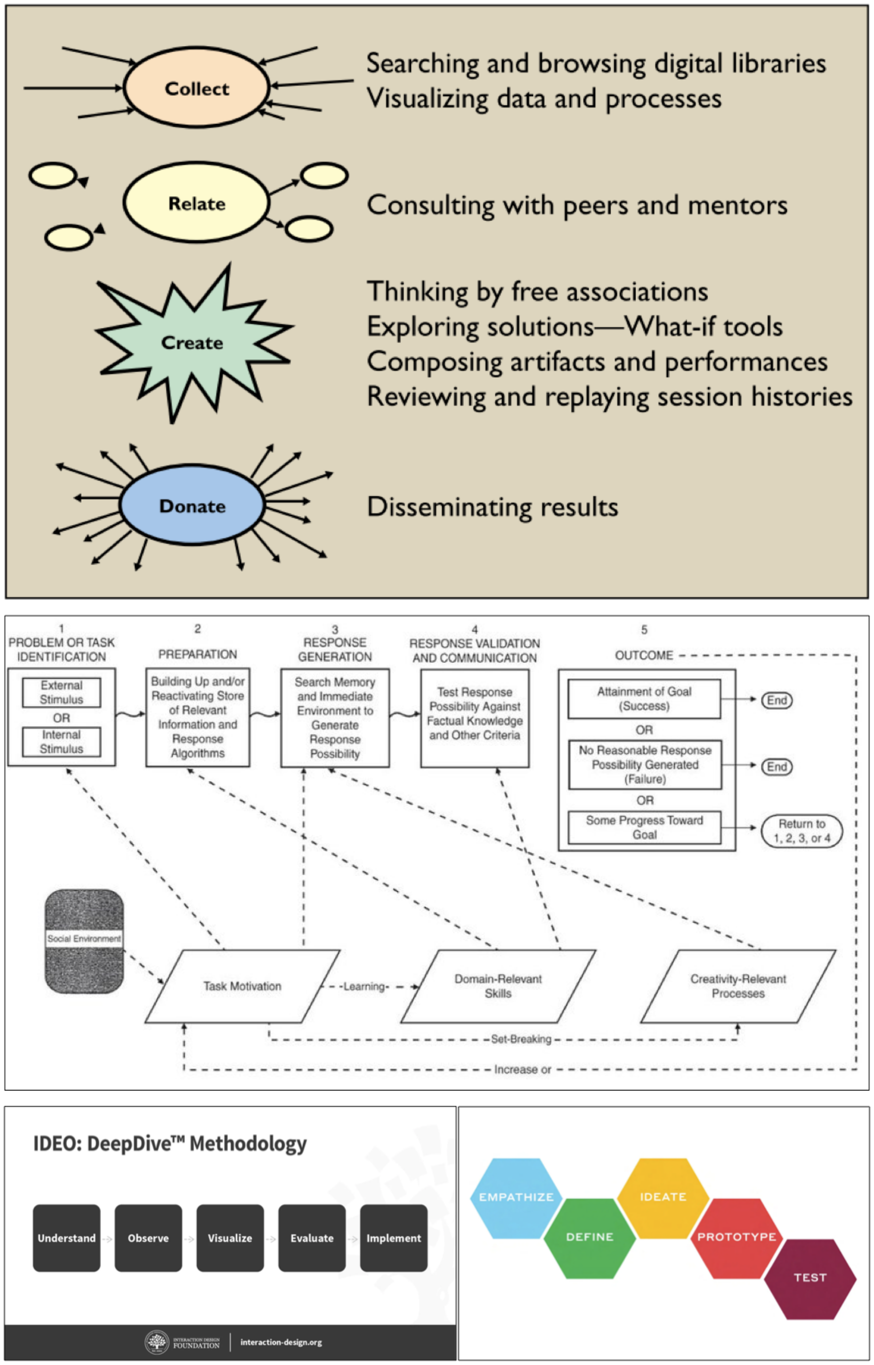

Figure 2.3: Examples of well-known creative frameworks. From top: Shneiderman's model of creativity (Shneiderman 2002), Amabile's Componential Model of Creativity (Amabile 2018), IDEO's design thinking methodology (Dam et al. 2020), Stanford d.school's design thinking methodology (Dam et al. 2020).

ticular tools (folders of text documents), supports a healthy mindset towards creative work. While prototyping might be considered a "framework stage" or a "task" by different process models, particular strategies can be applied to shape how one prototypes. For example, Dow et al. showed that parallel prototyping instead of serial prototyping can improve exploration and final output quality (Dow et al. 2010). Knowledge of the parallel prototyping technique can be applied as a creative heuristic to improve one's process.

In this dissertation, I focus the discussion of *creative process* on how practitioners use mindsets and strategies to inform tasks and make progress in and between stages of creative work.

2.2.4 Process Pluralism

Some actions or heuristics may be more or less useful to specific domains or practitioners. While an individualist perspective that focuses entirely on creativity as an internal trait is unnecessarily limiting to our understanding of how to learn and practice creativity, it is equally reductive to claim there is one singular process that will work in all cases. If that were true, the problem to be solved would no longer require creativity, as the process itself would be algorithmic.

A second consequence of singular perspectives on process is restricting who is able to perform creative work. Turkle and Papert present an argument for *epistemological pluralism* in programming, demonstrating multiple common mindsets and processes different people take when programming (Turkle et al. 1992). In creative programming tasks, some participants prefer an analytical approach to process, while others take a bricolage approach. Only through valuing multiple ways of knowing and types of process are all of these individuals welcomed into programming practice.

Pluralism of process in creative work is widely accepted in HCI work. Inie et al. discuss the importance of supporting multiple processes in idea management, where structuring content or workflows in a singular predefined way can have adverse effects on creativity (Inie, Frich, et al. 2022). Li et al. discuss how the unique workflows of artists shape their personal styles (Li et al. 2021). Torres champions workflow pluralism as a tenet of future digital fabrication frameworks (Torres 2019). In this dissertation, I consider process pluralism an essential perspective for understanding creativity and designing effective and inclusive tools.

Though individuals may have particular ways of thinking and working, there are similarities across domains and individuals, which reveal possibilities for sharing and learning effective components of process. Frich et al. explore how cross-domain studies of professionals' creative practice can inform the design of digital tools (Frich, Biskjaer, MacDonald Vermeulen, et al. 2019). Learning about process can happen across levels of expertise and types of creativity as well; while some researchers hold a "discrete" view of creativity that divides the behaviors of Big-C creativity from those of little-c creativity, Amabile and Kaufman et al. both consider there to be meaningful aspects of common process between these types of creativity. They see creativity as continuous, and capable of developing over an individual's lifetime (Amabile 2018; Kaufman et al. 2009).

In this dissertation, I follow in the continuous view on creativity. From this perspective, we can learn about, change, and improve our creative process over time, even between stages of creativity. For example, a practitioner of little-c creativity might develop a technique that serves them well when they begin working in Pro-c creativity, or a Pro-c practitioner might teach a little-c practitioner an approach that helps them be creative. In Chapter 4 and 5 we study professionals in creative domains who are involved in Pro-c creativity to help us understand how to better support creative process for professionals as well as novices and students. In Chapter 6, we explore some of the benefits and challenges of applying process techniques across Pro-c and mini-c contexts.

2.3 Values in Creative Process

The values we hold influence the tools we create. Therefore we must be intentional about the values we incorporate into technology, and how these will influence people's actions, behaviors, and outputs when they use the tools. One method for explicitly considering values in the design process is Value Sensitive Design (Friedman 1996). In proposing Value-Sensitive Design, Friedman et al. focus on "enduring human values," such as human welfare, rights, and justice (Friedman et al. 2002). While Value Sensitive Design can be applied to other values, such as pleasing aesthetics, its main role is to address moral and ethical questions.

In this thesis, I focus smaller scale values, rather than moral and ethical imperatives. In the contexts of creativity, a value might be "spontenaiety", "adaptability", or "clear documentation": underlying aspects of the creative process that a practitioner desires to embody in how they work. These are values in the particular context, though they may not have universal moral weight; for example, one might desire spontaneity in one part of the creative process, but rigorous planning in another, and certainly would not value spontaneity in an airplane's preflight checklist.

In this thesis, I will use the term *process value* to refer to:

> *Process value:* An underlying principle a practitioner prioritizes in their workflow.

The principles practitioners prioritize have histories; they are situated in cultural contexts, legacies of work and social organizations. For example, a modern maker of violins draws from traditions developed over centuries, and has different tools, techniques, and values based on the lineage of violin making they embrace. In *The Reflective Practitioner*, Donald Schön describes the importance of understanding the history of values to make sense of modern work and ensure future success (Schön 1983).

Schön proposes "reflection-in-action" as a key type of process performed by professionals. Reflection-in-action stands in contrast to technical rationality as a way of making sense of process. In the view of technical rationality, professional process is "grounded in systematic, fundamental knowledge," systematically applied to specified ends. Schön argues that instead, professional work is characterized by ambiguous, changing ends, and relies on tacit, skillful process. In situations of "uncertainty, instability, uniqueness, and value conflict," reflection-in-action is necessary to successful professional work. We might note in this description of the contexts of reflection-in-action a marked similarity to contexts of creativity, where the problems are uncertain, unstable, and unique.

When Schön proposed reflection-in-action in 1983, it came as an apparent contradiction to the epistemology of technical rationality. Where the positivist framing of technical rationality valued scientific methods, reflection-in-action appeared more like an art. Where technical rationality valued systematic, generalizeable knowledge, reflection-in-action operated within individual, unique experiences. In proposing reflection-in-action as a valid and essential type of process, Schön challenged not just existing conceptions of how process operated, but of the underlying values inherent in the predominant mindset.

This thesis considers a similar challenge. Are the values in our tools and mindsets about computational work at odds with the values of our creative process? What other capabilities or possibilities become clear when we look at successful process to guide our values, rather than inheriting values from prior domains? Specifically, this thesis focuses on *value inversions*, moments where the values identified in creative process are explicitly at odds with those expected by the tools or context of computational systems.

For example, "organization" is often a core value of computational systems; we can see this in the way many tools are built with file system metaphors, and present information in neat grids and lists. Yet creative spaces are often messy — studios or workshops are familiar examples of creative mess. Instead of neat lists or menus that separate tools from content, a violin maker's studio is a mix of old pieces, in-progress work, materials, tools, and references. Psychology research has found that there are benefits to mess, showing that messy environments encourage creativity and a preference for novelty (Vohs et al. 2013). A second example is memory "failures." Many computational systems help prevent these, storing and recalling information on demand. Yet recent work in psychology has uncovered the ways in which errors can be beneficial to mental processes, including evidence that memory failures can facilitate novel thinking, reducing idea fixation and assisting with distilling important ideas (Ditta et al. 2018).

Memory errors suggest the possibility of forgetting as a benefit to creative process. In Chapters 4 and 5, we explore this idea through the value inversion of *retention and forgetting*. Pierce et al. explore inverting the value of "functionality" in their concept of counterfunctional design (Pierce et al. 2014), and in the specific example of the Obscura 1-C camera, engage specifically with forgetting. The Obscura 1-C camera is a digital camera whose data cannot be retrieved without destroying the camera itself (Pierce et al. 2015). By restricting access to its information, the device plays with ideas of remembering and forgetting, and what it means to have data if you cannot access it. Within Pierce's frame of counterfunctional design, this object is a provocative conceptual piece rather than intended to have widespread practical impact. In this thesis, I explore the value inversion of retention/forgetting specifically in relation to concrete impacts on effective creative workflows.

In Chapter 5, I explore the value inversion of *precision and imprecision*, or the amount of exactness and detail in a piece of information. Gaver and co-authors proposed ambiguity as a resource for design, specifically calling out imprecision as one way to create ambiguity (W. Gaver et al. 2003). The goal of imprecision in service of ambiguity is to create and complicate self-reflection and relationships to information and objects. In this dissertation, we see imprecision within the frame of ambiguity, but also as a technique for structuring creative work, and in cases where imprecision is a necessary quality of information rather than a design choice.

In Chapter 3, the first system example in this dissertation addresses *accuracy and uncertainty*. There are multiple ways of valuing uncertainty; in visualization literature, uncertainty is often seen as a fact of data that must be revealed or explained in order for the user to gain more clarity. For example, showing bus arrival times as probability distributions rather than a single time uses the uncertainty of the prediction to provide more accurate information to users (Greis et al. 2017). This approach acknowledges uncertainty in the interface, but seeks to reduce the end user's uncertainty. In contrast, this dissertation approaches uncertainty as a valuable resource to the creative process. AniThings is an example of uncertainty as a resource, proposing creative AI assistants with unique personalities that surface content to the user based on their own internal states, using the uncertainty of why the content was displayed to support creative ideation and exploration (Allen et al. 2013).

In this dissertation, I embrace these value inversions as an important part of creative process. Value inversions may feel uncomfortable or messy, but I hope to demonstrate that such process mess is a benefit to creative output and experience.

2.4 Creativity Support Tools

2.4.1 Conceptualizing the role of tools

Like environments or social contexts, the tools we use affect our creativity and creative process. As we move from a general discussion of creativity to how tools can support creative work and creative process, we must first discuss frameworks for understanding the relationship of tools to process.

Bruno Latour presents Actor-Network Theory as a way of articulating the relationship of people and tools — that we are not agents using a tool, but rather that the combination of person and tool creates a new agent, with new possible goals, actions, and results (Latour 1994). From the perspective of actor-network theory, creativity support tools don't just "support" or "improve" creativity, they produce a new creative agent in combination with the practitioner which is capable of different actions and has different goals than the practitioner alone. From this perspective, creativity support tools (CSTs) become clear as shapers of process — how we work with a CST is inherently different from how we work alone, and the results therefore also change. But it is not just the results and goals that change when we consider the person-tool agent; the capabilities and perspectives of the person may also change. In doing so, the tool may affect what the person values, how they approach problems, their emotional state, and their sense of self. In *Instruments of Inquiry*, Dalsgaard articulates a similar philosophy, that design tools shape the outputs of design work, guiding designers to particular solutions through their way of working (Dalsgaard 2017).

In each of these philosophies, tools by their nature affect *how* work is performed as well as the possible goals and outputs from that work. Tools also encode values, either explicitly or implicitly, in how they codify representations of data, of interaction, or of process. Friedman et al. describe this interactional relationship clearly: "People and social systems affect technological development, and new technologies shape (but do not rigidly determine) individual behavior and social systems" (Friedman et al. 2002).

2.4.2 Early computational creativity support tools

Digital tools have been used in creative work from some of the earliest applications of computer systems. In the 1940s, Vannevar Bush imagined applying computational systems to knowledge organization and research, to accelerate and extend scientific creativity (Bush 1945). In the 1960s, Ivan Sutherland created Sketchpad, the first CAD program, providing new capabilities for design, drafting and artistic drawing (Sutherland 1963). In 1968, Engelbart presented the Mother of All Demos, introducing essential tools and capabilities such as word processing, collaborative real-time editing, and revision control which have become essential to many types of creative work (Engelbart 1968).

In the early 2000s, Ben Shneiderman introduced the term "creativity support tool" as a contrast to a prior focus in human-computer interaction on the frame of "productivity support tools" (Shneiderman 2002; Shneiderman 2007). He identified creativity as a key and growing challenge for solving problems in the modern world, and highlighted how computational tools had dramatically increased abilities and mediums for creativity. Since then, creativity support tools have been a large and growing area of interest in HCI. In 2018, Frich et al. published a survey of creativity and creativity support tool research in the ACM, reviewing the trajectory of the research area across the past twenty years and showing a continuous increase in papers about creativity (Figure 2.4, Frich, Biskjaer, and Dalsgaard 2018a). Across nearly a thousand research papers, Frich et al. find that creativity research in HCI mostly focuses on tools (67% of papers), either developing a new tool or studying an existing tool.

2.4.3 Supporting Creative Process

Creativity support tools take different approaches to the idea of "supporting" creative work. One way to organize these approaches is to identify which components of Amabile's componential framework of creativity they address (Figure 2.5).

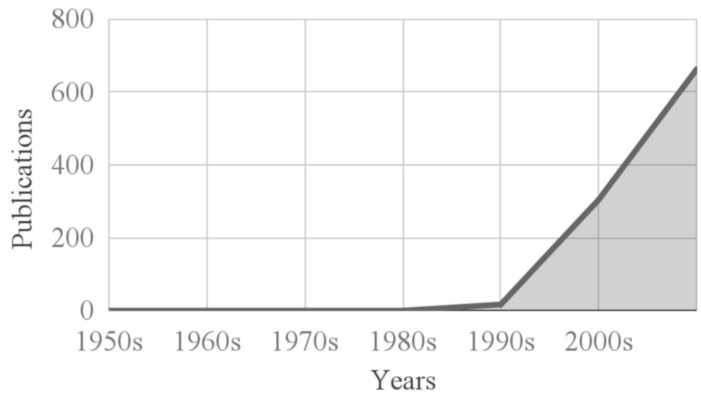

Figure 3. Publications per year in all of ACM DL with author keyword: creativity.

Figure 2.4: Growth in research on creativity in the HCI community. Frich et al. graph the frequency of the keyword "creativity" in publications in the ACM's digital library, demonstrating an increasing interest in creativity among HCI researchers in the last thirty years (figure from Frich, Biskjaer, and Dalsgaard 2018a). They also note that not only has the absolute number of papers, grown, but so has the overall percentage of publications about creativity compared to the ACM DL overall, "from 0.03% in the 1990s to 0.19% in the 2000s and 0.33% in 2010".

2.4.3.1 Tools for Domain-Specific Skills

A common goal for novel tools is to support "domain-specific skills." In drawing domains, Sketchpad made drawing repetitive or precise diagrams easier for designers, engineers, and artists (Sutherland 1963). SILK helped interface designers make rapid, interactive prototypes, leveraging the computer to make reuse and editing easier and automating interactivity (Landay 1996). PortraitSketch adjusts users' drawings as they sketch to make more realistic portraits (Xie et al. 2014). In physical making domains, FreeD (Zoran et al. 2013) provides automatic guidance to a handheld milling device, augmenting the domain skill of freehand carving, and the position correcting router (Rivers et al. 2012) provides automatic local adjustments to a handheld 2D router to help the maker cut more precise lines. In a music domain, ChordRipple makes automatic chord recommendations to help novice composers be more adventurous in their chord choices (C.-Z. A. Huang et al. 2016).

Besides making existing skills easier, novel systems can also introduce new capabilities or mediums. For example, conductive ink lets children create and trigger audio recordings on their drawings (Jacoby et al. 2013). "Community blocks" for the Scratch programming language allow users to access data about their own participation in the Scratch community, enabling new kinds of art, games, and data-based questions (Dasgupta et al. 2017). Modular robotic joints let users create and animate physical toys with craft materials (Yoon et al. 2015).

Figure 2.5: Components of creative performance and examples of corresponding CSTs. Amabile's Componential Model of creativity organizes the required components of creative performance into three categories: domain-relevant skills, creativity-relevant processes, and task motivation. The left column of this figure reproduces Amabile's description of these components (Amabile 2018). Each of these components can be supported by tools, which can help structure or improve the abilities of the practitioner. The right column of this figure presents selected examples of tools that support each component: PortraitSketch (Xie et al. 2014), FreeD (Zoran et al. 2013), Guardians of Practice (Torres, Sterman, et al. 2018), Motif (J. Kim, Dontcheva, et al. 2015), SonAmi (Belakova et al. 2021), and Mosaic (J. Kim, Agrawala, et al. 2017).

2.4.3.2 Tools for Task Motivation

We might also consider how creativity support tools can affect motivation, another of Amabile's core components of creativity. Over-criticism caused by fear of external judgement can stymie creative writers; SonAmi is a tangible device for helping creative writers reduce self-criticism (Belakova et al. 2021). Mosaic is an online creative community focused on sharing works-in-progress, shifting the motivation for sharing creative work from gaining praise for successful outcomes to sharing process and encouraging creative growth (J. Kim, Bagla, et al. 2015). The technique of parallel prototyping reduces the fear of external criticism by providing multiple sites for feedback and focusing on the process rather than a singular output (Dow et al. 2010).

2.4.3.3 Tools for Creativity-Relevant Processes

The final of Amabile's components is creativity-relevant processes. Here we find many behaviors and strategies creative practitioners use to structure their work, as well as tools that embody and assist with these strategies. Motif surfaces expert patterns to help guide novices to think of story structure when they film video content (J. Kim, Dontcheva, et al. 2015). Terry et al. propose designs for supporting particular process strategies, including authentic previews of actions and enhanced parameter sliders to support near-term experimentation and exploration (Terry et al. 2002). *Guardians of Practice* explores a set of strategies creative practitioners use to embrace failure as a constructive component of creative process (Torres, Sterman, et al. 2018).

Many pieces of work address multiple components of the creative model; for example, parallel prototyping can affect motivation and self-efficacy, as well as acting as a creativity-relevant heuristic (Dow et al. 2010); SonAmi addresses an unhelpful motivational mindset, while also providing a helpful process for editing (Belakova et al. 2021).

Learning from creative process in non-software domains can be important for supporting creativity-relevant processes in computational tools; for example merging manual drawing practices and digital art (Jacobs, Gogia, et al. 2017; Jacobs, Brandt, et al. 2018), or enabling material-centric interactions with digital mediums for hybrid artists (Torres 2019).

Recent work has emphasized the importance of understanding the creative *experience* in addition to creative outputs (Glăveanu et al. 2021). This represents an opportunity for CST research: tools that take into account the overall creative experience can facilitate growth and sustainable practice by mediating mutable intrapersonal aspects of creativity. Understanding how experts engage with and manage creativity-relevant processes provides a particularly rich foundation of knowledge for the CST community.

2.4.4 Studying Process with Creativity Support Tools

Creativity support tools are ubiquitous now in personal and professional computing contexts (some examples can be seen in Figure 2.6). While some of these creativity support tools

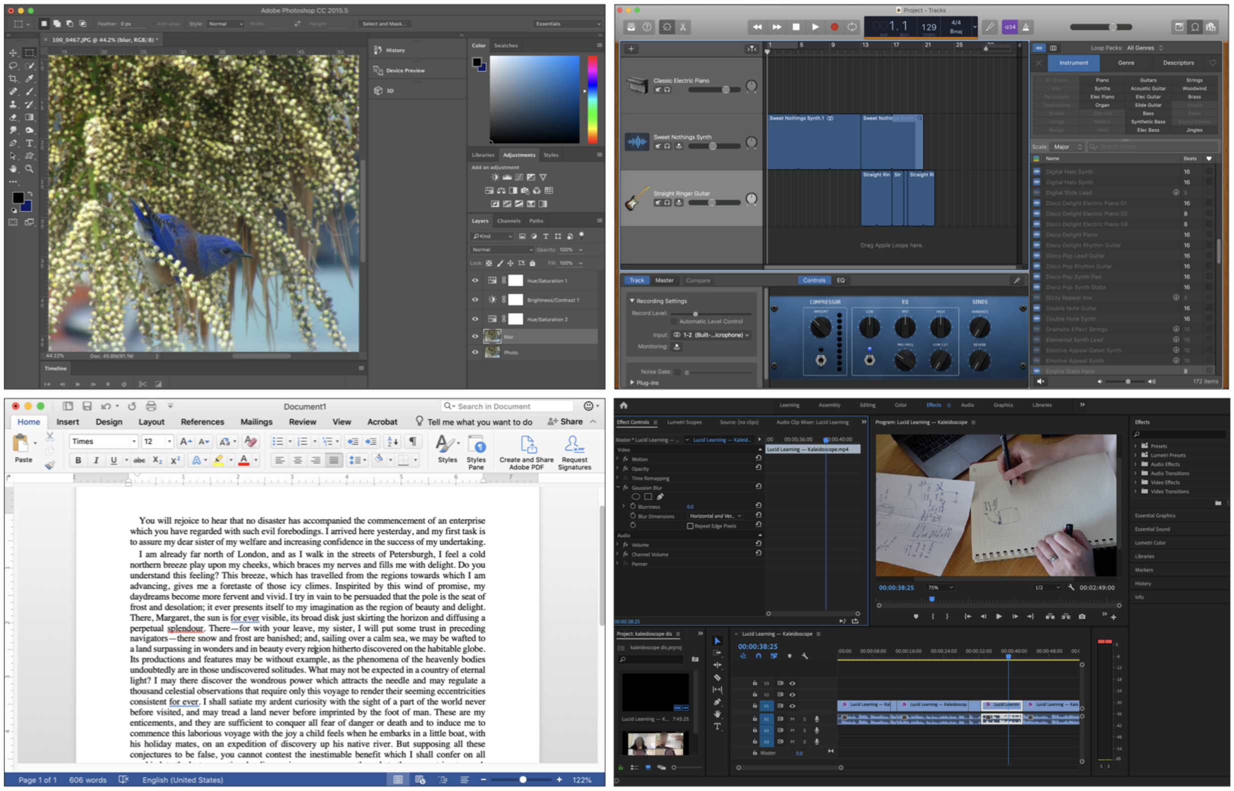

Figure 2.6: Creativity support tools are ubiquitous now in personal and professional computing contexts. From left: Adobe Photoshop (image editing), Apple GarageBand (music composition), Microsoft Word (text editing), Adobe Premiere (video editing).

may be primarily or solely used in creative contexts, such as Apple GarageBand for music composition, others are used in both creativity and productivity support contexts. For example Microsoft Word and other text editors are used for both creative and non-creative writing; spreadsheets are both essential productivity tools in many businesses, and used for creating knitting patterns and weaving drafts. Studying tools that have been adopted in professional practice offers the opportunity to understand successful strategies and processes. For example, Frich et al. identified two strategies in creative practitioners' use of digital tools: 'margins', and 'view-shifts' (Frich, Biskjaer, MacDonald Vermeulen, et al. 2019). These are tool-agnostic strategies used by expert practitioners as they iterate through a design process.

Process is also important to studying novel creativity support tools. In 2014, Cherry et al. developed a metric for evaluating creativity support tools: the Creativity Support Index (CSI) (Cherry et al. 2014). Out of six categories in the Creativity Support Index, only one focuses on output: "results worth effort". The rest address the experience of the work, drawing from past research on creativity and creativity support tools: did the tool support "collaboration", "enjoyment", "exploration", "expressiveness", and "immersion". The CSI establishes the experience of being creative as the key goal for a creativity support tool, rather than primarily evaluating the outputs a practitioner creates.

Understanding and improving process increases the quality of creative outputs (Amabile 2018), but it is equally important to consider process for its own sake. Focusing on the experience of work foregrounds human expression and flourishing as important outcomes of creative work and essential goals of creativity support tools. *Doing* creative work can be as valuable as producing a creative *output*.

Chapter 3

Computational Representations of Literary Style

To begin our exploration of designing tools for creative process, we will look at a specific topic within a single domain: how creative writers work with style in creative writing. This case will allow us to explore each of the three key research questions posed in this thesis, and demonstrate the value of this method in approaching process.

> **R1:** What process values are present in existing creative practices?

Style is an important aspect of writing, shaping how audiences interpret and engage with literary works, and how authors express their voice and intent. First, we will investigate existing approaches to style, both in individuals' creative processes, and in computational tools. Through a series of interviews with creative writers about style, we develop a process-focused definition of style.

In particular, we will reframe our question from *what* is style, to *how* do people understand style. While this might seem a minor alteration, it redirects our attention from a prescriptive definition of output to an active process of meaning making. Foregrounding the process of understanding style reveals places where the values held by readers and writers do not align with the design of existing tools for analyzing style: participants value *interpretation* instead of *categorization*, and grapple with *uncertainty* rather than seeking *accuracy*.

> **R2:** How do creative practitioners instantiate these values in specific strategies and behaviors? How do tools, computational and otherwise, support or inhibit these strategies?

Computational tools exist for analyzing style, for instance stylometric analysis techniques used for authorship attribution and plagiarism detection via style. These approaches draw

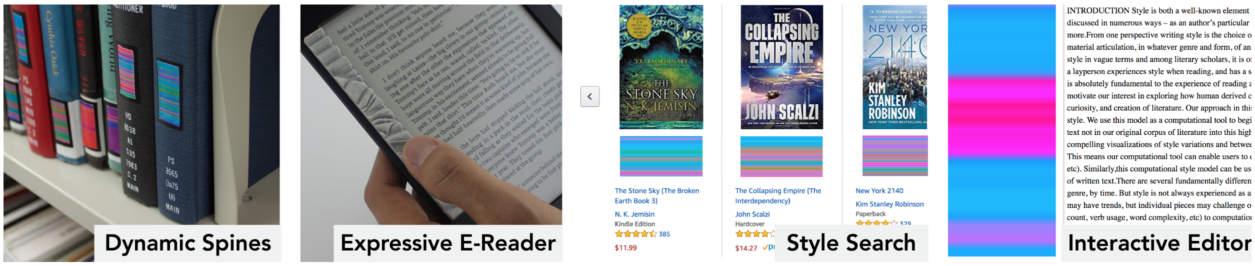

Figure 3.1: Envisioned style interfaces. We envision many types of style applications based on the style analysis technique presented here. From Left: Dynamic Spines use color screens to display style visualizations on physical books. Expressive E-Readers use a shape-changing case to morph the texture to match the style of the page, expressing style through touch rather than visuals. Style Search interfaces allow exploring diverse repositories of published or amateur writing through style. The Style Editor (which we implemented and studied) allows writers to forefront style as they edit their own writing; for example finding mismatched authorial styles between collaborators in an early draft of the introduction of this chapter (shown at right).

from a particular set of metrics and assumptions common in computational systems to define style. In particular, they treat style as a *categorical* concept, where a style can be defined by the author, the genre, the year, or another specific categorical proxy. Successful style analysis is defined by the *accuracy* with which texts can be categorized by their style.

While these approaches are effective for tasks like authorship attribution, we might ask whether they are appropriately matched to creative tasks, or whether another type of style analysis and system values might better support tasks such as creative writing, close reading, or discussion, by drawing on the value inversions identified in our formative interviews.

R3: How can creativity support tool designers leverage process values and techniques to create computational tools that support process as well as output?

We design a system for style analysis, guided by these value inversions, leaning into style as a form of tacit knowledge and highlighting interpretation and uncertainty as valuable aspects of creative meaning-making in reading and writing. This system exemplar engages with the *process* of writing or interpreting style, rather than centering an output as the final goal of the system.

In this chapter, we approach literary style from a process-sensitive lens, identifying how practitioners engage with style in their process, what values are at work in their tools and behaviors, and designing a novel system to support an unexpected part of their creative process.

3.1 Introduction

Style is a well-known element of written language, yet notoriously difficult to precisely identify and describe. Style is variously defined as an author's individual signature, a genre's conventions, a work's particular use of language, and many more. Among literary scholars, style is a philosophical and often controversial topic. Yet laypeople experience style when reading, and have a style when writing,[1] though they may lack the knowledge to articulate these ideas formally, and so rely on vague descriptions.

Despite these complexities, style is fundamental to the experience of reading and writing. In this chapter, we seek to develop ways for people to communicate with each other and with computational systems about style. To do so, we develop a new representation of style that reflects tacit knowledge and community consensus, releasing the restrictions of formal terms and objective definitions.

In a formative study of conceptions of style, we find that people have strong feelings about style that they cannot put into words, and experience style as an overall effect, rather than as categories. They learn through experience, and communicate style by comparison rather than with formal terms. In other words, style is a tacit experience.[2] However, most computational systems take a categorical approach to style, formalizing it into groups by author, genre, or time period. But style is not always experienced as an authorial monolith; individuals may write differently at different times, or in different contexts. Genres may have trends, but individual works may challenge such boundaries, or contain many styles at once. By taking a tacit approach, we create a new computational lens with which to look at the experience of style beyond these categorizations.

To access tacit knowledge of style, we design a crowdsourcing task to elicit human judgments of style similarity between passages of text, and create the first dataset of human comparisons of style in fiction, with ˜66,000 judgments across ˜21,000 comparisons. We train a machine learning model on this dataset, and operationalize this model through two interface probes. First, an "Explorer" interface plots excerpts by their style in a 2-D style space, allowing the exploration of style between texts. Second, an "Editor" interface presents a co-located visualization of style next to editable text. The Editor foregrounds style as it ebbs and flows through the text and allows instant update of the visual representation as the text is altered. These interfaces can process new texts not in the original dataset, enabling users to explore style across any written collection, even beyond our dataset. Through a user study, we highlight how these interface probes expose style, inviting new curiosity, reflection, and creativity in reading and writing.

Style is and likely always will be a literary concept resisting exact classification. This work should not be interpreted as attempting to mechanize literature or style into an exact computational model. To the contrary, the joy we experience from engaging with literature inspires this work. We believe that even partially and selectively exposing style within texts

[1] According to some literary theorists, though others may disagree (Herrmann et al. 2015)

[2] Tacit knowledge (Polanyi 1967) refers to what we can know without being able to explicitly articulate to others (e.g. riding a bicycle, playing a musical instrument, or perhaps describing literary style).

can be inspiring, inviting genuine curiosity and the discovery of new, similar, or different styles. Our hope is that such computational literary tools can augment and accelerate the discovery, appreciation, joy, and celebration of literature.

3.2 Related Work

This chapter draws from techniques across several disciplines. We discuss how these disciplines have engaged with style and how we integrate elements from these fields to offer a new perspective on approaching style with computational tools.

3.2.1 Literary Theory and Defining Style

Literary theorists have examined the question of style for centuries; no universally accepted conclusions have been reached. However, Herrmann et al. present a potential definition for computational style research: "Style is a property of texts constituted by an ensemble of formal features which can be observed quantitatively or qualitatively" (Herrmann et al. 2015). This definition encompasses both "complete texts or fragments of texts," and "is not limited to a given author's style." Herrmann et al. draw from the history of literary theories of style to propose a definition that creates common ground for literary scholars, digital humanists, and computational researchers. Here, we will base our exploration of style on this definition to bridge the areas of literary theory and human computer interaction. Specifically, we focus on style in "fragments of texts," at the unit of 200 word excerpts. We approach entire works as combinations of excerpts. Therefore we do not expect texts to have a uniform style throughout; rather the overall style of a text includes the variations in style within it. However, we are also influenced by other traditions of style, as we are interested in understanding people's subjective aesthetic experience, rather than adhering to a single formal definition.

3.2.2 Quantitative Features of Style

Since the first use of statistical methods for authorship attribution in the 1960s (Mosteller et al. 1963), the field of stylometry has used analytical and computational methods to build quantitative models of style to classify unknown texts. Stylometry is commonly used for authorship identification (Zhao et al. 2007), plagiarism detection (Meyer zu Eissen et al. 2007), author gender identification (Argamon et al. 2003), and genre classification (Stamatatos et al. 2000), among others (Lipka et al. 2010; Yang et al. 2012). Researchers have identified features that perform well for these uses (Khosmood et al. 2011), including lexical features (e.g. word frequencies), character features (e.g. n-grams), and syntactic features (e.g. parts of speech) (Stamatatos 2009), and used computational methodologies such as support vector machines, neural nets, self-organizing maps, and spanning trees (He et al. 2004; Neme et al. 2015; Shalymov et al. 2016). Some quantitative style metrics have come into common use;

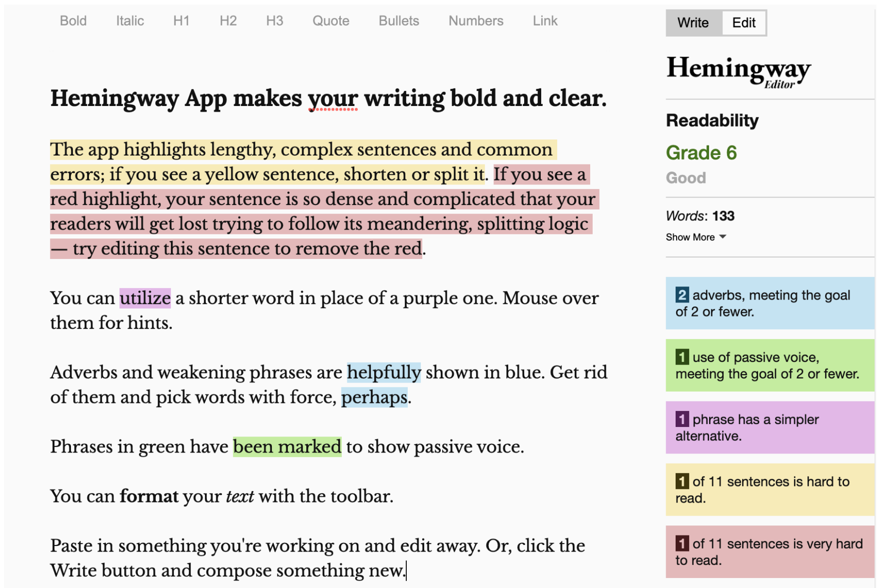

Figure 3.2: The Hemingway App is an online text editor that uses visual highlighting to provide feedback on writing style according to a particular set of metrics, including complexity of sentences and number of adverbs (Ben et al. 2017)).

for example, the Flesch-Kincaid readability tests compute how difficult a passage is to understand based on sentence length and the number of syllables per word (Kincaid et al. 1981). Online resources such as Hemingway App (Figure 3.2, Ben et al. 2017) use highlighting to suggest ways to improve scores on these metrics. We ground our work in these methods, but instead of investigating authorship attribution or categorizations through explicit features, we create our model using a human-defined definition of style informed by tacit knowledge. A similar tacit aspect in knowledge about genres is noted in Karlgren 2004.

Most datasets for stylometric work are created through categorization, using metadata such as authorship or genre to define classes. Looking beyond this approach, Crosbie et al. investigate the quality of "literariness" using stylometric techniques, and generate a small dataset of 10 passages rated by the general public on a Likert scale for literariness (Crosbie et al. 2013). We similarly build a dataset from human judgments, but focus on a distinctly different approach to style: comparative similarity based on tacit knowledge. We create a dataset of 800 passages combined into 21,000 comparisons. To our knowledge, no other such direct dataset of style similarity judgments exists.

3.2.3 Natural Language Processing

Natural language processing techniques provide approaches to semantic understanding and automatic text generation. Word embeddings (Pennington et al. 2014) have been used to understand similarities between words, and improve semantic analysis of text. A conceptual extension of word embeddings, document embeddings have been used for sentiment analysis and text classification (Le et al. 2014; Dai et al. 2015), and can effectively cluster texts based on similarity. A technique for auto-generating text (Radford et al. 2019) can produce, to some extent, stylistically coherent content. While these techniques may be able to capture some aspects of style, they do not separate style from semantics. We demonstrate an architecture that generates a separable representation of style.

3.2.4 Human Computer Interaction and Writing Support Tools

We highlight here the subset of work in writing support tools most related to our approach to style. Bernstein et al. integrated crowd-powered editing tools into a text editor to handle tasks relying on human judgment (Bernstein et al. 2010); similarly, we leverage crowd knowledge to approach a problem that requires human judgment: tacit knowledge of style. Pera et al. used readability and style characteristics derived from reviews, in addition to content, to recommend books for children (Pera et al. 2015). Vaz et al. explored the integration of style analysis into recommendation systems, showing that stylometric features improve results (Vaz, Martins de Matos, et al. 2012). Vaz et al.'s prototype system used stylometric comparisons to recommend similar books (Vaz, Ribeiro, et al. 2013). We also use style to inform computational tools, but rather than utilizing the formal metrics derived from authorship identification directly, we surface the gestalt experience of style and support interactive interpretation through visualizations, rather than generating specific recommendations.

3.2.5 Digital Humanities and Visualization

In the literary technique of "close reading," annotating in situ and preserving the structure of the text are essential to analysis. In contrast, "distant reading" is a data-driven approach to studying texts (Jänicke et al. 2015; Moretti 2007), in which the structure of the text is removed to provide a global view of the text or its relation to a larger corpus. Here we discuss research which combines close and distant reading to take a computational approach to text while preserving structure or detail through visualizations. Muralidharan et al. created a tool for investigating patterns in text collections through visualization (Muralidharan et al. 2012). Weber used a word-highlighting approach where each part of speech is assigned a color to reveal contrasting visual patterns in fiction and scientific writing (Weber 2007). Keim et al. visualized texts by computing a sequence of values for individual stylometric features, creating "fingerprints" that can be compared across works (Keim et al. 2007). McCurdy et al. visualized the sound of a poem in the context of the text (McCurdy et al. 2016). These each use explicit characteristics, directly represented. Our visualizations similarly leverage considerations of both close and distant reading, but are driven by our tacit model of style, not by explicit features.

3.3 Formative Study: Understanding Style

Our research began with a formative study to elicit the personal concepts, perceptions, and articulations of style from people with significant knowledge of literature. We recruited 14 participants (6 men, 8 women; mean age 23, range 18-30) who self-identified as "writers" or "avid readers" from university mailing lists for creative writing, design, and computer science. We conducted semi-structured interviews around their reading and writing practice, focusing on their thoughts about style and writing support tools. Afterwards, they interacted with an early prototype of a style exploration tool. Interviews lasted an hour, and participants were compensated US$20. We analyzed the interviews using Grounded Theory (Charmaz 2006).

Most participants reported experience in creative writing (12 participants) and academic writing (9), as well as other types of long-form writing, with a mean of 7 years of writing experience (range 4-15). Three participants were actively studying literature, one participant wrote in a professional capacity outside of academia, and three others held volunteer editorial positions.

We found that all of our participants had a personal definition for literary style, as well as particular styles they liked and disliked. Most valued style in choosing what to read or in shaping their own writing. Only one participant considered it irrelevant to their reading and writing. As important as style was, participants did not have a clear way of talking about it:

F4 [I react to style], but I think it's hard to articulate what I like about it.

F7 I know the vibe...I don't really have a word for it.

Instead of explicit terms, interviewees relied on examples, referencing other works as touchpoints to get their meaning across:

F3 There are styles, but I don't know how to communicate to you, but I can tell you check out this author, see how he writes.

When asked explicitly to define style, participants described it as a "gut feeling" **(F7)**, "an overall effect" **(F13)**, and "more of an instinct" **(F2)**.

Participants repeatedly articulated that style is learned through experience and communicated through comparisons, suggesting that style is a form of tacit knowledge. Though most computational approaches to style rely on identifying and reporting explicit quantitative features of texts, our participants experience style in a much more intuitive way. This insight motivates the design of our dataset collection, model, and applications, to capture and enhance people's tacit approach to style.

3.4 Dataset: Style Similarity in Fiction

To develop tools capturing tacit approaches to style, we collected a novel dataset of style judgments.[3] Rather than asking individuals to categorize or label style, we collect judgments of stylistic similarity, using comparisons within triplets of excerpts, as shown to be effective in Agarwal et al. 2007 and Tamuz et al. 2011. Excerpts are drawn from contemporary fiction, as it is accessible, commonly read, and showcases diverse styles. We would expect to find a great deal of disagreement across individuals in how they judge passages, therefore we collected seven judgments per comparison. The dataset consists of:

- *Comparisons:* Crowdworkers read a set of three excerpts of text and compare the style of the first excerpt (A) to the following two (B, C), then judge which of B or C is most stylistically similar to A.
- *Explanations:* Each crowdworker provides a few words of free text to justify their decision, by describing what is similar between A and their choice of B/C.
- *Intensities:* Each crowdworker indicates on a scale of 1-5 how similar their choice of B/C is to A.

3.4.1 Excerpt Generation and Comparison Triplets

Each comparison used in the crowdsourcing task consists of three excerpts from contemporary fiction displayed side by side, a "triplet." We separate the data into seven sets of triplets, with between 1,050 and 6,300 triplets, created from disjoint sets of texts. This provides disjoint sets of triplets for training and testing machine learning models, and varies the parameters used to select excerpts to enable different ways of looking at style (see Table 3.1 for a summary of parameters).

To generate the excerpts, we retrieved plain text from publicly available previews of fiction published through Amazon Kindle (Figure 3.3). These books were pulled from seven genre categories as listed by Amazon: Action and Adventure, Contemporary, Historical, Horror, Humor, Literary Fiction, and World Literature. Each set includes texts from all of these genres. Amazon Kindle is used to emphasize contemporary fiction. Other sources, such as Project Gutenberg, emphasize older works in which the conventions of the era may overwhelm more subtle differences in style.

We extracted excerpts of approximately 200 words from each preview. Since the first paragraphs of a book are often quite different from the rest of the text, excerpts were extracted from the middles and ends of the previews. We rounded each to the nearest sentence end above 200 words. Choosing a style unit of 200 words allows us to analyze prose style at the paragraph level. While choosing a granular unit of comparison means we cannot look at style on the level of narrative structure, it supports investigating the local style of fragments of text (such as rhythm, sentence structure, vocabulary, etc.).

[3] `https://github.com/style-dataset`

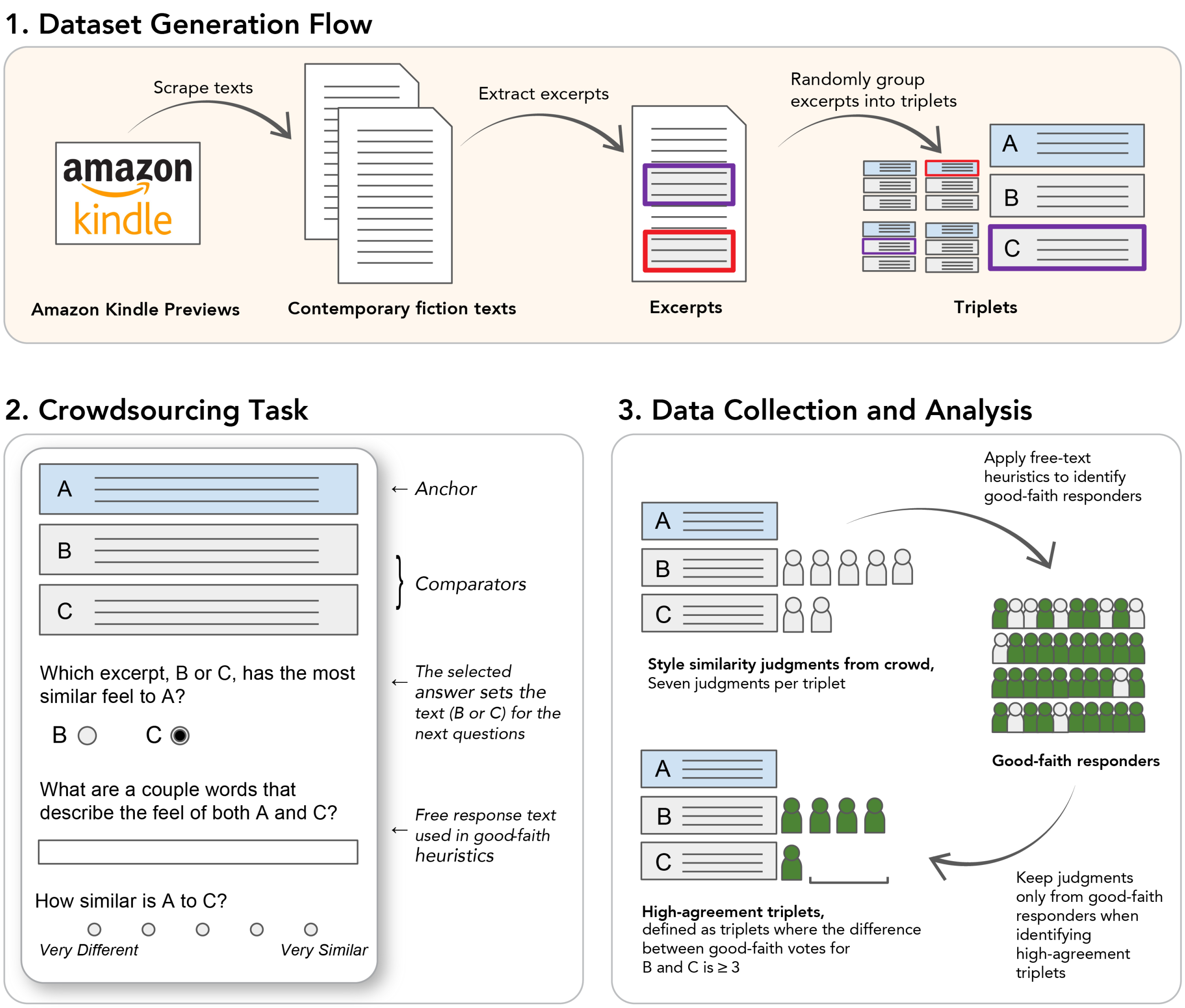

Figure 3.3: Dataset creation method. 1) Dataset Generation: Excerpts are extracted from texts, then combined into triplets. 2) Crowdsourcing Task: The task presents a triplet of excerpts followed by three questions about their style, or "feel." The first excerpt (A) is the anchor, to which B and C are compared. Free response text is used to identify "good-faith" respondents, i.e. those who provide reasonable free-text answers. 3) Data Collection and Analysis: Crowdsourced judgments of stylistic similarity are analyzed for reliability and agreement to identify high-agreement triplets. Here, the triplet shown is high-agreement, since 4 good-faith respondents voted for B, and only 1 voted for C, resulting in a difference of 3.

Since the number of combinations of three excerpts is prohibitively large, we generated a random subset of possible triplets for crowdsourcing. Each excerpt serves as the "anchor" in a triplet a fixed number of times; the anchor refers to excerpt A, against which B and C are compared (see Figure 3.3, part 2). To avoid confounds such as shared character names, excerpts from the same text do not occur in the same triplet. Table 3.1 summarizes the dataset parameters; the open-source dataset provides a full characterization.

3.4.2 Crowdsourcing Method

To collect human judgments of style, the comparison triplets were released on a crowdsourcing platform.

Participants/platform: We recruited crowdworkers from the crowdsourcing platform *Figure Eight*.[4] This platform provides a curated workforce from around the world, with built-in quality control mechanisms, discussed below. We recruited 836 participants, from 38 countries.

Training: Participants were given an example comparison, instructions, and a brief tutorial on some concepts related to literary style. To minimize bias towards one specific interpretation of style, participants were instructed to use their intuition, rather than specific metrics. The full training instructions are provided with the dataset. After the instructions, participants completed an example task to become familiar with the task layout.

Task: After training, participants were presented with style triplets from the dataset, and answered three questions for each (Figure 3.3, part 2), where the letter displayed in questions (2) and (3) depends on the answer to (1):

1. *Which text, B or C, has the most similar feel to A?*
2. *What are a couple words that describe the feel of both A and [B or C]?*
3. *How similar is A to [B or C]? (On a 5 point Likert scale from Very Different to Very Similar)*

Each triplet was presented to seven participants. Participants were paid US$0.10-0.15 per judgment.

Quality control: We used several built-in quality control mechanisms on the *Figure Eight* platform. First, participants were dropped if less time was taken than an estimate of minimum reading time for the passages. Second, participants were dropped if they failed to maintain a sufficient score on "test questions" seeded throughout the task. Test questions used the same format as the comparison triplets but consisted of two excerpts from a single text, and one from a different text, chosen to have a significantly different style.

3.4.3 Cleaning

To ensure that respondents took the task seriously and provided "good-faith" answers, we remove potentially "bad-faith" responses using heuristics drawing on the free-response text,

[4] `https://www.figure-eight.com/`

Style Similarity Dataset: Dataset Generation Parameters	
Total Texts	798
Total Excerpts	1806
Total Triplets	21,630
Excerpt Extraction Parameters	
# of excerpts per text	2-4
Words per excerpt	~200
Do excerpts include dialogue?	[None, Some, All]
Triplet Creation Parameters	
# of times an excerpt is the anchor	5-30

Table 3.1: Style similarity dataset. We generate a set of triplets of excerpts in order to crowdsource style similarity judgments. Triplets are separated into disjoints sets to support various machine learning techniques as well as ways of looking at style. Reported totals are the sum of all sets; ranges represent parameters that vary between sets. A full characterization of all parameters and sets can be found with the open source dataset.

Style Similarity Dataset: Crowdsourcing Results	
Collected Judgments	150,720
Judgments From Good-Faith Responders	66,061
% Good-faith judgments of all judgments	44%
High-Agreement Triplets	5,162
High-Agreement Triplets as a percentage of all triplets with ≥ 3 good-faith judgments	45%

Table 3.2: Style similarity dataset: crowdsourcing results. We crowdsource style similarity judgments for the generated triplets, and process them to select a set of good-faith, high-agreement results. Good-faith judgments refer to those left after cleaning (see subsection Dataset - Cleaning). High-agreement triplets refers to those with a preponderance of raters choosing the same answer (see subsection Modeling Style - Defining High-Agreement Triplets).

such as finding nonsense words. These heuristics are provided with the dataset. 307 contributors provided good-faith judgments, with a mean of 215 good-faith judgments each (range 1 to 1715). The cleaning stage is separate from and prior to determining triplets with "high-agreement," as discussed in the next section: *Modeling Style* (Figure 3.3, part 3). 45% of triplets with at least 3 good-faith judgments qualify as "high-agreement triplets."

3.4.4 Validation

Krippendorff's alpha is extremely low: 0.13 for all responses, and 0.15 for the cleaned responses. In crowdsourcing tasks with correct answers, low inter-rater reliability could indicate that participants lacked knowledge of the task domain or did not take care in responding. However, the interviews with experts suggest that perceptions of style are tacit, inherently subjective and vary across individuals. Due to the quality checks in place, we believe the second case holds.

We recruited three experienced writers unfamiliar with the project to perform the same task as the crowdworkers on a random sample of 30 triplets with high crowd agreement. These colleagues were recruited in-person, and completed the task remotely. All are native English speakers. The majority answer of these participants agreed with the aggregate crowd response 70% of the time. If the crowd responses were random, we would expect to see an agreement of 50%. The results show there is a perceptible style signal that aligns with overall perceptions, with individual variation.

3.4.5 Organization

The dataset is organized by set into comma-separated values (CSV) files. Anonymous keys link to demographic data. We provide scripts with heuristics for evaluating "good-faith" responses as discussed below, examples of how to parse the CSVs, and a full characterization of set parameters, as well as an example of how to use the data for the machine learning model described below.

This is the first dataset of tacit perceptions of style in fiction. It crosses genres and authorship boundaries, opening new directions for computational style research.

3.5 Modeling Style with the Similarity Dataset

To create computational interfaces for literary style in contemporary fiction, we need a model that reflects human experiences of style. Using the dataset presented above, we develop a model of style by training a neural net to make judgments of stylistic similarity of the form described above ("Is A more similar to B or C?"). The goal is for the model's results to align with the crowdsourced human consensus of style, instantiating the crowd's shared tacit knowledge.

3.5.1 Defining High-Agreement Triplets

Since style is highly subjective, no single model can reflect every individual's choices. We therefore focused on the stylistic comparisons for which there was high agreement among crowdworkers. In this way, we may develop a model that effectively captures some shared opinions about style, though it may not be effective at handling controversial cases. We define "high-agreement" triplets as those where at least three more crowdworkers chose the

Figure 3.4: Interface design method. From left: Style comparisons from the collected dataset are used to train a predictive model, which learns a high-dimensional vector embedding associated with how people perceive style. The embedding is projected to 2 dimensions using principal component analysis (PCA). By mapping a color space to the 2D projection, the style of text excerpts can be associated with a color, and used to create interactive experiences (Left Interface: Explorer; Right Interface: Editor).

majority answer than the other answer (Figure 3.3, Part 3). Of triplets with at least 3 good-faith judgments, 45% qualify as high-agreement (Table 3.2).

3.5.2 Training a Predictive Model

The model was trained on 916 high-agreement triplets (as 1,008 triplets had been collected at the time of the user study, and 92 were reserved for testing). We created a binary classifier trained with a binary cross entropy loss function. It takes as input an excerpt triplet, and classifies it into two categories, B or C, indicating which excerpt is most similar to A. We pre-process each excerpt in the triplet into sequences of characters, sequences of parts of speech, and sequences of word embeddings (Pennington et al. 2014). These transformations are motivated by features canonically used in stylometric work: character n-grams, syntactic features (which depend on parts of speech), and lexical features (which depend on the words themselves) (Stamatatos 2009). The neural net then operates on the sequences independently, following the approach in Athira et al. 2015, which explored the benefit of processing multiple input types (sequences of parts of speech, lexical features, and word n-grams) independently in the context of authorship analysis. An LSTM is used for parts of speech, and separate convolutional nets are used for characters and embeddings. After processing, the output vectors are recombined into a single vector of length 48 that represents each excerpt. A modified L2 norm of these vectors is used to calculate the distances between A and B, and A and C, which determines the final classification. See the supplemental dataset for additional details.

The model was tested against 92 high-agreement triplets. These triplets are completely disjoint from the training data, with no overlap between source texts. We achieve 67% test accuracy ((True B + True C) / All Points), and an F1-score of .67 (precision = .61, recall

= .73), with a baseline of 55%. While low in comparison to the accuracy of neural nets in domains with well-defined correct answers, accuracy is similar to that achieved by the in-person validation (70%) described above. This represents a meaningful signal in a highly subjective problem domain. Additional training data might lead to further improvement, but there may be limits to potential improvement, because people themselves disagree about style. There is no universal ground truth, so it is unlikely that any model could deliver extreme accuracy.

3.5.3 Visualizations

In order to predict style judgments, the model learns a 48D vector embedding of the excerpts, associated with how people perceive style. While effective for machine learning, this high-dimensional space is an intractable representation for people. To make the style information comprehensible, we downproject it to a 2D plane, which is easily represented on a screen (however, 3D or other dimensionalities could be equally valid). We call the projection the "style space."

We use principal component analysis (PCA) for the downprojection. As PCA is a common method, it provides a familiar baseline for initial explorations. To interpret the resulting axes, we identify their correlations with stylometric features in the subsection *Validating the Style Space*, below. The 15 dimensions in the embedding most important to PCA are normal or nearly normal; remaining dimension are mostly sparse.

We map colors onto the style space to help users interpret and discuss the results. Colors provide a memorable and describable representation of sub-areas. Each text excerpt can be mapped to a single color based on its position (Figure 3.4, right). The color mappings also support the full-text visualizations described in the next section. We use the CIELAB color space (McLaren 1976), a perceptually uniform 3D representation of color, and fix it to a single lightness value to reduce the parameter space to 2D. Colors come laden with many, often contradictory, cultural associations; we do not attempt to align the style space with any prior color associations. Below we demonstrate how users successfully engaged with this visual mapping in discussing style. These representations help users interpret the style space by presenting the information in familiar ways: colors and 2D scatterplots can reveal patterns at a glance that are not apparent from numerical data.

A single color can represent an individual excerpt. An entire work, however, may consist of passages with different styles, and the work's full effect may depend on their interplay. We use the colors of the style space to create a gradient for an entire text, using a ˜20 word sliding window to analyze chunks of ˜200 words. Each chunk is represented as a narrow bar of its associated color; transitions are smoothed with a gradient (Figure 3.5 B, C). We call this visualization a "style barcode."

We leverage the considerations of both close and distant reading in designing the barcode visualizations. By retaining the vertical structure of text and aligning each color with the lines of text that produced it, a "zoomed in" view of the barcode facilitates an interaction in the manner of close reading (Figure 3.5B). A "zoomed out" view can display a global

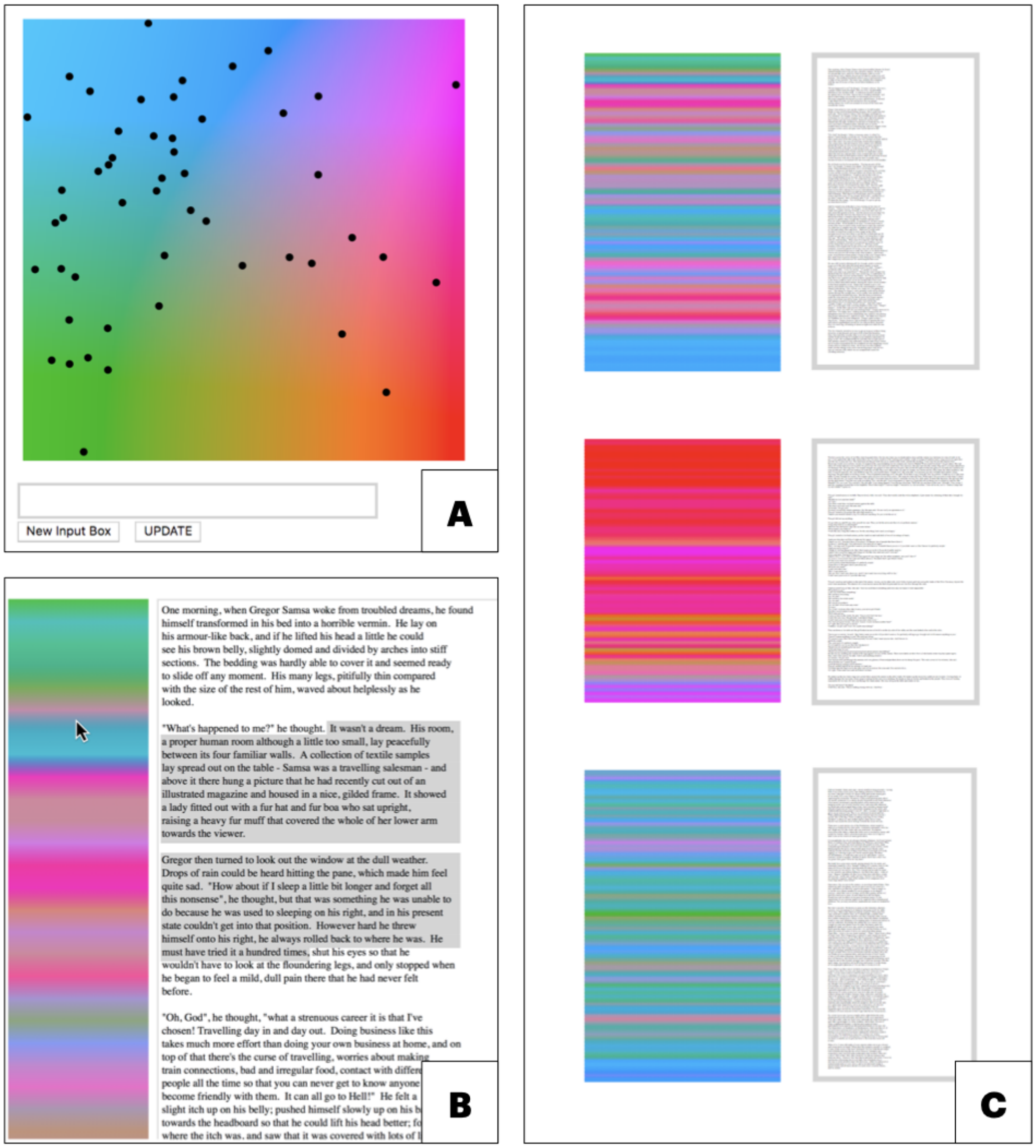

Figure 3.5: Style interfaces. We implemented two style interfaces: the Explorer and the Editor. (A) Explorer: 200-word excerpts are plotted as points on a color plane. New excerpts can be added with the text box. Hovering over a point displays its text to the right of the style space. (B, C) Editor: Style is shown as a color barcode beside longer texts. (B) Franz Kafka's *The Metamorphosis* is zoomed in for a detailed view, demonstrating the section highlighting. Lines highlighted in grey contribute to the analysis of the blue bar directly under the cursor position. The highlighted area animates as the cursor is moved. As users edit the text, the visualization updates. (C) Three 1500-word excerpts of canonical texts are shown in the zoomed out mode for distant comparison. (Top C) Kafka's *The Metamorphosis*, (Middle C) Hemingway's *Hills Like White Elephants*, and (Bottom C) Melville's *Moby Dick*.

perspective of multiple texts at once (Figure 3.5C), facilitating high-level analysis and comparisons among texts in the manner of distant reading. In both views, the sequential nature of the data is retained, enabling users to see how style shifts within a story, and giving a visual sense for local as well as overall style.

3.5.4 Validating the Style Space

Since there are no universally accepted definitions of style, we validate the model and projection using several heuristic analyses.

Style Projection: The book *Exercises in Style*, by French novelist and poet Raymond Queneau, retells a single brief story (about 1 paragraph long) in 99 different styles. It has been translated into many languages, including English (Queneau et al. 1958). For example, the first retelling is "Notation", a straightforward description of a chance meeting on a bus:

> In the S bus, in the rush hour. A chap of about 26, felt hat with a cord instead of a ribbon, neck too long, as if someone's been having a tug-of-war with it. People getting off. The chap in question gets annoyed with one of the men standing next to him. He accuses him of jostling him every time anyone goes past. A snivelling tone which is meant to be aggressive. When he sees a vacant seat he throws himself on to it. Two hours later, I meet him in the Cour de Rome, in front of the gare Saint-Lazare. He's with a friend who's saying: 'You ought to get an extra button put on your overcoat.' He shows him where (at the lapels) and why. (Queneau et al. 1958)

The second retelling, "Double Entry," is longer and more verbose, using repetition and restatement to change the style and feeling of the paragraph and text:

> Towards the middle of the day and at midday I happened to be on and got on to the platform and the balcony at the back of an S-line and of a Contrescarpe-Champerret bus and passenger transport vehicle which was packed and to all intents and purposes full. I saw and noticed a young man and an old adolescent who was rather ridiculous and pretty grotesque; thin neck and skinny windpipe, string and cord round his hat and tile. After a scrimmage and scuffle he says and states in a lachrymose and snivelling voice and tone that his neighbour and fellow-traveller is deliberately trying and doing his utmost to push him and obtrude himself on him every time anyone gets off and makes an exit. This having been declared and having spoken he rushes headlong and wends his way towards a vacant and a free place and seat. Two hours after and a hundred-and-twenty minutes later, I meet him and see him again in the Cour de Rome and in front of the gare Saint-Lazare. He is with and in the company of a friend and pal who is advising and urging him to have a button and vegetable and ivory disc added and sewn on to his overcoat and mantle. (Queneau et al. 1958)

If the style space axes identified above (Figure 3.5A) effectively separate styles, Queneau's intentionally stylistically distinct retellings should spread out across the style space. Note that we do not recalculate PCA here, rather we project the retellings onto the existing space. As expected, the retellings spread across most of the style space (Figure 3.6). Some interesting clusters do arise: for example, the cluster along the top edge consists mostly of "nonsense" retellings, such as the *Anagrams* version in which the letters are mixed up into nonsense anagrams.[5] These nonsense retellings take extreme values in the style space; the visualization clips their positions to fit them in the view, resulting in clustering along the top edge.

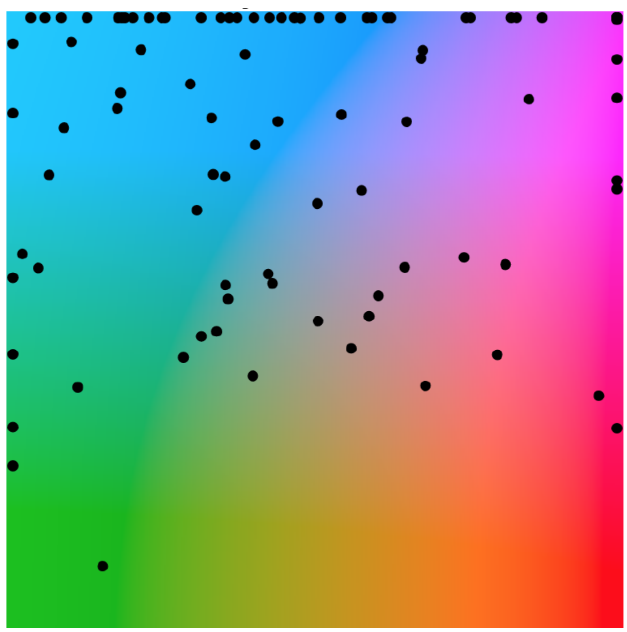

Figure 3.6: ***Exercises in Style*** by Raymond Queneau retells one scene in 99 styles. The retellings spread across much of the style space derived in Figure 3.5. The cluster along the top edge arises from 'nonsense' retellings (e.g. *Anagrams)*.

Stylometric Correlations: We would expect to see mild correlations between our style space and standard stylometric features. Perfect correlation would indicate that our approach adds little to the current understanding of style; conversely, no correlation might indicate that our model captures noise. We performed a linear regression between a selection of 23 standard stylometric features (Stamatatos 2009; Yang et al. 2012; Zhao et al. 2007) (Table 3.3) and the 48D style space. The most correlated metrics are average word length ($R^2 = .25$), and the ratio of verbs to all words ($R^2 = .22$) (Table 3.3), indicating that the high-dimensional style space is weakly correlated with these common stylometric features.

[5] *Exercises in Style - Anagrams*: "In het s sub in het hurs hour a pach of tabou swinettyx, who had a glon, hint cken and a tah mmitred with a droc instead of a borbin, had an urmagent with athrone gaspenser whom he uccased of stoljing him on sporeup. Having had a good oman he dame to shad orf a feer teas. An hour trale I emt him in het Cour ed More, in norft of het rage Tsian-Zalare. He saw with a refind who was yasing to him: 'You tough to heav an artex tutnob upt on your oectrova.' He woshed him hewer (at het peninog.)" (Queneau et al. 1958)

Our model captures signals associated with the stylometric approach, but cannot be fully reduced to these explicit features.

We also note correlations between the main dimension used by the second component of the PCA projection (mapped to the vertical axis of the 2D style space) and specific stylometric features associated with sentence length (e.g. average sentence length, average clause length, ratio of verbs). The vertical axis of our style space is weakly correlated with sentence length, but also represents additional nuance in the data not captured by common stylometric features.

Metric	$\mathbf{R^2}$
avg. word length	0.25
ratio verbs	0.22
ratio adverbs	0.17
ratio adjectives	0.17
ratio punctuation	0.16
avg. sentence length	0.14
function words	0.13
avg. clause length	0.11

Table 3.3: Linear regression of stylometric features on the 48D style space shows correlations with several common metrics. Ratios = metric / words in passage. 23 metrics were calculated; table shows those with $R^2 > 0.10$

3.6 Applications

We instantiate our visual representations of style in two applications for searching and composing text. These applications are presented as probes into possible uses of style-aware interfaces, and explored in the user study presented below. The applications are implemented as web pages. New texts are analyzed using the model discussed in the preceding section.

Explorer: The explorer interface displays the style space with interactive points representing excerpts. Hovering over a point displays its associated excerpt on the screen to the right of the style space. Interactive text boxes allow the user to add new texts. Users may input their own writing or other texts. The Explorer allows users both to learn how to interpret the style space and to gain insight into the styles of works of interest to them. For the user study, we pre-loaded a subset of excerpts from the style similarity dataset (Figure 3.5A).

Editor: The editor interface displays style barcodes for longer texts. Interactive text boxes allow users to input and edit text, while viewing the associated visualization. Users can view the texts at two levels of zoom: the smallest allows entire works to be seen at a glance and compared against other works (Figure 3.5B), and the largest allows line-by-line style inspection and interactive editing (Figure 3.5C). Hovering over a location on the barcode highlights the lines of text that generated the selected color bar. A button updates the visualizations after text has been modified. Users can visualize the style of a work in progress, or of an existing text, in the context of both close and distant reading, and can see patterns of style change within the overall work and over time as it is edited.

The applications leverage the comparative nature of the style model. Because distance encodes similarity in style space, interpreting it requires comparing excerpts, as done via the Explorer. The Editor facilitates comparisons within or between longer works (Figure 3.5A).

3.7 User Study

We performed an exploratory study to investigate how users interacted with the style applications. We recruited 6 participants (1 man, 4 women, 1 not stated) from campus mailing lists for English, Literature, Computer Science, Design, and Creative Writing. All used long-form writing in their academic, personal, or professional lives. Formal training in literary analysis varied from high school or equivalent to extensive graduate training. Three are graduate students in writing-related fields. One is a professor of creative writing. All are native English speakers. Mean age was 30 (21-45), with a mean of 10 years experience in their main writing domain. Participants were compensated US$20 for a 1 hour study.

Participants began by explaining their own definition of style and discussing whether and how considerations of style featured in their reading or writing habits. They were then introduced to the Explorer interface (Figure 3.5A). We demonstrated the possible interactions, and explained how the projection was created from the model, including the accuracy limitations of the model and how those errors might manifest in the projection as misplaced points. Participants were then instructed to talk aloud as they spent ten minutes investigating the excerpts projected in the style space, and to describe any patterns or contradictions they noticed. Some chose to add additional excerpts using the interactive text boxes, including academic papers, news articles, and short stories. Once they were familiar with the style space, they were introduced to the Editing interface (Figure 3.5 B, C). They were asked to read an excerpt of a fairy tale, and describe its style, then use the interfaces however they wished to edit that excerpt into a new style. Afterwards, they discussed their use of the tool and the style of the modified fairy tale. Finally, an open-ended interview explored their thoughts about the interfaces, whether and how they might use such tools in their everyday writing and reading, and whether their thoughts about style had changed.

3.8 Results

Due to small sample size, we present qualitative results.

3.8.1 New Experiences of Style

Users reported that the tools prompted deeper engagement with the notion of style. Even experienced participants, who think about and teach elements of style on a daily basis, challenged their own conceptions of style:

P4 Seeing [excerpts] on the color map really made me try to articulate the differences. I could feel each one is different but I have not thought about [how] I could put them on different axes.

P5 I think that when I framed what style is in the beginning, I talked most about sentence and paragraph...Now I'm wondering...what is the smallest unit of style and what is the largest unit of style that is meaningful?

P6 What I first said, that style is about time, actually this is making me think that maybe style is the opposite of that, what remains constant regardless of subject matter and time span.

The authors are aware of no other writing interfaces that afford this type of critical engagement with style. Interfaces based on feature counts suppress the ambiguity and dialogue between users and texts. As Gaver et al. discuss, ambiguity of information can make an interface "evocative rather than didactic," and encourage self-reflection and critical engagement with the system (W. Gaver et al. 2003). Our interface invites users to bring their own interpretations of style to the interaction, while encouraging them to challenge their instincts and preconceptions about style. As **P6** noted, "It's just cool to be able to play with the idea of what style is...it could be useful as much to trouble definitions of style versus fixing a definition of style. To me, making trouble is useful."

3.8.2 Gestalt Over Details

The idea of 'gestalt' is that of "an organized whole that is perceived as more than the sum of its parts."[6] Gestalt effects are important in writing, for instance:

P5 What feels right depends on how many sentences you read before and after; there is a rhythm to each paragraph that you don't get if you just go sentence by sentence.

Several participants found more value in the gestalt of the visualization than the details, appreciating the high-level view of the barcode representation:

P2 You can look at [the barcode] and it makes sense as both being diverse, but also unified, and different than the other text, which has its own diversity.

[6] Oxford University Press, Lexico.com, 2019

Viewing the barcodes as a whole gave a sense of variation and similarity that would be absent if individual passages were examined separately. The barcodes successfully surfaced both impressions of local and global style, and enabled discussion of comparisons between works. Focusing on details of exact color or position was less productive. When a detailed inspection is needed, a more explicit tool might be more appropriate, while the ambiguous visualization of style is effective for gaining an overall sense of a work and prompting engagement with style.

3.8.3 The Continued Ineffability of Style

Participants repeatedly confirmed that style remains best understood as a tacit, ineffable experience.

> **P6** It's just that this word is better here, I don't know why. I can make up a reason – you know the number of syllables, it's fewer syllables than the alternative and it reads faster – but a lot of times it's just that it sounds better because it sounds better.

Notably, while formal training influences the way people describe aspects of style decisions or analyze style, it remains tacit within their own practice. P1, a published author and professor of creative writing, said:

> **P1** The way I explain it to my students...Ideally you're absorbing [style] in class and when you're actively learning so when you do it you don't think about it. So it's like a ballet dancer who learns in class to hold in your stomach, lift your elbow, lift your chin, but then when she's on stage she's not thinking about any of those things.

These descriptions illustrate the tacit understanding of style. Explicit language and direct recommendations for changing stylistic features have value, but not during creative production, when the experience should remain tacit.

The color space supports the tacit approach through its open and flexible representation. Participants engaged with the changing colors as they changed the style of editable text, and constructed their own meanings as the colors updated:

> **P4** This section is pinker. It wasn't pink before. I imagine it's because I structured the sentences differently and took out a lot of fairy-tale style by making it super simple...I looked back at the interface, based on my estimates of different styles, what those colors meant to me, and use[d] that to figure out if this is enough of a style change.

Sometimes the ambiguity of the interface was uncomfortable,

> **P2** "It's weird to not know what do the pink and blue do, but try to talk about them."

At the same time, it was "stimulating" **(P2)**, and inspired playful interactions with style:

P5 [Ernest Vincent Wright] wrote a book without using the letter 'e'...so I want to write a book that is all beige...I want to paste some of my writing and...see what kind of sunset I get.

With this kind of visual language, we could imagine interactions around learned associations: embracing a tacit approach through a shared vocabulary that does not require precise definition may encourage discussions of style; glancing at a visualization may give a sense of style instantly for text that would otherwise take hours to read and analyze.

3.8.4 Ambiguity Invites Personal Interpretations

As expected from the formative study, style continues to be highly personal, contextual, and fluid. There was a certain level of consistency in interpretations of the style space: for example, two participants separately arrived at the same description for the upper left section of the style space:

P4 [The] blue section is maybe more descriptive and not trying to mimic the way people speak.

P3 [The] ones in blue are like describing something, some situation...[the] blue ones might be about description.

A third participant described that area as "ornate, maybe introspective," **(P5)** which may correlate with "descriptive."

But no theories were universally supported; participants often encountered incongruities:

P2 [Rowling] has more lively style and [is] more straightforward. I am puzzled why [these two authors] are nested together.

P6 Let me look at other [points] closest to it. This would seem to go against what I just said, because this is a first person, character based story. So maybe there's not as clear of a difference as I thought.

P5 This one has longer words and denser paragraphs, so maybe that's something. Down here we have more back and forth text...well it's not universally true.

Some uncertainties may arise from flaws in the model or the projection; since it only yields 67% accuracy, and reducing style to two dimensions discards many nuances. But it may also represent the fundamental ambiguity of style: since there is no universally accepted definition, results that makes sense to one person may strike another as odd. Our tool supports this natural engagement with the fluidity of style, enabling a wide variety of interpretations. Participants spoke of looking for different metrics in the space; for example, P1 thought about how removed the reader feels from the action, P5 about word and sentence length, and P2 noticed gender in the narrative voices. No generalized representation of style will perfectly satisfy every individual's personal judgments, and should not claim to. The value lies in encouraging the interpretation.

3.9 Discussion

Writers have long used libraries, references, thesauruses, and other tools to help shape their work. Word processors with grammar checking and stylometric heuristics have further shaped how people write, edit, and critique their and others' work. Our computational approach to style opens new possibilities for interactions with word processors, exploratory discovery, collaborative writing and cooperative literary spaces.

3.9.0.1 Collaborative Style and Editing

In the user study, participants envisioned uses around editing contexts, such as working on a long document like a dissertation (P4), where picking out inconsistent sections quickly is essential, or maintaining a coherent character voice (P6). Indeed, while editing this work, the Editor application enabled the authors to see places where each had written stylistically incompatible sections. In this case, we sought a unified stylistic voice, but in other situations the visualization could also help ensure styles remain distinct when authors want separate voices (Figure 3.1, far right). The style interfaces also provide access to community knowledge: the shared color representation between the Editor, which displays own style, and the Explorer, which shows examples of other writing, supports investigating how one's own style fits into the broader landscape.

3.9.0.2 Learning Style

Since knowledge of style is tacit, it can be hard to teach and learn, especially for those first encountering literary critique, learning to apply it in their own creative writing, or writing in a new language. Style interfaces may provide assistance in these contexts. Participants noted the benefits of surfacing style through a computational interface for students who are still learning to critically engage with style: "I can imagine it being useful for students...operating with hunches, to see the breakdown and evidence of what they feel" **(P2)**. Revealing student "hunches," or tacit knowledge, through the visualizations could encourage critical reflection and further engagement. A participant in the formative study discussed the challenges of adjusting her academic writing style for an English-speaking audience:

> **F1** It's just the American way, direct sentences and simple sentences, rather than complex, long sentences. I used to write sentences that [were] like 3, 4 lines long, and that was acceptable in India, which is not how most [of the] English speaking world writes.

Style interfaces could help writers adapt to new style norms through visualizations of current or target styles.

3.9.0.3 Exploratory Discovery in Online Communities

Nontraditional corpora and cooperative literary communities may be a fruitful application area for computational style tools. In domains such as fanfiction and other free, online writing, automated recommendation systems are not common. Instead, users depend on the community and on content-based search tools to find stories. For fanfiction in particular, where writers share the same characters, settings, and plots, style might provide helpful information to users seeking stories they would enjoy. Since style is subjective, an interface that invites the user's participation and interpretations, such as visualizations, may be more appropriate than black-boxed recommendations. Visualizations could carry meaning across platforms, allowing a user to identify a style they like on a fanfiction site, then find similar styles on another site, like Amazon.com (Figure 3.1, second from right). Style interfaces might even extend beyond computer screens, and into physical contexts, such as dynamic screens on book spines (Figure 3.1, far left).

3.9.0.4 Enhanced Experiences

E-readers are beginning to introduce computational tools for interacting with e-books, such as the Kindle X-Ray feature, which displays the frequency of occurrences of names and key terms. Style tools offer another form of computational insight into texts. Furthermore, representations of style need not always be visual; texture could carry a similar information in a tactile manner, opening up modalities for blind or color-blind users (Figure 3.1, second from left).

3.10 Limitations and Future Work

Some of the confusions identified in the user study may be associated with the performance of the model. While a perfect model is neither possible nor desirable, pursuing higher performance may be valuable. Evaluating different text encoding methods could provide insight into the most effective modeling approach and improve performance; for instance, comparing document embeddings (Dai et al. 2015) to the encoding used here (combining sequences of parts of speech, word embeddings, and characters). Our data may be influenced by a wide range of stylistic norms, as the crowdworkers who contributed to the dataset come from many countries, and many spoke English as a second language.

Regardless of model performance, the nature of style is such that certain aspects cannot be identified by current techniques. How can we capture 'intent,' or discriminate between subversion or reinforcement of convention in an excerpt of text? These are questions of nuance that currently remain in the human realm.

Exploring other representations of style may be valuable. Nuance is lost in the downprojection from the high-dimensional representation to 2D space; while PCA is a straightforward method to project the style space, it is not the only way. One could imagine anchoring a plane on three specific works, to define a style space based on the characteristics of well-known authors, or using an interactive approach such as that described by H. Kim et al. 2016 to dynamically find relevant views. The user study here focused on web-based interfaces; future work could explore user reactions to visualizations in other contexts (e.g. the envisioned applications on book spines or in online marketplaces). The interfaces could move beyond colors, exploring alternate visual representations, or beyond visual representations entirely, using textural representations or adapting to an individual's own associations with style.

Finally, it is important to note that we do not wish for style interfaces to replace close reading or direct interaction with the texts themselves. Style tools are complementary, assisting in contexts where traditional close reading is not the desired interaction.

3.11 Conclusion

For most people, knowledge of style is tacit. Formal analysis by literary scholars and existing computational metrics are valuable, but do not necessarily capture people's experience of style. Here we demonstrated a new way to analyze writing focused on people's tacit sense of style. Rather than using categories such as authorship or genre, we created a novel crowd-sourced dataset of direct comparisons of style, leveraging the tacit knowledge of hundreds of readers, and published the dataset for others to use. We then developed a machine learning model to predict these comparisons, yielding a high-dimensional style space. Using the model, we created interactive tools for the exploration and editing of style. In a user study, we found that such interfaces afford new interactions with style and provoke creative, critical engagement. Addressing the tacit dimension of style opens up exciting new directions for computational style research and interactive style interfaces.

In addition to the specific context of literary style, this chapter demonstrated how a process-focused approach to a creative task reveals new understanding of the task. Identifying the values involved in the process of working with style – interpretation, uncertainty, comparison – suggests new ways for creativity support tools to integrate with process, rather than seeking the most "accurate" or "successful" output. In the next chapter, we return to the first two research questions, and explore process values across multiple domains to expand our understanding of creative process.

Chapter 4

Studying Creative Process Across Domains

In Chapter 3, I discussed a specific example of investigating creative process in a single domain: understanding how writers and readers engage with literary style in prose fiction. In this chapter, I will introduce a study of process across multiple diverse domains of creative practice. This will allow us to dive deeply into the first and second research questions:

R1: What process values are present in existing creative practices?

R2: How do creative practitioners instantiate these values in specific strategies and behaviors? How do tools, computational and otherwise, support or inhibit these strategies?

I will discuss a set of creative strategies identified across domains, and how this type of analysis can provide the groundwork for process-sensitive CST design. These strategies are one way to make sense of creative process, revealing values that practitioners hold through how they structure behaviors that support motivation, inspiration, affect, and long-term engagement with creative work. Understanding process strategies and values can inform creativity support tools that enhance practitioners' experiences, especially in cases where the values or strategies appear contradictory to expected approaches, or unintuitive. For example, we will explore the value of *forgetting* information instead of always prioritizing *retention*, and the benefits of deliberately introducing *friction* instead of always seeking *ease*.

In Chapter 5, we will return to this study through a second lens, that of the values embedded in version control tools across diverse practices, and examine how a process-sensitive approach can inform our understanding of the role that version control systems play in structuring creative work.

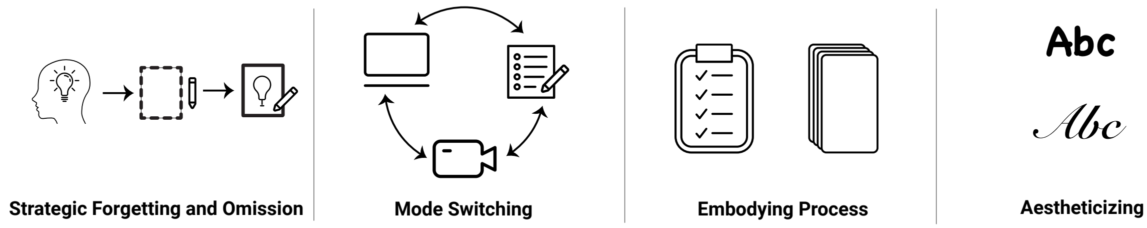

Figure 4.1: Creative strategies. Through interviews with 15 creative practitioners in diverse domains, we identified four strategies for managing motivation and structuring process in creative work: *Strategic Forgetting*, specifically avoiding capture of creative output (Section 4.4.1); *Mode Switching*, consciously selecting a tool to shift into a particular creative mindset (Section 4.4.2); *Embodying Process*, the emotional benefits of tracking and visualizing an otherwise ephemeral process (Section 4.4.3); *Aestheticizing*, making deliberate aesthetic choices to manage intrinsic motivation (Section 4.4.4).

4.1 Introduction

Creative practitioners deliberately structure their process, environment, and mindsets to navigate the ambiguous and complex space of creative work. These strategies shape motivation and emotional affect, as well as output: for example, parallel prototyping (Dow et al. 2010) is a particular process technique that encourages creating multiple alternatives in parallel, and results in both better outputs and in increased self-efficacy among designers.

The knowledge of such strategies creates a toolbox for practitioners to draw from when approaching creative problems and structuring their experience. Some strategies may be so deeply entwined with an individual's process that they cannot work without it; others may be used more selectively, in particular situations or to remove particular blockers. Practitioners experiment with their individual creative processes by applying new strategies or embracing different mindsets, in order to seek more effective approaches and deepen their understanding of themselves and how they work.

Some techniques are specific to particular tools or domains, while others can be tool- and domain-agnostic. These techniques can be shared and learned across practices and between tools. In this chapter, we investigate tool- and domain-agnostic strategies, seeking creative techniques that have the potential to be shared and adopted broadly.

Designers can support creative practitioners by incorporating understandings of such techniques and strategies into tools and systems to support these essential yet undersupported aspects of the creative process. Creativity support tools can help expert creative practitioners maintain sustainable daily practice and scaffold newcomers into lifelong engagement by considering metacognition, emotional affect, task motivation, and working style. Such tools would go beyond skill- and task-oriented support, to address the overall experience of "being creative." We suggest that increased attention to the process-oriented aspects of sustained creative practice will improve the overall design of Creativity Support Tools (CSTs). In service of this goal, this work presents a selection of techniques that expert practitioners use to structure their personal creative experience as both a description of existing practices and a foundation for CST designers to draw from when considering process-sensitive CSTs.

This work builds on studies which focus on supporting the personal experience and emotional well-being of the artist as they engage in the creative process. For example, Treadaway articulated the importance of a tool supporting feelings of satisfaction, rather than focusing only on the tool's effect on creative output (Treadaway 2009). In some of our prior work, Torres, Sterman, et al. 2018 explored the benefits of supporting process by developing healthy relationships with failure. Other recent work that addresses the creative experience and practitioner well-being include supporting productive procrastination (Belakova et al. 2021), and enabling positive self-conception (Dow et al. 2010; J. Kim, Agrawala, et al. 2017) during creative work. Taking a process-oriented perspective, in this chapter we identify techniques used by experts across diverse fields that embody intra-personal aspects of creativity such as metacognitive skills, emotional support needs, working style, and intrinsic motivation. While some theories of creativity focus on immutable personality characteristics, these techniques can be used intentionally to increase and improve creativity. Tools can be effective agents for structuring and enabling these creative strategies. Understanding how experts currently manage and perceive their own creative strategies can inform the design of future tools that amplify the benefits of successful strategies and scaffold new techniques. This chapter addresses the question: *What characterizes creative strategies for creative professionals across domains?*

The study of creativity spans disciplines (Gardner 1988), so it is crucial to work with experts across a wide range of domains, fields, and communities of practice as we seek to identify how experts manage meta-cognitive and emotional needs. Looking at a diversity of creative processes provides both a lens onto broader commonalities of practice, as well as insights into specific details of unique creative processes, both of which can enrich approaches across domains. Frich et al. observed that current HCI research only sparsely draws from skillful creative practitioners' tool-use and behaviours (Frich, MacDonald Vermeulen, et al. 2019); by drawing on experiences in diverse disciplines we expand existing bodies of knowledge about expert tool-use. Qualitative methods are uniquely appropriate for identifying and curating descriptions of creative strategies, which can provide a source of long-lasting and technology-agnostic knowledge. This type of knowledge complements that gained from novel CSTs, which instantiate new ideas but are often ephemeral and hard to maintain (Frich, Biskjaer, MacDonald Vermeulen, et al. 2019). Strong foundational understanding of creative processes can develop our perspective on how creativity works, and help construct new design directions. For example, Terry and Mynatt described three creative strategies from a series of case studies of expert practitioners across diverse fields (Terry et al. 2002); these rich descriptions remain relevant to the design of creativity support tools (CSTs) even many years later.

In this chapter, we first situate this work within related literature in creativity theory and CST design. Then, we introduce our methodology and analysis. Through analysis of our interviews, we identified strategies and techniques for overcoming ambiguity, staying inspired, and managing the creative process used by expert practitioners across diverse domains of performance, craft, engineering, science, art, and design. Each theme is grounded in descriptions of the behaviors of specific practitioners. We synthesize our observations into four strategies: *Strategic Forgetting*, *Mode Switching*, *Embodying Process*, and *Aestheticizing*. Some of these are different from or even contrary to common design recommendations, expanding our understanding of the range of creative process behaviors: for example, the strategy of Strategic Forgetting recommends *against* capturing output for future reference. These contrasts are examples of value inversions, where identifying our surprise at the unexpected approach can reveal undersupported aspects of process. Each strategy and technique is placed into our categorization of CSTs, to clarify relationships to prior work. We then ground these strategies in existing research about cognition, design practice, and creativity. Finally, we encourage a shift in CST research and design to focus on strategies that support creative process.

4.2 Related Work

4.2.1 Creativity Research

This work is part of ongoing efforts to connect creativity research and HCI more deeply (Frich, Biskjaer, and Dalsgaard 2018b; N. Davis et al. 2017), as well as to leverage practitioner expertise in our understanding of tool-use and creativity (Kaufman et al. 2009; Frich, Biskjaer, MacDonald Vermeulen, et al. 2019). We first establish a shared definition of creativity and a summary of current creativity research. The study of creativity spans disciplines, from neuroscience, cognitive science, psychology, and human computer interaction, to history, anthropology, and beyond, requiring a "synthesis of different disciplinary perspectives" (Gardner 1988). As designers of CSTs, we draw on these myriad creativity theories to inform our approach. Rather than attempt a complete summary of all theories of creativity, here we discuss those most relevant to our work.

While the definition of 'creativity' has evolved over time, the widely accepted (Barron 1955; Stein 1953; Plucker et al. 2004; Amabile 2018; Kaufman et al. 2009; Frich, Biskjaer, MacDonald Vermeulen, et al. 2019) "standard definition" as articulated by Runco and Jaeger (Runco et al. 2012) requires both originality and effectiveness. Embracing this core definition, this work additionally takes a social constructivist (Von Glasersfeld 2012) perspective, which embraces a broad understanding of the ways in which people, environments, and tools combine to shape both process and outcome (Dalsgaard 2014; James Hollan et al. 2000; Latour 1996; Suchman and Jordan 1990; Von Glasersfeld 2012; Plucker et al. 2004; Dalsgaard 2017). Plucker et al. articulate such a vision of creativity research, focusing on the interaction between "aptitude, process, and environment", a definition that is particularly relevant to HCI researchers (Plucker et al. 2004). Fundamentally, we understand creative work as being done in a particular social and environmental context.

An example of a particularly influential framing that takes into account both aptitude and process is Amabile's Componential Model of creativity. Amabile emphasizes three core aspects of creativity: domain-relevant skills, creativity-relevant processes, and task motiva-

<table>
<tr><th>Task Support</th><th>Creative Strategy</th><th>Motivation Management</th></tr>
<tr><td>Astral
(Ledo et al. 2018)</td><td>View-shifts, margins
(Frich, Biskjaer, MacDonald Vermeulen, et al. 2019)</td><td>Relationships with failure
(Torres, Sterman, et al. 2018)</td></tr>
<tr><td>Montage
(Leiva and Beaudouin-Lafon 2018)</td><td>Parallel prototyping
(Dow et al. 2010)</td><td>Increased self-efficacy
(Dow et al. 2010)</td></tr>
<tr><td>Kitty
(Kazi et al. 2014)</td><td>Near-term experimentation
(Terry et al. 2002)</td><td>Reduced over-criticizing
(Belakova et al. 2021)</td></tr>
<tr><td>Rapido
(Leiva, Grønbæk, et al. 2021)</td><td>Design by enaction (Leiva, Maudet, et al. 2019)</td><td>Feelings of satisfaction
(Treadaway 2009)</td></tr>
<tr><td>iStuff (Ballagas et al. 2003)</td><td>Creative voicing
(Belakova et al. 2021)</td><td></td></tr>
<tr><td>Luminaire tool
(Torres, O'Leary, et al. 2017)</td><td>Meta-cognitive awareness
(Yan et al. 2019)</td><td></td></tr>
<tr><td>Read-Wear/Edit-Wear
(Hill et al. 1992)</td><td>Increased reflection
(Hook et al. 2015)</td><td></td></tr>
<tr><td></td><td>Cognitive appraisal
(De Rooij et al. 2015)</td><td></td></tr>
<tr><td></td><td>Strategic Forgetting (4.4.1)</td><td></td></tr>
<tr><td></td><td colspan="2">Mode Switching (4.4.2)</td></tr>
<tr><td></td><td colspan="2">Embodying Proces (4.4.3)</td></tr>
<tr><td></td><td></td><td>Aestheticizing (4.4.4)</td></tr>
</table>

Table 4.1: Categories of CSTs. To contextualize the field of creativity support tools research, we consider three categories of research, based on Amabile's Componential Model of Creativity (Amabile 2018). Research that focuses on *task support* creates specialized systems and tools to enable specific types of outputs to be created. Research that identifies *creative strategy* provides insight into how creative practitioners work, such as how they generate ideas, gain new perspective, or reflect. *Motivation management* research focuses on how practitioners create and maintain motivation. The four techniques described in this work fall under *creative strategy* and *motivation management*, aspects of creative process.

tion (especially intrinsic motivation) (Amabile and Pillemer 2012). Our work focuses on the latter two components, creativity-relevant processes, which include cognitive style, working style, and knowledge of heuristics, and task motivation (Amabile 2018). While some of these 'processes' may be immutable personality characteristics, many can be shaped by intentional tool use (e.g., "tolerance for ambiguity" and "suspending judgment"). Creativity researchers emphasize the value of focusing on dynamic, mutable aptitudes rather than on the study of static, immutable traits (Amabile 2018; Plucker et al. 2004; Glăveanu et al. 2021; Diakidoy et al. 2001). Recent work has emphasized the importance of understanding the creative *experience* in addition to creative outputs (Glăveanu et al. 2021). This represents an opportunity for CST research: tools that take into account the overall creative experience can facilitate growth and sustainable practice by mediating mutable intrapersonal aspects of creativity. Understanding how experts engage with and manage creativity-relevant processes provides a particularly rich foundation of knowledge for the CST community.

Kaufman and Beghetto identify different levels of creative practice (Kaufman et al. 2009): our interviews focus on professionals, the "Pro-c" level, with significant experience and established success in their fields. Professional practice is a rich source for understanding creative behaviour (Kaufman et al. 2009; Frich, Biskjaer, MacDonald Vermeulen, et al. 2019). We seek to contribute to deeper understandings of the way experts, operating at a high level of professional skill, manage and shape their own personal creative experiences, and how tools and systems could support that.

4.2.2 Process-Oriented Creativity Support Tools

HCI research related to creative strategies often focuses on designing tools whose primary purpose is to facilitate high quality output by supporting specific tasks (Figure 4.1) (Ledo et al. 2018; Leiva and Beaudouin-Lafon 2018; Kazi et al. 2014; Leiva, Grønbæk, et al. 2021; Ballagas et al. 2003; Torres, O'Leary, et al. 2017; Belakova et al. 2021; Hill et al. 1992).

In contrast, our work focuses on identifying tool-agnostic creative strategies (Frich, Biskjaer, MacDonald Vermeulen, et al. 2019; Terry et al. 2002; Myers, Lai, et al. 2015; Jalal et al. 2015; Dow et al. 2010; Leiva, Maudet, et al. 2019; Belakova et al. 2021), that can inform the designs and uses of many types of tools. For example, Frich et al. (Frich, Biskjaer, MacDonald Vermeulen, et al. 2019) identified two strategies in creative practitioners' use of digital tools: 'margins', and 'view-shifts'. Both are tool-agnostic strategies used by expert practitioners as they iterate through a design process. We additionally focus on supporting mindsets that enable creativity. By supporting intrapersonal aspects of the creative process, we seek to improve and enrich day-to-day work and satisfaction (Figure 4.1).

The relationship between affect and creativity is complex, with some evidence showing the positive impact of positive moods on creativity (Isen et al. 1985; Phillips et al. 2002; Amabile, Barsade, et al. 2005) and other findings that add nuance to this perspective (Bartolic et al. 1999; Clapham 2001; Bledow et al. 2013). Bartolic et al. found that brain activity associated with negative moods improves figural fluency compared with verbal fluency, while brain activity associated with positive moods had the opposite effect (Bartolic et al. 1999). Sowden and Dawson similarly found that a negative mood helped participants assess the usefulness of a given evaluation, while a positive mood enhances performance on ideation tasks (Sowden et al. 2011). Bledow et al. described the impact of an *affective shift* on creativity, taking a dynamic view in which "the emergence of new ideas [and positive affect] is often preceded by and depends on a phase of negative affect" (Bledow et al. 2013).

Creativity support tools can be designed to take emotional affect into account. For example, De Rooij et al. designed a system to enhance positive emotions which they argued would increase creativity (De Rooij et al. 2015). Increasing positive emotions is not the only way to affect creativity, however: Torres et al. articulated strategies that expert practitioners use to manage experiences and feelings related to failure, including embracing failure, mitigation of the effects, and reframing failure entirely (Torres, Sterman, et al. 2018). Belakova and Mackay reframed a 'negative' behaviour in their design of SonAmi: this tool addresses *over-criticizing* – a common barrier to creativity among writers – by providing creative distance from the authors' own writing by replaying written snippets with a computer-generated voice (Belakova et al. 2021). The computer-generated voice enhanced the authors' ability to both appreciate and constructively critique their own work. Kim et al. designed Mosaic to celebrate incremental process, a way of reframing the value of unfinished work. Mosaic displays works-in-progress as a way to both promote healthy communities and positive self-conception (J. Kim, Agrawala, et al. 2017). Complementary to Kim et al.'s findings, in this work we focus on how practitioners manage their individual creative process, rather than community interactions. Dow et al.'s research on parallel prototyping (Dow et al. 2010) articulates not only a specific prototyping strategy, but also the impact of such a strategy on a novice designer's sense of self-efficacy, which has been shown to influence a variety of outcomes (Bandura et al. 1999), including one's ability to learn (Dweck 2008), find enjoyment in (Csikszentmihalyi 1990) and persist through (Mele 2003) challenges, and engage in activities (Bandura et al. 1999).

Directly influencing emotional affect is only one way to support creativity. Other researchers have discovered ways to support creativity by making the creative process itself more visible and legible. Increased awareness of one's own process can improve metacognitive understanding and learning outcomes (Yan et al. 2019). Creating artifacts can be understood as a way to capture and view 'fleeting moments' of progress for visual artists (Hook et al. 2015), or a way to maintain focus (Marshall et al. 2004). While these strategies do ultimately improve the final creative output, the immediate benefit is to improve the emotional well-being of the creator by engendering a sense of progress. Our work similarly seeks to scaffold healthy mindsets by designing systems that take into account the emotional well-being of creative practitioners by reframing negative experiences, increasing positive affect, and supporting healthy awareness of process. Building on these earlier findings, we expand the conversation beyond students, designers, and engineers to include the rich practice across other domains, including performance, craft, science, and art.

4.3 Methodology

4.3.1 Interview Methods

To understand practice “in the wild” we carried out semi-structured interviews with 12 expert creative practitioners and 3 early career practitioners. Interview questions were guided by grounding themes of artifact use and personal creative practice, and shaped by the individuals’ background and reflections. Each interview lasted 1-2.5 hours, during which we asked semi-structured interview questions, focusing on personal creative practice and background. Most interviews took place in participants’ primary workspaces to understand their tool use in context (Beyer et al. 1999; Suchman, Blomberg, et al. 1999) [1]. To ground our discussion in concrete examples of daily work, we followed principles of contextual inquiry (Beyer et al. 1999): topics centered on how each practitioner engages in their creative practice, how they use artifacts in their process, the tools and materials they use, and the techniques and strategies of their creative process. Participants were asked to walk us through concrete examples of their work-flows as a starting point for surfacing details about their personal working style. Using a recent project of the participant as a grounding example, each participant was asked questions such as *How do you make progress when you feel stuck? How do you explore alternatives? How do you assess your growth as an artist over time?* and *What tools do you use during different stages of your process?*

Our interviews are interactional events (Suchman and Jordan 1990), in which the questions evolve in response to participant background, shaped by earlier interviews. We examined the use and creation of artifacts – rather than their functional properties – embracing Suchman’s idea that a tool can only be understood in relation to its social environment and use (Suchman, Blomberg, et al. 1999; Inie and Dalsgaard 2020). Focusing on artifact use additionally allowed us to foreground custom-made tools, such as paper templates for weaving and violin making, or objects not typically understood as “creativity support tools,” such as a pile of handwritten notes, or an old project hung up on the wall. These artifacts could be understood as elements of an ‘Annotated Portfolio’ (B. Gaver et al. 2012; Bowers 2012), generated as part of a creative practitioner’s independent practice, helping to convey the decisions and the philosophy of each practitioner.

We followed a cognitive ethnography approach (James Hollan et al. 2000), focusing on how expert practitioners understand and reflect on their own practice. We are specifically interested in the reflective and meta-cognitive activities that creative individuals carry out, as well as their cognitive style (Gardner 1988). Reflective self-report allowed us to investigate the ways that people interpret and manage their own behaviors in their creative process, and what meaning they ascribe to their own actions (James Hollan et al. 2000; Kaufman et al. 2009). As Glăveanu and Beghetto put it, “processes cannot be easily inferred from

[1] In the case of five participants, video conferencing was used to remotely connect to the subjects at their workspaces due to travel limitations, one because of the COVID-19 pandemic. One participant travels frequently, renting workspaces in different cities, so agreed to meet in a public space and share pictures from her rehearsal spaces.

outcomes" (Glăveanu et al. 2021), so we asked practitioners to engage in reflection about their own techniques and strategies.

4.3.2 Practitioners

Our informants represent domains that require novelty and open-ended problem solving, where practitioners must use creativity skills in daily work (Kaufman et al. 2009). Many domains and practices are creative, even if they are not colloquially considered creative the way that art and performance are. We take a broad view of what domains are creative, as an area in which the practitioner utilizes creativity. For example, software development is creative, as it requires open-ended problem solving and the creation of contextually novel solutions (Mahoney 2017). Recruitment began by selecting sites and interviewees according to an *a priori* set of distinctions that seemed most likely to be relevant (e.g. collaborative vs independent work). We chose subsequent creative practices and experience levels to maximize the range and diversity of experiences as our understanding evolved, in concert with our research questions. Following Charmaz's Grounded Theory approach, we chose additional practices and experience levels within this frame that would support theory construction, rather than seeking a representative population across "all" creative practices (Charmaz and Belgrave 2007). Each expert participant self-identified as an expert in their field, with a mean of 21 years of experience (range 10-47 years; Table 4.2). The three early career participants had fewer than ten years of experience in their main domain (range 5-9 years). Participants were asked to walk through concrete examples of their workflows as a starting point for surfacing details about their personal working styles.

4.3.3 Analysis

Since the inception of Grounded Theory, it has split into three main branches: Strauss and Corbin; Glaser; and Charmaz (Sato 2019). We embrace Charmaz's constructionist research style that understands knowledge as co-constructed between interviewee and researcher (Charmaz and Belgrave 2007; Charmaz 2006). Our analysis is interpretivist, seeking to understand how our informants create meaning in their work (Gligor et al. 2016), and is rooted in the social construction of knowledge and polysemic understandings of truth (Kvale 1995).

Our goals are to "provide a rich, contextualized understanding of human experience through the intensive study of particular cases" (Polit et al. 2010), and to perform analysis that identifies the transferability of findings (Polit et al. 2010). We contrast quantitative understanding of generalizability, or statistical generalizability (generalizing from subjects drawn at random from a representative sample), with both analytical generalizability (generalizing to a construct or a theory), and transferability (a collaboration between readers and authors, where authors provide rich, thick description and readers do work to apply the findings to other fields) (Polit et al. 2010; Carminati 2018; Kvale 1995).

Interview Participant (Main Creative Domain)	**Years of Experience**
Animal Behaviour Researcher	11
AR/VR Artist	19
Ceramicist	21
Director	47
Industrial Designer	23
Museum Curator	19
Physical Performer	22
Software Engineer 1	10
Software Engineer 2	12
Stylist	25
Tapestry Weaver	43
Violin Maker	18
Academic	9
Design Lead	6
Software Engineer 3	5

Table 4.2: Participants. We interviewed 12 expert creative practitioners and 3 early career practitioners across diverse creative domains.

Following best practices for Charmaz's branch of Grounded Theory, we simultaneously engaged in analysis and data collection, iteratively constructing our analytic frame and updating our question prompts for future interviews as we identified and synthesized emerging themes (Charmaz 2006). For thematic analysis, we first transcribed each semi-structured interview, then performed open-coding (Strauss et al. 1990) on the transcripts. We iteratively reviewed and analyzed all interview data and discussed all emerging themes (McDonald et al. 2019).

The themes clustered into two high-level groups. First, we identified a set of process strategies that participants used to structure ideation, motivation, and mindset. While the interviews were structured around a general theme of documentation tools, several of these strategies arose as more general techniques, related to but not constrained to the concept of documentation. Second, we identified themes directly related to version control tools and how practitioners use version history as an active material in their creative processes. In this chapter, we will address the first set of themes. The second set of themes will be explored in Chapter 5.

Figure 4.2: Performance Director. The Performance Director keeps and displays many artifacts from his career, including notebooks with extensive rehearsal content. He is dedicated to building a collection of artifacts to track and manage his creative process. Despite his dedication to capturing, his creative practice also involves Strategic Forgetting (described in Section 4.4.1). These images represent selected artifacts from his creative space, the tangible history of what has not been "strategically forgotten". From left to right: 1. and 2. The Performance Director's working space, filled with props, costumes, set pieces, and memorabilia from his long career as a working artist. 3. A notebook containing notes on acrobatic tricks. 4. Hand-drawn stick figures showing acrobatic tricks, from the notebook. 5. A cut-out from a magazine, used to recall technique.

4.4 Findings

Throughout the interviews, we identified themes relating to creative process, creative cognition, motivation, and emotional affect (discussed below). We additionally uncovered tensions around version control systems, and identified values embedded in CSTs which are at odds with some aspects of creative process. For a full discussion centering these additional topics, please see Chapter 5. Because each interview evolved organically, following discussion topics relevant to the creator at hand and our evolving analytic frame, we did not address each topic with each practitioner in depth. As such, we focus the below discussion on the creative and motivational techniques emphasized by eight of our informants. We identified four themes across our interviews as dominant strategies used by creative practitioners: Strategic Forgetting, Mode Switching, Embodying Process, and Aestheticizing. We highlight each with a description and grounded observations.

4.4.1 Strategic Forgetting

Inverting the common practice of capturing ideas at the moment of creation, we observed several practitioners purposefully leverage the natural forgetfulness of their mind as part of their creative process. We observed this technique of *Strategic Forgetting* in the Performance Director and Physical Performer. The Performance Director has been performing professionally for 47 years, and teaching performance for 30 (Table 4.2). He has performed as an acrobat, juggler, and clown, and worked as a teaching artist, producer, director, and playwright for both theatre and circus shows. His primary domain is physical performance; recently he has expanded into writing and consulting. As a playwright, his process draws from his background as a performer, acting out scenes as he writes them.

When developing material for a show, the Performance Director relies on his imperfect human memory as a filtering mechanism that results in only "memorable" work getting saved. Even while engaged in a writing process, the Performance Director first generates many ideas through physical improvisation – a familiar and comfortable practice for him. The nature of these improvisational sessions is fleeting; yet rather than taking notes or recording the sessions, he purposefully prevents himself from capturing them:

Performance Director [My mentor] would say "Here's the scene, try it," and then I would do it... he would not let me write it down in rehearsal. [He would] say "write the scene up tonight," on the theory that whatever I remembered was worth keeping from the scene. Which I found incredibly frustrating. But it works!

In other words, the Performance Director relies on the inherently ephemeral nature of his craft to allow himself to forget ideas. After some time has passed, he will finally write down notes on the rehearsal from earlier, capturing the ideas "worth" remembering.

The Physical Performer engages in a similar process. The Physical Performer has been working in performance for 22 years. She designs, directs, and performs one-woman physical comedy shows, drawing on her years of training in mime, acrobatics, and physical comedy. Her primary creative domain is physical performance; recently she has expanded into music and spoken comedy. Her creative process involves improvisation, or "playing": trying out new ideas and cycling back to old ideas. This improvisation is inherently physical, acting out the details of a scene to feel it in her body. She often deliberately avoids referencing her notes while improvising, and does not write a script:

Physical Performer I'd spend the week journaling, [then] I would flip through whatever I had written that week... And then I'd get on stage, put the notebook down, and I would just improvise for 10-15 minutes... Things that were not important didn't get put in and things that were important got said.

Like the Director, the Physical Performer found this to be a very successful method. She trusts her subconscious processing to foreground the parts of the story that were important to tell. She specifically structures her working style to enable her subconscious mind to play an active role in the creative process.

Through this process, the Physical Performer maintains freedom, flexibility, and liveness in her individual process and her collaborations by deliberately omitting certain information. For example, the Physical Performer would audio record instead of video record her performances, because she didn't want to constrain herself by repeating the gestures she had done in that earlier performance. This practice supports her own expectations and values of what a performance should be, and how it should feel from her perspective:

Physical Performer I need to keep something unscripted, otherwise I feel like it dies.

The two performers found value in purposefully embracing the ephemerality of their medium in the generative phases of their work. Strategic Forgetting supports liveness and curation of ideas.

4.4.2 Mode Switching

In Actor-Network Theory, Latour articulates what happens when a person (actor) works with a tool: a new actor entity comes into existence that represents the unique combination of them both (Latour 1994; Latour 1996). Creative practitioners similarly change which tool is in use in a conscious effort to bring a new, combined, person-tool entity into existence. We see Software Engineer 3 and the Physical Performer both leveraging this relationship with tools to enter and support particular *modes* of creative behavior by deliberately changing *tools*.

Software Engineer 3 has been working professionally as an engineer for 5 years. He works in the Research and Development arm of a wireless technology company. He has a habit of printing out new code he's learning, taping the pages together, and adding hand-written annotations to track his thinking. He keeps three different whiteboards in his office, one on his desk for quick notes, one on his wall for brainstorming, and one behind his computer for longer-term reference. The affordances of the different whiteboards initiate certain creative modes:

> **Software Engineer 3** I like the size of [the wall whiteboard]: it's a nice big whiteboard, you can draw big things. It's also easier to reference – to look at [up on the wall]. Because sometimes I'll sit here, [puts legs up on desk], and I'm just staring at my whiteboard, like "what am I going to do with this..." It's harder to do that with a small, 8x11 piece of paper.

The large whiteboard prompted a creative *mode* that supported engagement with "big ideas". Participants such as Software Engineer 3 are attuned to the ways in which different tools shape and define their creative process, and they consciously select a tool to shift into a particular creative mode. This behavior is distinct from choosing a tool in order to generate a specific output; instead, the tool is chosen to shape the practitioner's behavior or mindset, driven by changing creative, cognitive, and emotional needs.

The Performer also described consciously leveraging different tools to generate a particular mode of engagement with her work. For example, when she creates a new show, she sometimes improvises in front of a video-camera. The video-camera acts as a pseudo-audience, allowing her to access her performing mindset "without a lot of pressure, and with a lot of freedom and a lot of joy." Next, she re-watches these recordings, and writes down her favorite parts. Switching to writing is a deliberate choice; writing is a more difficult medium for her than improvising, and has "different vibes" from videotaping. Switching mediums allows her to switch mindsets, from "the improv, physical, playful channel" to the "gleaner of info channel" within the more difficult medium. While improvising is an easy medium, the friction in writing helps change how she approaches the task. Her choice to switch between

Figure 4.3: Physical Performer. The Physical Performer finds benefits in consciously leveraging different capabilities of tools in her practice to manage and respond to her evolving creative needs (*Mode Switching,* described in Section 4.4.2). Left: A rehearsal room the Performer used while on tour. The Performer improvises when designing shows, using a video camera to help her access the "freedom and joy" of her performance mindset. Right: The Performer uses rearrangeable notecards to explore possible components of a show in a "distilling" stage of show design.

mediums is driven by her physical and emotional needs, rather than a need for a particular type of recording:

> **Physical Performer** There's a time when it's right for me to get up and move and then there's a time when that window closes and it's a time to reflect and it doesn't feel right to get up and move – it would be forceful to do that. It's almost like a switch: different channels are open. There's a point where it's "off". The door on that [mode] is closed.

Writing in a journal was a relatively new introduction to the Physical Performer's creative process. Her previous techniques involved meditating on mental images, and sketching high-level 'texture maps' of her shows. She discovered journal writing in a class designed to help performers create a new show. The instructions from the course involved writing a script that would later be performed, but instead she found it more beneficial to integrate this new journaling technique with her "home domain" of improvisation, and uses each medium at different parts of the process.

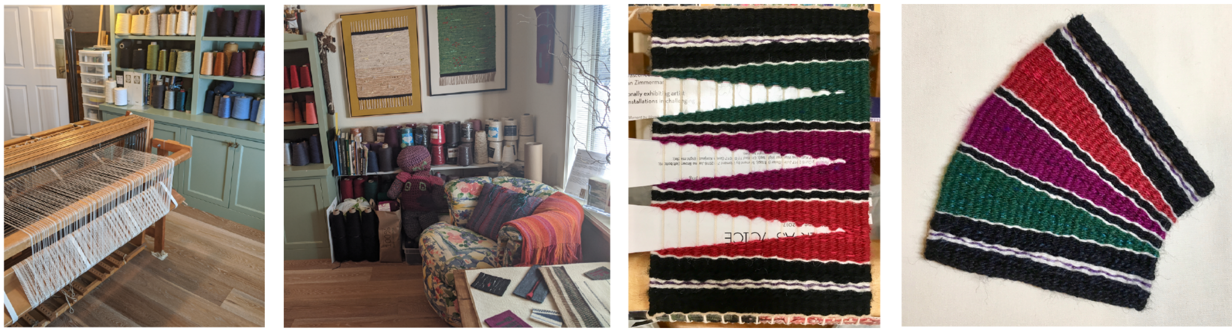

Figure 4.4: Tapestry Weaver. The Tapestry Weaver saves and displays 'unsuccessful' projects on her wall (second image) to reframe them as part of her process (*Embodying Process,* Section 4.4.3). Here we share additional images from the Weaver's practice. From left to right: 1. The weaver's in-home weaving studio, featuring a large loom, and materials in open cabinets. 2. Framed tapestries - her own work. More shelves and raw weaving materials. In the foreground, the table on the right displays woven studies of new techniques, laid out to encourage tactile exploration. 3. Tagboard holding space in a weaving to create a curved shape. 4. The completed weaving with the warp pulled taut after removing the tagboard.

> **Physical Performer** Many times I've videotaped 15-25 minutes [of improv] and that's like 3 minutes of something I like. So the writing would be grabbing the 3 minutes. And then the next video I would look at [the writing] and start with that, or I'd just put that to the side and [see] what wants to come through today. And then take the 2 minutes from that one, and then put the 2 minutes and 3 minutes together. And then do another video session that's 1 minute. ...It feels like a distilling process. One modality to the other modality would distill it.

Here, the Physical Performer is deliberately leveraging different forms of reflective conversations by using different tools and mediums through the strategy of mode switching.

4.4.3 Embodying Process

Completing a task and feeling that you've completed a task are sometimes two separate experiences. Especially for knowledge workers, whose output can seem ephemeral, having tangible, physical, visible, embodied proof of intermediate effort provides motivational benefits, both as concrete reminders of progress and completed work, and as tools to understand and reflect on personal process.

For example, the Animal Behavior Researcher takes care to design her tools around visible access to progress. The Animal Behavior Researcher has been working in the field of animal behavior for 11 years. She is as a post-doctoral researcher at a university in the United States and runs her own business helping clients with cat behavioral issues. As a scientist, she collects and generates many different forms of data, nearly all of which she has saved for the past several years, despite having no pragmatic need for the raw data. Instead, these notebooks, datasheets, annotated images, and other forms of information about her work support her emotional well-being: for example, the Animal Behavior Researcher has saved a notebook full of technical details from a complicated process she never plans to repeat. The process itself represents a particular scientific method that she associates with "real science", so the notebook acts as a physical reminder of that experience and validation of her own competence:

Animal Behavior Researcher: [It is] proof that I actually did it.

She also keeps copies of datasheets, maps, and notes from a complicated and time-consuming research project as large stacks of paper in a cabinet in her house. Even though all the research with that data was already published, and there is no practical reason to keep physical records, the primary benefit for her is emotional: she finds emotional value in keeping the original physical pages as a reminder of her achievements.

The Animal Behavior Researcher also maintains a notebook for tracking various todo lists, meeting notes, and ideas. While pragmatically useful as a way to track her work, the act of writing down tasks prompts reflection, and provides her with useful visibility into her process:

Animal Behavior Researcher When I find myself writing the same task over and over it usually represents some kind of internal struggle.

The Animal Behavior Researcher deliberately constructs an environment that supports personal feelings of success, and provides visibility into her own process by capturing both process and progress in a physical lab notebook.

Foregrounding and physicalizing artifacts can also reframe failures and mistakes as essential stages of the creative process, which supports continued engagement with challenging tasks and a productive learning mindset. Keeping even unsuccessful artifacts available and visible can provide concrete benefit to future projects, and buffer against negative feelings of waste or lack of progress.

The Tapestry Weaver has been working on her craft for 43 years. Over her career as a weaver she has created everything from yardage for clothing to artistic pieces meant for display in exhibits. Her workspace (Figure 4.4) has boxes of old weavings, raw materials, notebooks, and works-in-progress tucked under every table and filling multiple bookshelves, and old artworks on the walls. The artworks she chooses to display are often ones she considers "incomplete", or "unsuccessful". Instead of discarding or hiding a failure, she hangs it up so that she can continue thinking about how to re-appropriate or improve it. The purpose of a tapestry does not end when it is completed, but rather feeds back into the creative process:

Weaver And so I keep on thinking, well, this one wasn't so successful but I can play with it. And start reworking it.

The Weaver conceptualized even completed artwork as potential "grist" for her creative mill, especially if she was dissatisfied with the final output.

Compare the Animal Behavior Researcher's sense of accomplishment triggered by her old notebook, or feelings of potential created by the visibility of the Weaver's unsuccessful work, with Software Engineer 3's feelings of despair when his process of brainstorming on a whiteboard generates no artifacts:

Software Engineer 3 What doesn't feel productive is indecision. Sometimes I'll spend the day like "should I make this design decision or should I make that design decision, I don't like this," and I always feel like I'm just going back and forth and not really making much progress. Just sitting there staring at my whiteboard like "should I do it this way or should I do it that way." I feel like I can waste a lot of time without any decision.

The whiteboard used by Software Engineer 3 – easily erased, leaving no 'artifacts' of a brainstorming session whether successful or not – does not provide the benefit of embodied progress.

4.4.4 Aestheticizing

Brainstorming literature shows that encouraging quantity (over quality) produce both higher quantity *and* higher quality ideas in the end (Paulus et al. 2011; Diehl et al. 1987; Reinig et al. 2008; Osborn 1953). In the context of brainstorming there is no trade-off between quality and quantity: by focusing on quantity, you get quality too. But for prototypes, which involve more time and effort to construct, this trade-off is an important concern. Design practitioners often sacrifice aesthetic refinement in favor of quickly generating many low-fidelity prototypes, which while individually less accurate or refined, lead to better end results (Dow et al. 2010; Wulff et al. 1990; Muller 1991). However the aesthetics of an artifact do not only affect the output: deliberate choices around aesthetics are key factors in intrinsic motivation and overall creative experience. Motivation is an essential component of the process of creative work, with intrinsic motivation supporting creativity, and extrinsic motivation often suppressing it (Amabile 2018). Among some of our participants, aesthetic refinement in their work was a source of intrinsic motivation.

Attention to beauty suffused all aspects of the AR/VR Artist's workflow, not just in his artistic outputs but also in even basic documentation. The AR/VR Artist is an expert in creating digital art in augmented and virtual reality. His creative process involves building reusable digital assets and creating documentation that he or others can use in the future to learn skills and process. The AR/VR Artist invests considerable time and effort into saving information, resources, and research if he feels that they might be useful for himself or others later. Yet even if a document will never be shared publicly, he takes time to make the visuals feel "finished". For example, as he collected examples for how to write campaign emails, he structured them into a beautiful slide deck because it satisfied his own sense of progress:

AR/VR Artist I like to at some point take my ideas from a notepad document to...something that is a little bit more nice to look at. ...It helps me visualize it as being more done, or presentable.

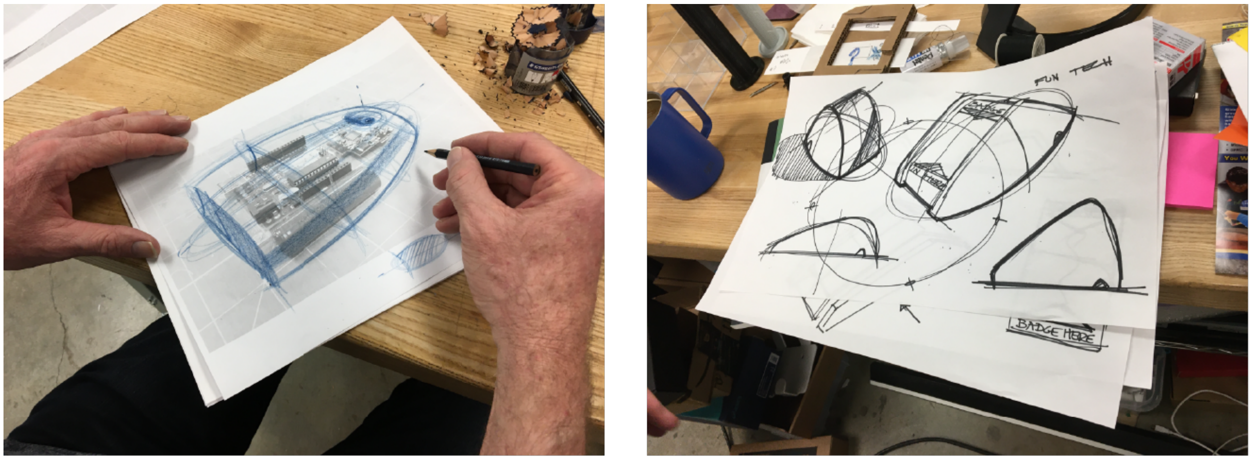

Figure 4.5: Industrial Designer. 'Happy sketches' created by the Industrial Designer. Sketches with a polished aesthetic improve his ability to communicate ideas with others and give him personal satisfaction in his work (*Aestheticizing,* Section 4.4.4).

While he begins with less aesthetically refined collections of screenshots and notes, the act of creating a beautiful presentation helps him distill his thoughts. After creation, the aesthetic artifact is one he desires to return to and continue working with, which keeps his task motivation high. He emphasized how much this process benefited not only others, but upheld his own satisfaction with his work:

AR/VR Artist It helps me feel like it's officially out there... it motivates me, more, than – if it were just in a notebook, I might feel like I were just scrawling out ideas.

The AR/VR Artist is highly intrinsically motivated by creating visually appealing content, and by designing for an audience, whether that audience is real or imagined (he described creating a 60-page document in InDesign that "no one asked for"). He finds the additional aesthetic labor involved is worth the benefit to his motivation and satisfaction.

The Industrial Designer similarly described being motivated to make even quick sketching appealing to the eye. The Industrial Designer has been working in design for 23 years, on a wide variety of products, including toys, cars, medical devices and hand-held electronics, as well as experiences such as museums and restaurants. His process is highly physical and visual; a notebook or a piece of cardboard is always at hand, ready to be drawn on or reshaped. The impulse to externalize is almost reflexive at this point in his career; a conversation about ideas inevitably will become a sketching session, or example materials will come out to be handled, considered, and recombined. For him, the main purpose of sketching is to "inspire thinking", sketching itself is "exploration on the page". Yet he values making beautiful sketches, regardless of whether they are to be kept long term or used only briefly, shown to others or only himself. Creating sketches with a polished aesthetic both improves his ability to communicate ideas and gives him personal satisfaction in his work. He described wanting his drawings to be "happy to look at", and takes pains to ensure that even the quickest of sketches have this quality (see Figure 4.5 for examples of 'happy sketches').

While the AR/VR Artist and the Industrial Designer both increase intrinsic motivation through highly aesthetic artifacts, some participants felt an opposite effect. The Academic, early in his career, found freedom and motivation in "lowering the bar" of quality, both for aesthetics and content. The Academic is an advanced graduate student at a university in the United States. He specializes in studying how humans understand systems from an interdisciplinary lens and cares deeply about the craft of research. The Academic specifically described being "scared" by his "proper art notebook":

> **Academic** Because I want every piece of art that goes in there to be beautiful ...so whenever I go to draw in it, I'm like: "Once I draw in here, that page is in here forever, I can't remove it."

For him, the permanence and high quality of the art notebook was intimidating, stymieing creation. In this case, the art notebook placed external expectations of aesthetic refinement on his work, decreasing motivation. Instead, he prefers to hand-bind his own notebooks, using the cheapest possible printer paper.

> **Academic** If I put a real clunker of a poem in [the handbound notebook], it's like, eh, who cares, I'm probably not even going to come back and read these, no one is going to read them, it's ok. It gives me more latitude to just try something.

By deliberately de-emphasizing aesthetics, the Academic increases his motivation. While their approaches to aesthetics differed, the AR/VR Artist, Industrial Designer, and Academic all found deliberate choices around aesthetics to be key factors in intrinsic motivation and overall creative process.

4.5 Discussion

Here we situate our findings in current creativity support research, and identify future directions. While our findings primarily represent strategies used by expert creative practitioners, we speculate on ways in which these techniques may apply across domains, or be used to scaffold newcomers into sustainable creative practice.

4.5.1 The value of forgetting

Recent thinking in psychology has resulted in a major reframing of memory "failures", uncovering the ways in which errors can be beneficial to mental processes, including evidence that memory failures can facilitate novel thinking (Ditta et al. 2018). These recent findings have not yet been incorporated into the design of creativity support tools, but offer a structured way to consider how tools might leverage creative strategies like *Strategic Forgetting*. For

Theme	**Recommendations**
Strategic Forgetting	Design tools to flexibly support capture and omission, including no capture at all. A system that captures early brainstorming could also explicitly allow 'hiding' of early iterations to let the creative mind process.
Mode Switching	Support different creative modes through distinctive interfaces that take advantage of different mediums and modalities. Simplify transitions in and out of an application to help creators make a personalized 'pipeline' that works for their own process.
Embodying Process	Design progress-tracking systems to account for both practical and motivational needs. Provide visibility into process for personal reflection.
Aestheticizing	Provide tools that help creators become aware of and focus on the aesthetics of their creations. Highlight synergistic extrinsic and intrinsic motivations.

Table 4.3: Summary of study findings and design recommendations for process-focused creativity support tools.

example, memory errors that involve incomplete encoding, which the Director and Performer embrace, can be categorized as one of three types of 'omission' error (Ditta et al. 2018), two of which are relevant here: *transience* and *absentmindedness*. Transient memories, or those that gradually fade over time, may help break creative "fixation" by letting irrelevant information fade, resulting in more focus on the problem at hand. Deliberately not capturing ideas may allow the subconscious mind to distill out the valuable content, only retaining the ideas that resonate. Absentmindedness describes the tendency of the mind to drift to new topics, which may result in creative combinations of seemingly unrelated information. Not writing down notes about an idea may increase the chances of encountering new ideas together with the topic at top of mind.

Because the mind automatically has a tendency to drift to new topics, Strategic Forgetting may increase opportunities for new and creative connections. This technique is related to, but distinct from, a well-known strategy of *incubation*, framed by early discussions of mathematical creativity: "incubation generally precedes illumination. In this period of incubation, no work of the mind is consciously perceived" (Hadamard 1945). Incubation continues to be important to conceptions of creativity; Shneiderman refers to those who embrace incubation and illumination as "Inspirationalists" (Shneiderman 2002; Shneiderman 2007). Strategic Forgetting is a more extreme strategy: rather than only taking time away from a project to allow the mind to incubate and free-associate, Strategic Forgetting prevents the capture of any information during the generative phase or prior to incubation. Identifying

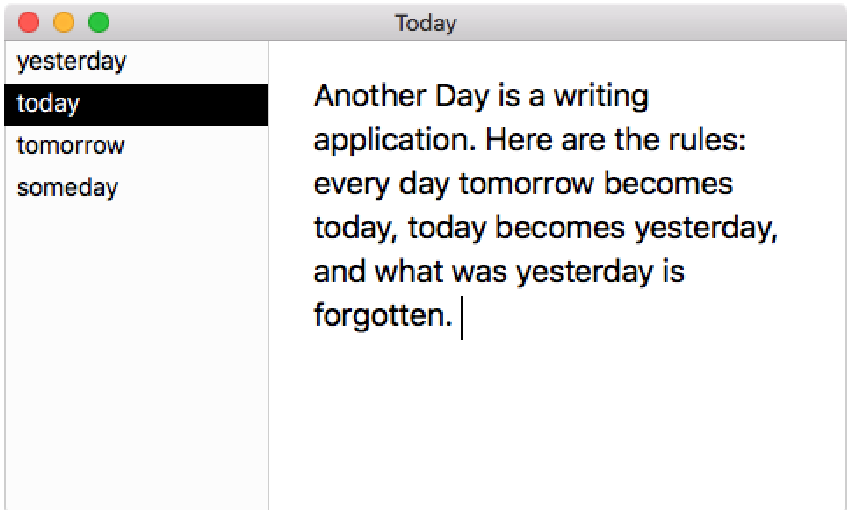

Figure 4.6: ***Another Day*** is a writing app, where there are only four pages, and the earliest page gets deleted each day (Buffet 2019). The interaction is described as: "every day tomorrow becomes today, today becomes yesterday, and what was yesterday is forgotten" (Buffet 2019). *Another Day* might be used to support a form of Strategic Forgetting for writing.

potential benefits of such a strategy is an area ripe for future exploration. CSTs could be designed to support hiding or obfuscation of data (e.g., by sub-sampling images, dithering, dropping frames, applying filters, etc).

While this strategy has recently begun to be explored within the field of creativity research, few designers[2] have attempted to incorporate this technique into a CST. Might a programmer think differently about the range of solution options if they prohibit themselves from writing down the details of an early solution draft? Would the architecture of an application simplify if an engineer had to remember it instead of writing it down? If we design digital tools that selectively blur notes and sketches to aid in "forgetting", should this forgetting be stochastic or predictable? Which details should be hidden, and when (if ever) should they reappear? At what point in a practitioner's development is it helpful to introduce these techniques - would a novice benefit from them as much as an established expert? Strategic forgetting may provide benefits through not creating artifacts at all. However, some practitioners must create artifacts in order to think-through-doing, such as a writer who develops their thoughts by drafting. To gain some of the benefits of strategic forgetting, a system could support the behavior of destroying that first draft. These represent themes that are currently underexplored in the world of software in particular, and creativity support tools in general.

[2]One example is "Another Day", a tool that allows the capture of only 4 days' worth of writing at a time (Figure 4.6)

4.5.2 Constructing creative modes via tool use

The Physical Performer's description of her relationship with her process, environment and tools closely parallels Dalsgaard's notion of *instruments of inquiry*, an understanding of the way the creative process "intertwines" and "co-evolves with" the environment and tools. This Deweyan pragmatist perspective, which underlies Dalsgaard's philosophy, elucidates the way the Performer leverages tools to augment her own cognition and creative process (Dalsgaard 2014).

For example, we can frame her use of Mode Switching as 'knowing-through-action': combining her expertise as a professional performer with the tools of video-recording and writing together produces output – in this case, a scene – that is meaningful and that moves her design process forward. This 'knowing-through-action' arises as she leverages different tools throughout her process. She explicitly describes the different 'modes of work' she taps into by using the video-camera, or the journal, and how these tools then shape the mindset she has and the way she interacts with her own output. Distributed cognition (James Hollan et al. 2000) presents a similar lens for understanding this concept, which also embraces the larger context of her working environment as part of her cognition. In other words, her creative process is an emergent property of the interaction between her own skills and the camera or the journal.

A similar method, reported by Frich et al, is the 'view-shift' strategy, described as: "deliberately shifting the perspective or view of the workspace in order to move between a view of the whole composition and a component that is part of it" (Frich, Biskjaer, MacDonald Vermeulen, et al. 2019). View-shifting is primarily about switching between two perspectives to gain additional perspective on a particular sub-part of a project. In contrast, Mode Switching is about deliberately using different tools to manage creative, cognitive, and emotional needs across a project's lifetime. However, both represent emergent properties of the interaction between the practitioner and their tools.

Seen through the lens of *instruments of inquiry* (Dalsgaard 2017) or distributed cognition (James Hollan et al. 2000), we can see the importance of understanding how closely enmeshed the creative behavior is with the tools at hand. In the example described above, switching modalities (from video-taping to writing) was nearly synonymous with switching creative modes (from generating to editing). It is difficult to separate the thinking and doing aspects of her working style, and difficult to separate the goal of the task from the tools used in that task. In what ways can tools support this process? Is the switch from paper-based to a video-based medium important? Our findings resonate with earlier work on tangible tools that tap into muscle memory and tacit, embodied forms of knowledge (Klemmer, Hartmann, et al. 2006). Finding ways to switch modes by switching tools can help practitioners transition across different stages of their creative process. Our work further motivates the design of tools that span modalities and mediums, or that have distinctive digital interfaces. More extreme switching of mediums may help more extreme switching of creative modes. Additionally, tools that make it easy to transition in and out of an application can help creators make a personalized 'pipeline' to support stages of a personal creative process.

4.5.3 Benefits of metacognitive awareness

To improve a process, it is important to first understand what the existing process is. Examining the steps involved in generating artifacts can bring awareness to the creative processes in place. Even during our interviews, our participants found that discussing, analyzing, and coming to a deeper understanding of their own processes was interesting, helpful, and at some points almost cathartic.

In addition to revealing process, artifacts can themselves provide metacognitive benefits. Some of our creative practitioners deliberately leveraged artifacts generated through their creative process as tangible reminders of a hard day's work. Supporting emotional well-being by embodying, foregrounding and visualizing progress is key to maintaining a long and sustainable creative practice. Hazzard et al. generated a 'taxonomy of failure' in the context of musical performance (Hazzard et al. 2019) highlighting another perspective on 'failure' in the context of artistic practice. Abtahi et al. recently explored ways in which people engage in manual self-tracking practices, finding similar benefits of creating personal, tangible traces (Abtahi et al. 2020). Would a software engineer feel more positively about the productivity of design sessions if that process generated a visible or tangible indication of activity? How can a system foreground these types of otherwise-ephemeral efforts in a way that supports creative work?

4.5.4 The role of aesthetics in task motivation

Some of our expert participants have found that embracing aesthetic refinement keeps them engaged in their creative practice. This engagement relates to the nature of motivation, intrinsic and extrinsic: the AR/VR Artist's and Industrial Designer's approaches are "synergistic extrinsic motivators", part of the task motivation component of Amabile's Componential Model of creativity (Amabile 2018). Synergistic extrinsic motivators both 1) support a "sense of competence" and 2) enable a deeper involvement with the task, without undermining their sense of self-determination (a known problem with extrinsic motivators such as gamification). For these creative practitioners, aesthetics is such a synergistic motivator. Aesthetic satisfaction also has echoes of the values of craftsmanship: "an enduring, basic human impulse, the desire to do a job well for its own sake" (Sennett 2008). Craftsmanship fosters a sense of pride and satisfaction in one's work, and ownership over process; for these creators, valuing aesthetics contributes to their sense of a job well done. Aesthetic enjoyment might also increase the length of time someone spends engaging with their creations, or make the creations themselves more memorable.

For some creators the pressure to create something beautiful can disrupt their creative process and cause writer's block. We note with interest that the early career Academic reported this, while the experts did not. For our expert informants, the joy they got from creating high quality artifacts kept them engaged in the process, and motivated them to continue creating. Our view is that nearly any behavior that keeps a creative practitioner joyfully engaged with their practice is valuable, as long as it does not become a fixation that prevents forward motion. Even if "best practices" recommend low fidelity creations, experts often find value in taking the time to enhance aesthetics when it works for them. Low-fidelity is often conflated with low-aesthetics, but even low-fi prototypes can maintain a level of craftsmanship and care. The Industrial Designer describes the extensive effort he put in to avoiding ragged edges when cutting foamcore, investing significant effort into creating clean cuts even during lo-fi prototyping. There is a certain level of craftsmanship that can be embraced even when other details are excluded. Because aesthetic taste is so personal, and tools cannot be designed to satisfy everyone, tools might instead help practitioners *identify* and *reflect on* their aesthetic preferences, and how these might be influencing their creative process.

4.6 Limitations and Future Work

In this study, we have engaged with a broad array of creative practices. We have identified tool- and domain-agnostic strategies that have great potential to provide insights that are relevant across domains, mediums, and approaches. Our primary interest is in what Kvale might describe as the "what could be" target of generalization (Kvale 1995); seeking insight from the true experiences of individuals. We have found that learning about others' successful creative strategies is often beneficial; though creative process is highly personal, heuristics and work styles can be learned, shared, and adapted between individuals (Amabile 2018). Indeed, people often informally share their creative strategies in online settings as part of their creative process.

Foregrounding creative strategies may help individual practitioners experiment with their own process by applying new heuristics. Designers of creativity support tools can engage with process-focused aspects of creativity, incorporating support for heuristics to assist users in developing satisfying, lifelong practice. In the future, we hope to present these strategies and techniques to practitioners across disciplines. For instance, what would the AR/VR Artist or the Weaver think about the concept of 'strategic forgetting'? How might the Animal Behavior Researcher incorporate 'Aestheticizing' into her process? In addition to expanding our understanding of these practices, this could help identify the extent to which such techniques are actually 'practice-agnostic'.

Our methodology engages primarily with techniques that a practitioner is consciously aware of and can actively reflect on. Complementary methodologies may surface techniques that practitioners are not aware of or are hesitant to share with an interviewer. In future work, observations and formal contextual inquiry, paired with further interviews and microgenetic techniques are a particularly promising area for generating deeper understanding of unconscious behaviors (Kaufman et al. 2009; Torres, Jörke, et al. 2019). We also note that the two practitioners who shared feelings of dissatisfaction with their process (the Academic and the Software Engineer 3) are both early career practitioners. Further work may explore how creative satisfaction evolves over time. An additional area of interest is how and when to scaffold newcomers into behaviours that experts identify as supporting successful, sustainable careers. The strategies reported here are a selection of examples; many more creativity heuristics exist, and could be identified and shared through further research with other practitioners and domains.

4.7 Conclusion

In this chapter, we have described strategies and techniques that diverse creative practitioners leverage throughout their practice to manage their cognitive state, working style, motivation, and creative output. We identified four strategies from semi-structured interviews: *Strategic Forgetting, Mode Switching, Embodying Process*, and *Aestheticizing*. We then connected these to existing creativity research literature, and synthesized our findings into recommendations that we hope will inform the future design of Creativity Support Tools that increase generation of creative work in a way that also enhances creativity itself.

In the next chapter, we return to these creative practitioners through the lens of version control tools, adding to our understanding of creative values and strategies in the pursuit of process-sensitive creativity support tools.

Chapter 5

Creative Version Control Systems

In Chapter 4, identifying process strategies across diverse domains informed the groundwork for understanding how computational systems might engage with creative workflows to support motivation, affect, and lifelong practice in many types of tasks or tools. In this chapter, we return to the cross-domains study described in Chapter 4, but focus on its implications for a particular type of computational tool: version control systems.

Version control systems are powerful tools for managing history information and shaping personal and collaborative processes. While many complex versioning tools exist for software engineering, and basic functionality for capturing versions is often found in collaborative applications such as text editors and design layout tools, these systems are not attuned to the needs and behaviors of creative practitioners within those domains, and fail to support creative practitioners in many other areas.

How might we better align version control tools with creative process? In this chapter, we return to the first two research questions of this dissertation:

> **R1:** What process values are present in existing creative practices?

We identify key values embedded in software version control, and the values apparent in how creative practitioners use version information in their process. A process-focused lens reveals some values shared between these contexts, as well as value inversions. By expanding our consideration of the role of history in creative process to the entire lifecycle of a creative practice, we reveal new potential for version control tools.

> **R2:** How do creative practitioners instantiate these values in specific strategies and behaviors? How do tools, computational and otherwise, support or inhibit these strategies?

In this chapter, we discuss how creative practitioners embrace, challenge, and complicate uses of version histories in four ways: using versions as a palette of materials, gaining

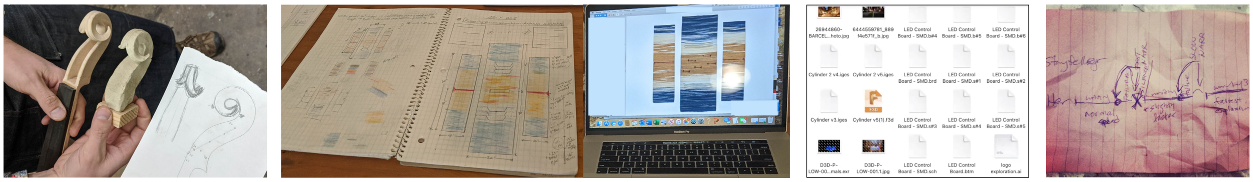

Figure 5.1: Creative practitioners capture and use version histories in their creative process. A selection of *version artifacts*, from left: a Violin Maker iterates a design for a custom scroll from sketch to clay model to final carving in wood. A Tapestry Weaver captures an idea in a notebook, then photographs the final tapestry. A New Media Artist saves multiple digital copies of circuit board designs and 3D models at different stages of the process. A Physical Performer captures the rhythm of a show in a quick sketch.

confidence and freedom to explore, leveraging low-fidelity version capture, and reflecting on and reusing versions across long time scales. The themes present across this wide range of mediums and domains provide insight into future designs and uses of version control systems to support creative process.

5.1 Introduction

The need to manage prior versions of artifacts and ideas exists across many domains: Writers create multiple drafts; programmers track incremental changes in large projects as they add features and fix bugs; instrument makers evolve violin designs over time. In each of these contexts, practitioners use tools to assist in managing the history of a project.

While the need for history management is common to each of these examples, such domains vary widely in other aspects – mediums, tools, outputs, traditions, and values. Yet despite these diverse needs, the structures of existing digital history management tools remain remarkably limited. Software development showcases the most widely adopted set of tools for history management in the form of version control systems (VCS). The core goals of VCS include supporting collaboration, recording changes, and reverting mistakes, in order to improve programmer effectiveness, efficiency, and collaboration (Koç et al. 2011; Zolkifli et al. 2018; Ruparelia 2010). These values recur within the design of creativity support tools more broadly: Shneiderman identifies “history-keeping” as a central design principle for creativity support tools and identifies its primary goals as recording and comparing alternatives, reverting to and modifying earlier alternatives, and communicating with colleagues (Shneiderman 2007). These goals closely parallel those of VCS. Digital history management interfaces embedded in consumer applications – such as the timestamped lists of revert-able versions that have become ubiquitous in collaborative online tools like text editors, spreadsheets, file sharing, and design tools – commonly support these goals as well, emphasizing collaboration, precise records, reversion, and efficiency (Figure 5.2). Such history management tools are used by a wide variety of people across many disciplines, including creative practitioners. Yet creative practices may also have different values from those embedded

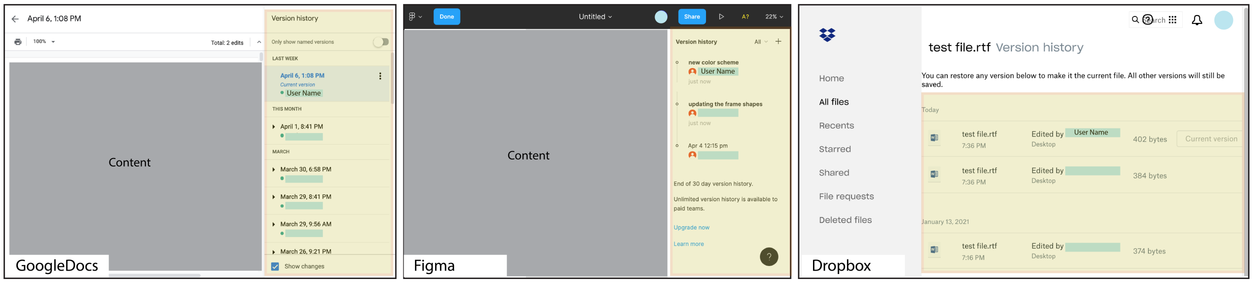

Figure 5.2: Interfaces for version histories. Many modern collaborative interfaces such as (from left) text editors (*Google Docs* 2022), design layout software (*Figma* 2022), and filesharing (*Dropbox* 2022) include version control interfaces as timestamped lists (highlighted in yellow), emphasizing precise records, reversion, efficiency, and collaboration.

in the design of software VCS. Might a visual artist prioritize a different set of values over efficiency, fidelity, or the ability to revert a 'mistake'?

Moreover, tools do not just support the goals of the users, they also shape goals and working styles (Dalsgaard 2017; Latour 1994). In software development, version control has become integral to the programming process, where capabilities like 'branching' and 'diffing' fundamentally shape how programmers structure collaboration and solve problems. As creative practitioners embrace digital history management methods, we must consider how to support history management not only as a stand-alone goal, but also as tool that shapes the creative process. Are existing capabilities of VCS equally well-matched to the working styles of practitioners in diverse domains? What are the values that best support creative practitioners, and might those considerations benefit programmers as well? Programming requires creative behaviors, especially in exploratory domains such as data science, machine learning, or creative coding, and these behaviors often do not mesh well with existing VCS (Kery et al. 2017).

While designers of software VCS have laid highly successful groundwork in history management, these tools have the potential to benefit many more users across diverse domains if they are designed with sensitivity to the needs of creative practice.

Through 18 semi-structured interviews with creative practitioners, this chapter explores how past versions of work are used as materials and as tools to support the creative process across a wide range of domains. By looking across widely varying domains and mediums, we can identify commonalities in how version information can support creative process, beyond the capabilities or constraints of particular tools. Interviews covered digital practices such as software engineering, creative coding, and academic writing; physical practices such as violin making, tapestry weaving, and industrial design; and experiential practices such as physical performance and museum installations. In each of these domains, practitioners use creative processes to complete their work. These processes rely on tools to record and manipulate versions, from software tools such as git and GitHub, to ubiquitous digital data formats such as photographs, to physical mediums like paper scripts, notebooks, or cardboard templates.

With the familiar paradigms and features of software version control as an organizing structure, we discuss how these creative practitioners embrace, challenge, and complicate uses of version histories in four ways:

- While versions can represent a progression of a project from start to finish, creative practitioners also use versions as a *palette* of materials.
- The capability to rapidly revert to an old state increases efficiency and protects against production failures. Yet saving versions also provides a sense of *confidence and freedom* that encourages risk-taking and exploration regardless of the amount of effort necessary to revert to an old state.
- High-fidelity capture saves all the details of a prior state, yet the deliberate choice to leave out information and capture only in *low-fidelity* creates space for productive variation, spontaneity, and adaptation.
- Considering captured versions *across project boundaries* and on *long timescales* allows practitioners to reflect on personal process and growth, and to return to and recombine old ideas.

The ways that these practitioners have adopted, appropriated, or rejected existing version control tools reveal opportunities for better supporting the paradigms of version use in creative practice. Tools that are sensitive to the process needs of creative practitioners may be considered *creative version control systems* (CVCS). Whether adapting popular version control systems to a creative workflow, or drawing on existing history behaviors to inform the designs of new tools for creative practice, understanding the techniques in use by expert creative practitioners is key to designing CVCS that support creative process across domains.

5.2 Related Work

5.2.1 History Management Tools

History management tools capture, organize, and support interaction with the information and artifacts that form a project history, such as documentation, commentary, specific artifacts, or versions of artifacts. Such a tool might focus on saving content, recording decisions and revisiting reasoning, or enabling group collaboration (Fuller et al. 1993), while also overlapping with other purposes: a design notebook supports active ideation; a website for documenting process shapes community norms (J. Kim, Agrawala, et al. 2017); a tool for visualizing version history enhances grading and instructor feedback (Yan et al. 2019). Digital history management tools include software version control systems such as *git*[1] or *Subversion*[2], as well as tools like file sharing platforms or email, which store the history of documents or conversations. Physical examples might include design notebooks, or a filing cabinet of old drafts.

[1]https://git-scm.com

[2]https://subversion.apache.org

Version control systems (VCS) are a specific subset of history management tools that organize iterative changes to specific digital artifacts (Chacon et al. 2014). While history management tools encompass information created after the fact to explain or contextualize an artifact, version control tools focus on the artifacts themselves, with metadata created at the same time as the artifact. While the most familiar artifact type is software source code, VCS have been created for and applied to digital artifacts beyond code, such as a custom tool for tangible information design (Klemmer, Thomsen, et al. 2002), or using GitHub to write books (Univalent Foundations Program 2013; Pe-Than et al. 2018). In this chapter, we focus primarily on history management behaviors through the lens of version control. Version control systems are particularly common and powerful tools, which are tightly bound to the creation of the artifacts themselves, and therefore integral to workflows and process. VCS are also key tools in software practices, providing a foundation to consider adaptations of existing tools to support creative process. In this chapter, we broaden the common conception of VCS as applying only to digital artifacts: certain physical artifacts or tools can be fruitfully considered as versions or version control systems.

It is useful to define three additional terms as they are used in this chapter:

Artifacts are physical or digital objects created by people. The final output of a creative process might be an artifact, such as a violin created by a luthier, or an ephemeral work, such as a performance. An ephemeral work might generate artifacts, such as an audio recording of a concert. Artifacts are also generated during the process, such as notes, tools, documentation, or drafts.

A *version* is an artifact captured at a particular point in time that is conceptually linked to prior or subsequent iterations. This is easy to imagine with digital artifacts, as they can be directly copied and modified. It also applies to physical artifacts: for example, we can understand two physical sketches as *versions* if one is an iterative change to the first. A paper sketch and a subsequent prototype might also be considered versions, despite the change in materials.

Documentation is an artifact or collection of artifacts specifically designed for communication about the project. This may be targeted at people other than the creators, or intended for the creators themselves in the future. Here, we focus on versions rather than documentation; while the two are often related, the ways they are created and used differ significantly.

5.2.2 Version Control Systems for Software

Version control systems for software development have transformed software development practices, providing essential infrastructure for collaboration on shared artifacts. Yet the conceptual models behind current software VCS have resulted in designs that do not always match the needs of practitioners. Version control, also referred to as revision control or source control, has been evolving for decades, tracing its roots back to the 1970s (Rochkind 1975). As version control systems grow increasingly more capable, the fundamental goals and concerns have remained relatively stable. In early systems, the focus was on identifying what changed and when, propagating fixes across versions, knowing what version a customer has, and reducing storage requirements (Rochkind 1975). More recent work identifies key goals as tracking reasons for changes, supporting collaboration, and allowing reversion (Koç et al. 2011), as well as coordination and organization (Zolkifli et al. 2018). These goals are supported by features such as merging, sandboxing, tracking history, reversion, and synchronization for collaboration (Ruparelia 2010). These features and goals are essential to modern software development practices, and have radically improved both individual and collaborative workflows since their adoption.

Yet software version control is not always successful even among people who write code. Kery et al. show how data scientists who work with code in an exploratory manner eschew version control systems for manual strategies, like copying snippets of code (Kery et al. 2017). These data scientists required speed, flexibility, and visibility of options for their exploratory processes, outweighing needs for collaboration features or reversion. Similar mismatches in the values of VCS and the processes of creative practitioners are present in our findings across creative domains, emphasizing the need for alternative paradigms for version control. *git*, created in 2005, is now one of the most common VCS tools, with GitHub, a graphical, collaborative tool for working with git, reporting over 73 million developers in 2021.[3] Yet Perez De Rosso et al. note that the difficulty of learning git turns away many new users (Perez De Rosso et al. 2013), and that its complex underlying conceptual model does not match how many people approach writing code. Aligning domain values with system capabilities is essential for a successful partnership between user and tool; in this work, we explore how versioning behaviors in a broad range of creative domains both share and challenge existing values in software VCS. By understanding the ways version history is used in creative domains, we can understand how the design principles of software VCS might be adopted and adapted to better serve the needs of creative practitioners, both when working with code and with other materials.

5.2.3 Version Control in Non-Software Domains

Code is not the only material for which version control tools have been developed. For example, version control tools are common for office software, CAD, and journal articles (Koç et al. 2011). When considering how to design VCS for CAD, Chou et al. note the importance of considering the uniqueness of the application domain, as different contexts require different capabilities (Chou et al. 1986). We align with this philosophy as we investigate creative processes to understand the capabilities and models of version control needed in creative domains.

Despite the variation across domains, existing VCS systems often share conceptual models and values with traditional software VCS. Khudyakov et al. identify increasing safety and stability, and reducing conflicts or usage of incorrect versions as specific goals for VCS for CAD (Khudyakov et al. 2018). In text editing and office documents, supporting collaboration

[3]https://github.com/about; retrieved Nov 1 2021

is again essential, with tracking history, merging, and diffing as key capabilities (Rönnau et al. 2005; Coakley et al. 2014; Filho et al. 2017). Version control is important to feedback and annotations in collaborative writing contexts, keeping comments in sync with content (Weng et al. 2004). Zünd et al. develop VCS for collaborative story authoring in various media, including images and video, again focusing on the collaboration benefits of features like merging changes from multiple authors (Zünd et al. 2017). Klemmer et al. develop a versioning system for early-stage information design, using digital media to capture the history of a tangible interface, focusing on the capabilities of reversion, collaboration, and reflection (Klemmer, Thomsen, et al. 2002). Such designs mirror the capabilities and goals of software version control. This similarity can be both a benefit and a drawback: leveraging existing capabilities makes VCS systems powerful, yet can constrain the role they play in the creative process. Of 4101 respondents to a 2020 survey about UX tools, 892 or 22% indicated that they were dissatisfied with their main version-tracking tool (Palmer et al. 2020). Shneiderman includes rich history-keeping as a key feature for creativity support tools (Shneiderman 2007), yet as we consider the role VCS plays in creative practices, we must go beyond existing models and values for VCS. To create or adapt VCS effectively for creative domains, we must understand how practitioners use version information to shape their own process, engaging how different materials and workflows affect history behaviors. In this chapter, we identify four themes that describe creative practitioners' uses of version histories, to broaden our understanding of how VCS can support creative domains.

5.2.4 Version Control and Creative Process

In this chapter, we are interested in understanding how tools for version control inform and support the creative process. Tools, including version control systems (Klemmer, Thomsen, et al. 2002), are not just things to be used, but influence the process and the user in return (Dalsgaard 2017; Latour 1994). To ground our approach to studying creativity, we draw on Amabile's Componential Model of creativity, in which there are three core aspects: domain-relevant skills, creativity-relevant processes, and task motivation (Amabile and Pillemer 2012). Here we focus on the second component, creativity-relevant processes (Amabile 2018). Kaufman and Beghetto identify particular levels of creative practice (Kaufman et al. 2009): our interviews focus on professionals, the "Pro-c" level, with significant experience and established success in their fields.

Many domains and practices are creative, even if they are not colloquially considered creative the way that art and performance are. We take a broad view of what domains are creative, as an area in which the practitioner utilizes creative process. For example, software development is creative, as it requires open-ended problem solving and the creation of contextually novel solutions (Mahoney 2017). There is no single "correct" process among programmers, and programming process has parallels in other creative disciplines (Turkle et al. 1992).

Frich et al. explore how creative practitioners use digital tools in their process across five domains of creative practice (Frich, Biskjaer, MacDonald Vermeulen, et al. 2019). We align with the value of exploring multiple, diverse domains to gain insight into commonalities of creative process for the benefit of digital tool design. Li et al. interview visual artists to understand how they use and create software tools in their artistic practice (Li et al. 2021). We use a similar method of in-depth interviews to understand creative practice, with a focus on versioning behaviors across domains. Li et al. discuss how mismatched values between the practices of visual artists and software developers reduce the adoption and usefulness of existing software tools to visual artists; similarly, we find that a mismatch in values between existing version control systems and versioning behaviors in creative process limit the adoption and usefulness of VCS for creative practitioners.

Large-scale VCSs are not the only way to think about process interactions with history data. "Undo," for example, is a ubiquitous feature in computational tools, allowing the reversion of mistakes on a small scale. The ability to undo is important to creative process to make temporally proximal changes, for example as explored in painting by Myers et al. (Myers, Lai, et al. 2015) and image manipulation by Terry et al. (Terry et al. 2002). Myers et al. additionally investigate how to support a "natural" approach to exploratory coding, integrating more complex backtracking in a code editor without requiring explicit version control (Myers, Oney, et al. 2013). Terry et al. discuss the importance of *variation* and *experimentation* to creative practitioners, exposing how creative practitioners appropriate the capabilities of existing software to store proximal history alternatives, such as using layers in photo editing software to store versions within a single file. They focus on near-term history behaviors to support reflection-in-action (Schön 1983). Jalal et al. explore the importance of version histories for choosing color palettes, and integrate versioning into color pickers, which are usually a component of a larger system (Jalal et al. 2015). In this chapter, we investigate the process-focused uses of history information to identify high-level themes that cross domain and tool boundaries. We discuss some similar values, such as the importance of alternatives and re-use of histories, expanding the context for these behaviors to a wider set of domains and longer time periods.

We present the idea of creative version control systems (CVCS): version control systems designed to support the process needs of creative practitioners. To motivate this approach, we use the lens of creative process to examine two existing CSTs that address version histories. First, Variolite is a versioning tool for "exploratory programmers" such as data scientists (Kery et al. 2017). Exploratory programming is a creative domain, requiring open-ended problem solving and creative exploration. Existing VCS do not support data scientists in their needs for fast interaction, quick comparisons of options, and versioning of small components; instead, data scientists used informal versioning practices such as copy-pasting from other files. Kery et al. identified the process needs of data scientists, and foregrounded those paradigms in the design of Variolite, while also providing the benefits of a formal versioning tool. By discussing a tool like Variolite through the frame of a CVCS, we gain a generalized way to address the importance understanding process and elevating the values of a creative practice in the design of version control tools. A second example, Knotation, is a documentation CST for choreographers that incorporates basic versioning (Ciolfi Felice et al. 2018). This tool draws from particular needs of choreographic practice in its design of information representation and exploratory features. Knotation supports version control for the ability to revert to previous states. A CVCS design lens might enrich the possibilities created by Knotation by considering other ways version histories might be valuable to choreographers' process: Might choreographers using a digital tool like Knotation benefit from a *palette* mindset? Would *low-fidelity* representations enhance the choreographers' reported desire for "informality" and "imprecision"?

5.3 Methods

In this chapter, we return to the interviews discussed in Chapter 4. In keeping with the iterative nature of Grounded Theory, we interviewed an additional three participants in the domains of creative coding (Figure 5.3) and new media art to follow up on questions that arose during analysis. While the analysis reported in Chapter 4 focused on cross-domain, tool-agnostic creative strategies, we discuss here themes around uses of version control tools.

5.3.1 Participants

To explore and understand creative process, we interviewed 18 expert creative practitioners across a wide variety of disciplines (Table 5.1). Participants were selected from domains that require novelty and open-ended problem solving, where practitioners must use creativity skills in daily work (Kaufman et al. 2009). We began by selecting sites and interviewees according to an *a priori* set of distinctions that seemed most likely to generate a broad range of behaviors: physical, digital, or ephemeral mediums; extent of collaboration; and use of computation in daily work. We chose subsequent creative practices to maximize the range and diversity of experiences as our understanding evolved, in concert with our research questions. Following Charmaz's Grounded Theory approach, we chose additional practices within this frame that would support theory construction, rather than seeking a representative population across"all" creative practices (Charmaz and Belgrave 2007).

Each participant is an expert in their field, with a mean of 18 years of experience (range 5 to 47 years). 14 practitioners have more than 10 years of experience; 4 are early-career practitioners with less than 10 years of experience. Among the 18 participants, there were 6 women and 12 men. Interviews took place either at the participants' primary workspaces (8 interviews), to enable better understanding of their tool use in context (Beyer et al. 1999; Suchman, Blomberg, et al. 1999), in a public location[4] (1 interview), or over video conferencing software (9 interviews). During the COVID-19 pandemic, all interviews were held remotely over video conferencing software for health and safety. During video interviews, participants used screensharing and their webcams to show their tools, workspaces, and creative outputs.

[4]The Physical Performer rents workspaces temporarily in various cities due to work travel. The interview was held in a public location; the participant showed pictures from prior rehearsal spaces and materials.

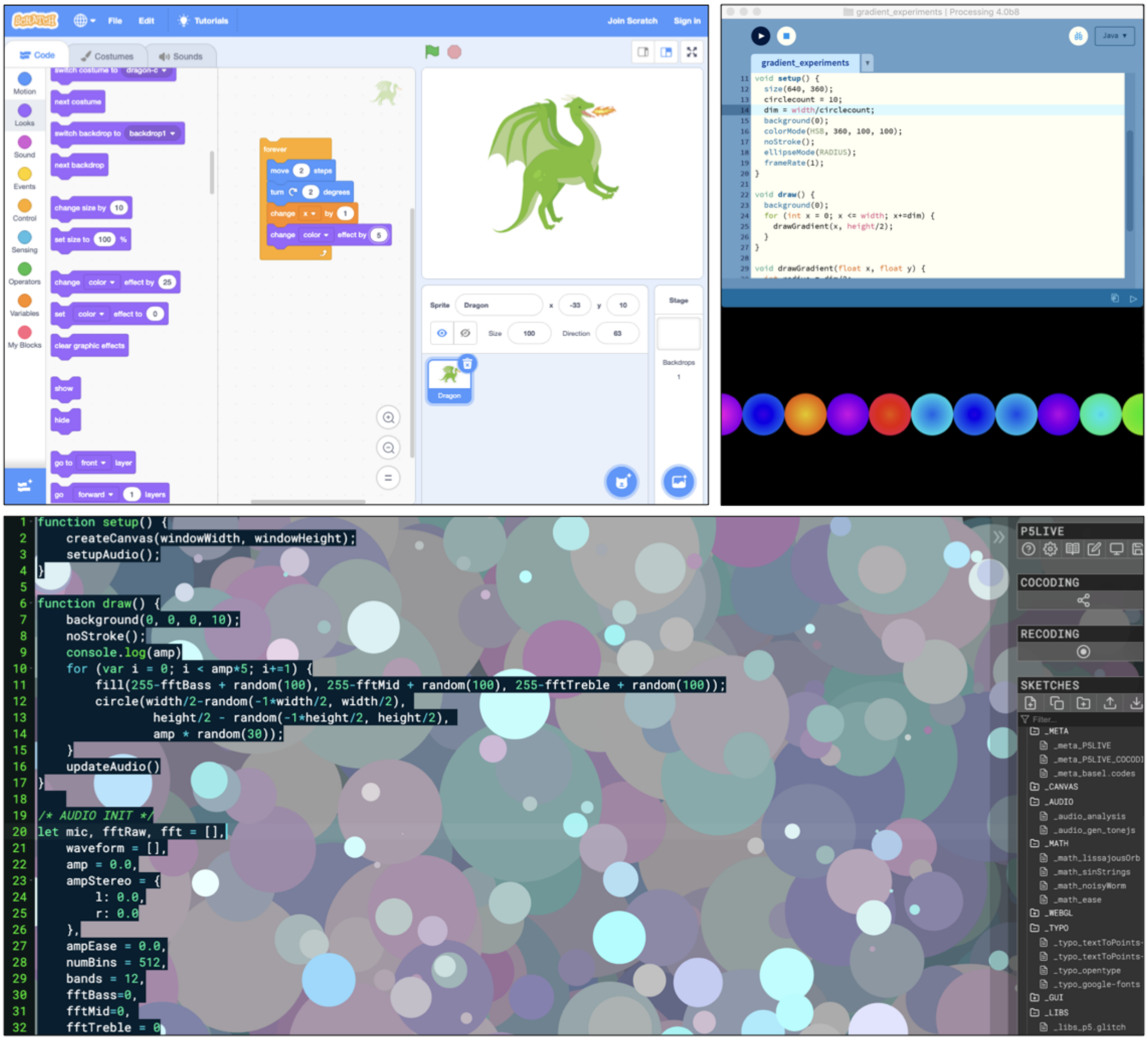

Figure 5.3: Creative coding interfaces. Creative coding involves using code to make expressive outputs. While many programmers use creative processes or make creative solutions to problems, "creative coding" as a term refers specifically to artistic practices. Creative coding can be done in any language or environment, however there are specific tools designed to support creative coding. For example, Scratch (top left) is a block-based coding language that foregrounds storytelling and art in its capabilities (Resnick et al. 2009). Processing (top right, v4.0b) is an open-source creative coding environment (Reas et al. 2007). P5Live (bottom) is an in-browser extension of Processing designed specifically for live coding, where the code is co-located with the output and changes to the code immediately alter the output (T. Davis 2022).

5.3.2 Interview Methods

Interviews were semi-structured, guided by grounding themes of artifact use and collection of information over time, and shaped by the individuals' practice and reflections. Each interview lasted between 1 and 2 hours, during which we asked a semi-structured set of interview questions, focusing on their personal creative practice and background. To ground our discussion in concrete examples of daily work (Beyer et al. 1999), the topics centered on how each practitioner creates artifacts and versions, how artifacts and versions are used in their process, the tools and materials they use, for how long artifacts and versions are kept and why, and the roles artifacts and versions play in the creative process. Following best practice for Grounded Theory (Charmaz 2006; Charmaz and Belgrave 2007), we evolved our research questions as we went, focusing more specifically on version control tools and frameworks in later interviews. Participants were asked to walk through concrete examples of their workflows, which served as a starting point for surfacing details about their personal working style.

Using a recent project of the participant as a grounding example, each participant was asked questions such as *How do you record versions of an ongoing project? What forms of documentation do you use in your creative process? How do you assess your growth as an artist over time? Do you revisit past artifacts/histories from old projects? How do you explore alternatives?* and *What tools do you use during different stages of your process?* Our interviews are interactional events (Suchman and Jordan 1990), in which the questions evolve in response to participant background, shaped by earlier interviews. Following best practices for Charmaz's grounded theory (Charmaz 2006), we simultaneously engaged in analysis and data collection, iteratively constructing our analytic frame and updating our question prompts for future interviews as we synthesized and identified emerging themes. We read and analyzed all interview data and discussed all emerging themes (McDonald et al. 2019), which are presented in Section 5.4: Findings.

5.3.3 Analysis

We analyzed the interview data using Grounded Theory. Grounded Theory has three main branches: Strauss and Corbin; Glaser; and Charmaz (Sato 2019). We embrace Charmaz's approach, a reflexive research style in which knowledge is co-constructed between interviewee and researcher (Charmaz and Belgrave 2007; Charmaz 2006). Our analysis is interpretivist, rooted in the social construction of knowledge and polysemic understandings of truth (Kvale 1995). To perform thematic analysis, we first transcribed each semi-structured interview, then performed open-coding (Strauss et al. 1990) on the transcripts. We iteratively reviewed and refined these into a closed set of codes, which we then re-applied to the transcripts as we performed additional interviews. We read and analyzed all interview data and discussed all emerging themes (McDonald et al. 2019), which are presented below.

Participant	**Primary Output Medium**	**Digital Versions**	**Physical Versions**
Academic	Digital	Text documents	Handwritten notes
Animal Behavior Researcher	Digital	Text documents, spreadsheets	Handwritten notes
AR/VR Artist	Digital	Text documents, screenshots, slideshows	-
Creative Coder	Digital	Code files, images, P5LIVE	-
Design Lead	Digital	Slideshows, photographs, wireframes	-
Generative Artist	Digital	git commits, images	-
New Media Artist	Digital	Code files, 3D models, P5LIVE, circuit schematics, Adobe Photoshop layers	Breadboard circuits, prototypes
Software Engineer 1	Digital	git commits	-
Software Engineer 2	Digital	git commits	-
Software Engineer 3	Digital	git commits	Printed out code, whiteboard notes
Museum Curator	Experience	Photographs	Handwritten notebook; binder with print-outs, hardcopies, and notes
Personal Stylist	Experience	Slideshows, photographs	Moodboards
Director	Performance	Video recordings, photographs	Photographs, handwritten notebook
Physical Performer	Performance	Audio recordings, photographs	Butcher paper
Ceramicist	Physical	Photographs	-
Industrial Designer	Physical	Photographs	Prototypes, sketches
Tapestry Weaver	Physical	Photographs	Sketches, handwritten notes, swatches, weavings
Violin Maker	Physical	-	Handwritten notes, paper templates, wooden molds, clay models

Table 5.1: Selection of mediums and tools used by participants to capture version histories in digital and physical forms. Many practitioners use both digital and physical versions.

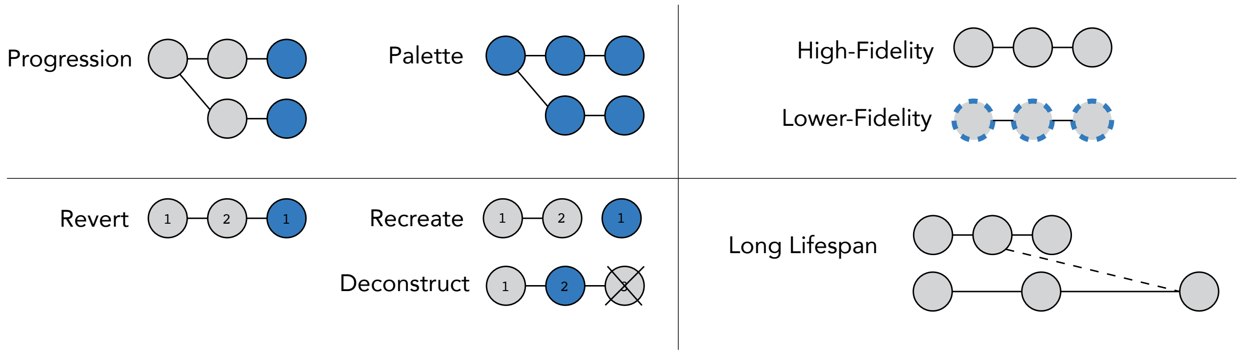

Figure 5.4: Creative version control themes. Four structural paradigms of standard version control are embraced, challenged, and complicated by creative practitioners: approaching versions as a *progression* towards a goal with only the most recent versions active (indicated by blue nodes), or as a *palette* of options, where all versions are concurrently active; gaining confidence and freedom through the ability go back to earlier states (indicated by blue nodes), whether through *reversion*, *deconstruction*, or *recreation*; choosing *high or low fidelity representations* of past versions to create space for variation in future iterations; and creating and revisiting version histories over *long time periods and across projects*.

5.4 Findings

In the analysis of the interview data, we identified four structural paradigms of standard version control that are embraced, challenged, and complicated by creative practitioners (Figure 5.4). In the following sections, we first introduce the range of mediums and tools practitioners used to capture and interact with version history, then present each paradigm through a selection of versioning behaviors participants used in the creative process to inspire, explore, create, and reflect.

5.4.1 Creating Version Histories with Diverse Materials and Tools

Version histories are created and captured with a wide variety of tools and mediums. By discussing and comparing different approaches, we can learn from a wide range of creative techniques and behaviors. Here, we introduce a few of the types of tools and mediums that arose in our interviews, to ground the following discussion of creative behaviors that rely on these versioning tools.

5.4.1.1 VCS for Software

Among creative practitioners working with code, some participants used established, commercial version control systems such as git or company-specific version control systems, and tools such as GitHub (Software Engineer 3, Software Engineer 1, Generative Artist). However we also saw some practitioners who have used these tools professionally nevertheless eschewing them in their creative work, either *manually* saving new copies of a file when making changes, or building personal, *custom* tools (New Media Artist, Creative Coder). For example, while the Generative Artist does use git in his creative process, he adapted the existing interaction paradigms of git to his personal creative workflow by building a custom toolchain.

5.4.1.2 Manual Versioning

Manual versioning, where the practitioner saves new copies of digital files to track version changes, was used by the New Media artist for code, as well as by the Animal Behavior Researcher for text documents and spreadsheets:

> **Animal Behavior Researcher** I am that person that has 8 million different versions of every Word document. It'll say like "use me" or "no, use me" or "final final final", or "final final final final version."

Both the Animal Behavior Researcher and the New Media Artist encountered challenges with the manual approach, where errors were more easily introduced into the workflow and key information was lost or forgotten through uncertainty about which files contained which changes, which version a collaborator was working with, or why certain copies had been made.

5.4.1.3 Digital Capture

Physical and ephemeral outputs were sometimes captured digitally. Digital mediums such as audio and video were used by performers to capture versions of ephemeral performances as they developed them during rehearsals (Physical Performer, Director). Photographs were essential for the Industrial Designer to capture intermediate states of physical prototypes.

5.4.1.4 Physical Capture

Paper was a common physical medium to capture versions in a physical format. The Performer used poster-sized scripts to share version state with a collaborator. Sketches and notebooks were common across a variety of physical practices (Tapestry Weaver, Industrial Designer, Violin Maker, New Media Artist) but not limited to physical practices, as practitioners who worked mostly in the digital world also used paper sketches, notebooks, and print-outs to capture early versions or create long-term archives of later versions (Animal Behavior Researcher, Academic, Software Engineer 3).

Version information was also captured in physical materials beyond paper. Physical prototypes encoded version information for the Industrial Designer. The Violin Maker retained version histories of his instrument designs in the templates and molds he used to carve and shape the wood; a new design requires an updated set of templates.

Whether the versions were captured digitally or physically, from originally digital, physical, or ephemeral works, the version data was essential to the creative process. In the next sections, we discuss four ways version histories support creative process.

5.4.2 Using Versions as a Palette of Materials

Version control systems often represent history as a sequence of serial versions. The most recent version represents the active, correct state, in a linear progression towards an improved outcome. While the concept of 'branching' allows exploration of alternative paths, there is commonly a single main branch that is considered the true current state of the project.

Software Engineer 1 is a software engineer at a large technology company, who has worked professionally with code for ten years. He describes how he uses version control within his company:

Software Engineer 1 We have the true copy of all the code, and then people can make deviations of that and then resubmit them back to the true copy.

This approach to development is a highly productive process technique when the creator or the team is pursuing a single, known goal. However, for many creative practitioners, the paradigm of a linear progression towards a single measurably better result is at odds with their process. Instead of considering version histories as a document of the past, they use versions as a palette of resources to enable a conversation with materials. All three practitioners who worked in creative code (New Media Artist, Generative Artist, and Creative Coder) use this approach, as well as the Tapestry Weaver and Animal Behavior Researcher.

The New Media Artist is a creative coder who has been working professionally on digital and hybrid artworks for twelve years, and teaching digital and electronic art for seven. The New Media Artist approaches code as a material, much in the same way a physical artist might work with paint or clay. In contrast to the "top-down" approach of working towards a goal, he calls this a "bottom-up" approach:

New Media Artist I don't have an end goal at first...it's more or less how artists usually start their practice, they play with sculpture, they play with clay, they mold it and then they look at it and along the way [they say] "Oh, this is the direction that I want"...so [when coding] I come up with "Oh, I want to create an easing function," or "I want to move one point to another point and leave a trace." And once I implement that...they become my modules – materials – to apply to different sketches.

In this approach, versions of the modules are not progressions towards a goal, but variations on a material, acting as a palette of paints or a selection of brushes. The New Media Artist saves all these versions as separate files, so that he can access them in parallel and quickly swap between alternatives.

Though the New Media Artist is experienced with version control, and has used such systems professionally as a developer, he does not use a version control system in his personal creative process. He shares his feeling that the mindset of progression is counterproductive to the artistic process:

> **New Media Artist** I think the mentality of *git* is: there's only one version that's keeping progress, but in art, progress doesn't really mean something. I want diversity, I want different versions, not one final best version.

Versions are essential to the New Media Artist's process, but his use of versions is at odds with the standard model of progression inherent to the design of tools like git.

The Generative Artist programmed professionally for seven years before discovering creative coding; he has been creating generative art with code for a year and a half. He is also an oil painter, working in traditional media for seven years. In his code-based creative work, his approach to version control is very different from his professional programming work: like the New Media Artist, past versions are a palette of options rather than a progression towards an end point.

Each time the Generative Artist modifies his code, he generates dozens of image outputs and saves each one (Figure 5.5). These outputs offer a set of options from which he can choose the most interesting or inspiring direction to continue pursuing. Often he cycles back to earlier versions to explore new directions or find new inspiration, regardless of how long ago they were created.

> **Generative Artist** I sometimes go back and look at my old art: maybe [I] can just do something with this, maybe mix it with different colors and see how things pop up.

We see this behavior of keeping past work accessible as a palette of options in a physical domain as well: the Tapestry Weaver deliberately sets up her studio to make past outputs accessible for inspiration or reworking. The Tapestry Weaver is a fiber artist, and has been weaving for 43 years. Her tapestries are handmade on looms in her home studio, each one an effort of weeks or months (Figure 5.8). She hangs many of her pieces on her walls, especially ones that were "unsuccessful." She keeps these pieces visible and available so that she can "rework" and "play with" them in the future. Sometimes this will be as inspiration to a new piece, or a direct modification to the old piece. She keeps notebooks and sketches of designs, along with photographs of the final outputs; sometimes she returns to an older design to weave it again with new colors or techniques. Like the creative coders, each version remains available as a palette of inspiration and a material to become a new design.

The Animal Behavior Researcher has been working in veterinary research for eleven years. Even in scientific domains, writing often has strong connections to creative process. She often has to write grant proposals, journal articles, and presentations, where she uses a hybrid approach to versions: while she keeps a single "current" copy of each document, she manually saves all past versions in an accessible folder. Like the New Media Artist, she values these easily accessible alternate versions, using them not as linear historical records, but as a selection of materials she can repurpose and recombine.

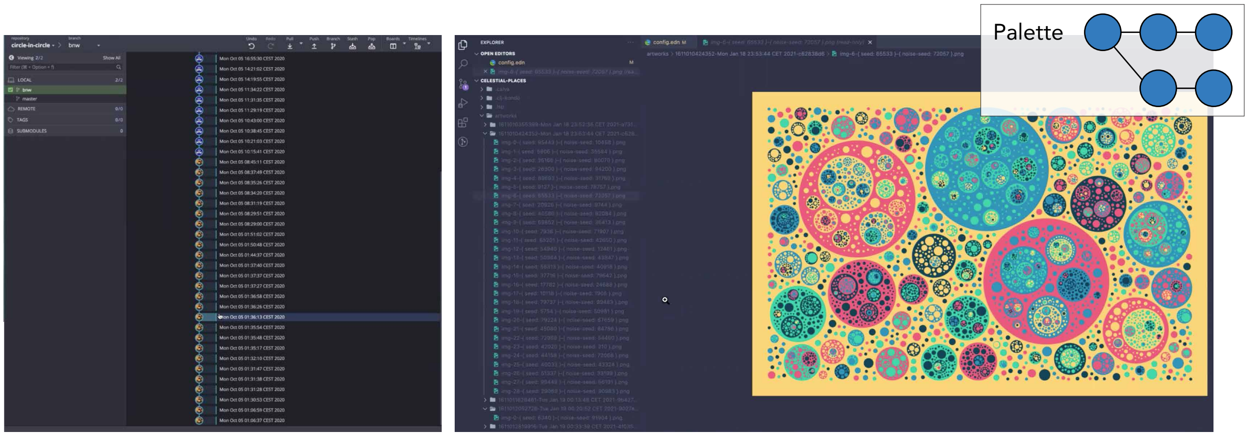

Figure 5.5: Palette interactions. The Generative Artist creates hundreds of commits that capture the complete state of each generated output (left). Though displayed as a chronological history, the Generative Artist uses these commits not as a linear history of improvement, but as a palette of options that he cycles back through to find new inspiration and pursue new directions. He navigates these commits by the associated images, saved in a separate folder (right).

> **Animal Behavior Researcher** "[For] a grant, I need this snippet here and that snippet there so there is a lot of...reusing or recycling or adjusting a lot of things you've written in the past.

A journal may want one version of a writeup, and a grant another. Neither is necessarily more correct or complete than the other; they exist in parallel as materials for reuse. For the Animal Behavior Researcher, she needs access to these versions "without necessarily rewind[ing] or undoing things."

While manual versioning does allow parallel interactions, it is also an error-prone method: it can be unclear which version contains which changes, which version a collaborator is working from, or even why a version was made. The New Media Artist and Animal Behavior Researcher both run into these problems. The Generative Artist, in contrast, has adapted git to serve his process as a palette, using custom scripts and additional software. Each time he generates an image, his custom scripts automatically save the image file and auto-commit the code. The image filename contains all the configuration variables as well as the commit hash, and the commit message contains the filename of the generated image (Figure 5.5). This allows him to match each output with the version of the code that created it, complete with the values of all random variables used in that iteration, and therefore allows him to recreate any image at any time in the future. Yet his interactions with the images are entirely separate from git, and rely on image curation tools. He can work around the standard chronological presentation of commits, but it provides no significant benefit to his workflow.

From creative coding to research to tapestry weaving, the framework of versions as a palette of materials supports bottom-up, material-centric approaches to the creative process,

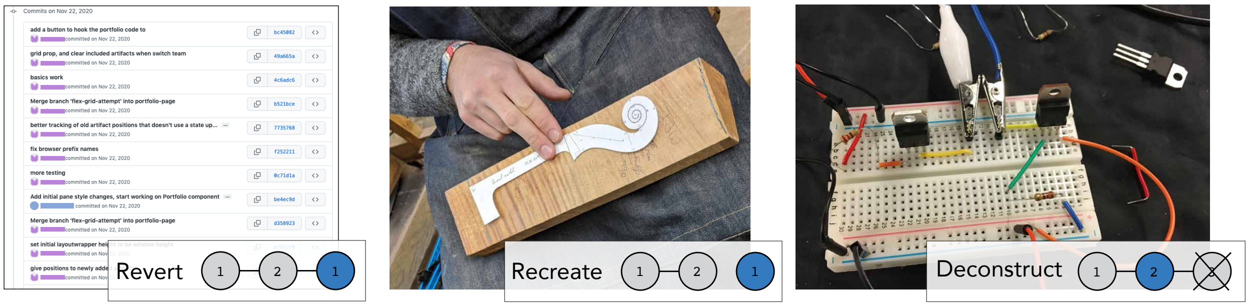

Figure 5.6: Reversion, recreation, deconstruction. Practitioners across domains store old versions to provide confidence to explore new alternatives. From left: a git history provides rapid, low-cost reversion to old states by reloading a prior commit. Physical objects require more labor: the Violin Maker must carve a violin neck from new material to return to an old state; breadboarded prototypes can be deconstructed to return to an old version captured by a photograph.

as well as enabling inspiration, re-use, and re-combination of past ideas. Yet standard VCS tools do not natively and effectively support this mindset.

5.4.3 Gaining Confidence and Freedom to Explore through Reversion, Deconstruction, or Recreation

Reversion, going back to an earlier state of the project and continuing forward from that point, is a highly valued capability of version control systems. Practically, it allows the easy undoing of mistakes, increasing programming efficiency and the uptime of production systems. For creative practitioners across a wide range of domains, the key benefit of reversion is psychological: a sense of confidence, safety, and comfort that enables radical exploration and risk-taking. For some practitioners, reversion need not even be easy; capturing version information is sufficient to gain the emotional benefits even if returning to the earlier state would require significant labor.

Software Engineer 3, who has been working as an engineer for 5 years in Research and Development for a wireless technology company, described the benefit of reversion to his process:

> **Software Engineer 3** [Committing] is kind of an insurance policy. Because a lot of times I'll make a change and I'll break something, and then I won't remember how I got there. So any time something kind of works, or I feel like I hit a milestone or a checkpoint, I'll make a commit so that I know I can at least get back to that point.

Because he can revert a commit to an earlier, working version, he feels free to make potentially breaking changes and explore solutions without fear. Similarly, the Generative Artist uses commits to allow him to return to any prior version, as his aesthetic intuition desires. Though he does not conceptualize alternatives as "correct" or "working" in the same way as Software Engineer 3, the feeling of support for exploration is the same.

> **Generative Artist** I wasn't exploring [in oil paints] and this medium [creative coding] allows me to explore, because now, I know I can just undo and get back to a state, so I do not have the fear of "Oh, I did something nice I don't want to lose it".

The New Media Artist also values the same feeling of safety, but does not use a formal version control system. Rather he saves duplicate copies of files before making a big change:

> **New Media Artist** Having a file saved in there before I made the change, made me feel I can always turn back. I just feel safe.

Using history as an insurance policy to enable experimentation also showed up in history management behaviors in domains that work in ephemeral performance and in physical materials. The Physical Performer sought such freedom to take chances when developing a physical comedy show. As the Physical Performer and her collaborator improvised together to design their show, they captured their evolving ideas in a scribbled "script" on butcher paper:

> **Performer** [On] a huge poster-size paper... we would write down "[A] grabs napkin, [B] double-takes, [A] this," every little minute movement.

Recording the "choreography" was essential to supporting free improvisation and exploration. Capturing even an extremely simplified form let them play, and freely negotiate about the show:

> **Performer** [The butcher paper] was the space where we agreed on what was going to happen, and so if we were ever playing and someone did something else, [and] then the other person was like "wait I don't know", we could refer back to [the poster] and be like "is this the best way, or should we do how we just improvised and change this thing". And then often times we *would* change it, but it helped us continue to anchor back to something.

The Physical Performer understood the butcher paper as an "anchor" to their initial creative idea. Capturing concepts allowed the collaborators to experiment freely without fear of losing access to their original creative intuition, or of forgetting something that had worked better. In this way, the butcher paper script is a tangible version history, providing the same feeling of safety while exploring that Software Engineer 3 gains from his version control software.

Exploration was also core to the Industrial Designer's process, and like Software Engineer 3 and Physical Performer, he gives himself freedom and confidence to explore by capturing version artifacts. However, the amount of labor required to return to a prior state complicates the idea of reversion for physical materials. The Industrial Designer has worked in many domains across his 23 year career, including automotive design, toys, medical devices, restaurant and museum experience design, and consumer electronics. He also teaches design, prototyping and sketching and runs a makerspace. Before he makes significant changes to a physical prototype, the Industrial Designer takes photographs of the current state:

> **Industrial Designer** I documented it so I'd have a recording of it, and if all else is ruined I still have the recording of it. I'm allowed to take chances.

However, the Industrial Designer must destructively undo changes to the physical prototype or rebuild a new one to return to the old state. One cannot automatically revert a physical prototype from a photograph. Despite the additional labor required by the medium, the photograph is still sufficient to provide the sense of safety that is necessary to support exploration.

In digital version control contexts, whether supported by a VCS or by manually copying files, the digital representation allows reversion with minimal labor from the user. A single command is typically enough to automatically recreate the state of the system at the previous point in time. In the cases of the Performer and the Industrial Designer, the version information is enough to recreate the former state, but requires labor by the user. The Industrial Designer must destructively undo changes to the physical prototype or build a new one to return to the old state, either *deconstructing* or *recreating* to reach the prior state. Likewise, the Violin Maker must carve a new violin to try a new direction; he cannot revert subtractive carving operations on a piece of wood, and so must create a new artifact from a new piece of material. The Performer can discuss and remember a version by referencing the script, however she and her collaborator must re-enact — *recreate* — the scene to truly return to the prior state. Yet deconstruction and recreation provide the same benefits to these practitioners as reversion does to programmers: confidence to explore. In these cases, the amount of labor required to return to the prior state is less important than the knowledge that the version information is saved, and could be returned to if necessary.

5.4.4 Opportunities for Variation through Low-Fidelity Capture

In software version control systems such as git, the information stored for each version represents a complete copy of the code content at that particular moment in time. Such a representation is *high-fidelity*, containing all the detail of the system state needed to recreate that content exactly as it was. However, practitioners did not universally value capturing complete detail. The amount of information stored at various points during the process varied widely, from complete snapshots of the entire system to the briefest of summaries. The choice of how much detail to capture was deliberate, in order to support productive variation, spontaneity, and adaptation.

For example, the Physical Performer deliberately omits detail in her captured versions in order to maintain a sense of spontaneity and liveness in her performances. The Physical Performer has been working in performance for 22 years and is trained in mime, acrobatics, and physical comedy. She creates, directs, and performs one-woman physical comedy shows.

While developing a spoken comedy show, the Physical Performer iteratively developed her content over 3-4 weeks by improvising from notes she had taken about moments in her life. She performed in front of a workshop audience, improvising her movements and stories as she went. These performances were early iterations of her show, from which she would later select good parts, abandon bad parts, and rearrange the content into a full-size show.

She recorded these performances for later review; these recordings act as version artifacts for the show under development. But rather than recording video, which would capture all the details of both sound and visuals, she only recorded audio:

> **Performer** Someone told me: "you should be videotaping this because...all your movement[s] are part of it." I never videotaped it... I need to keep some aspect of it unplanned so that I have this feeling of spontaneousness.

Capturing a version artifact is important to her process: using the audio recordings, she can remember particular phrasings that worked well, select individual parts, and recombine her stories in a later version. Equally important is *not* capturing the video: in this way, the performer allows the movements to develop and retains liveness in future iterations, rather than feeling scripted and restricted. In the context of a physical show, where visuals and audio are both essential material components, the audio-recordings are a form of low-fidelity versioning that supports a creative process that maintains liveness in future iterations.

We can also see the effects of using video to capture an ephemeral art form through the experience of the Performance Director, who has worked as an acrobat, clown, producer, director, and playwright for shows ranging from theater to circus for the past 47 years. In addition, he is an accomplished juggler. When watching a juggler in person, one cannot catch all the details of a trick. These errors can be productive, enabling the trick to evolve:

> **Director** Those little errors [are] like a little genetic mutation, generation to generation.

These mutations contribute to each juggler's unique style, and to the evolution of juggling as a field. These days, videos of juggling techniques are easily accessible on the Internet, and able to be replayed over and over to tease out the details:

> **Director** I don't think we lose [the mutations], I think that still happens with video. [But] it doesn't spread as fast.

Video slows the process of evolution by reducing the space for serendipitous variation. In this example we see a case where the amount of detail and accuracy of the past version, captured in memory or in video, changes how an individual's style develops.

Low-fidelity version artifacts can also support adaptation to material requirements. The Violin Maker works in the Cremonese tradition of instrument making, carving each instrument by hand from an ever-evolving set of molds and templates and flexibly adapting to mistakes and variation. He has been a professional luthier for 18 years, creating new violins and repairing old ones in his studio. Instrument-making is a deeply creative practice; the

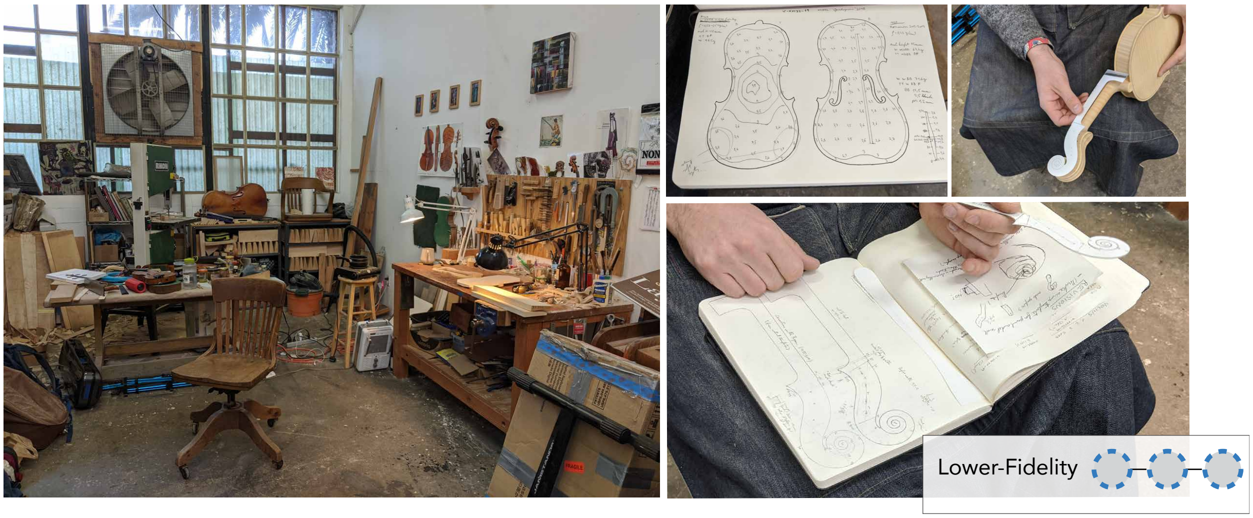

Figure 5.7: Low-fidelity records. The Violin Maker captures version histories in a variety of physical forms. From Left: The Violin Maker's workshop. Gradation diagrams used to record the depths of the top and back of a violin. Demonstrating a paper template for carving a neck and scroll on the partly-assembled instrument. The Violin Maker's notebook in which he records designs and modifications, showing versions of the neck template alongside the final template.

luthier is both artist and artisan as he explores new aesthetic forms and works intimately with new materials and tools to create unique instruments.

A new instrument design is developed in concert with the creation of the instrument itself: sketches become templates that are used to carve rough shapes; the depth of material across the back and top of the instrument are recorded on gradation diagrams after carving (Figure 5.7). The Violin Maker tracks these dimensions, shapes, and templates in order to maintain a history of successful and unsuccessful approaches, and to scaffold experimentation with new designs. However, each piece of wood has its own character, and requires unique variation on the recorded designs. Here he describes the character of a blank that will become a violin back:

> **Violin Maker** I know that it's going to be a little soft towards the outside, because the grain should be straight as possible, and this particular piece of wood, it's slanted like that... So I know that towards the end, towards the edges, I'm going to have to make it a little thicker. So I'll go to the violin that has the same kind of density of wood, and take those thicknesses, make it a little thicker, and take it from there. Start there and see where it ends. At the end it's just feeling.

The Violin Maker engages in a conversation with his materials (Schön 1983) as he works with a particular piece of wood. The collected history of his designs – versions of templates, gradation diagrams, and other notes – allows him to build off of earlier knowledge without starting over. The space left by the low-fidelity representations makes room to adapt to the needs of a particular piece of material. This space for creative variation is similar to that created by the Physical Performer when she excludes video capture of her performances.

Both low-fidelity and high-fidelity representations of past versions have their place in creative process. Low-fidelity version capture supports the techniques of creative process discussed above: the Performer creates space for spontaneity; the Director embraces productive error; the Violin-Maker adapts to materials. A familiar example of a process technique supported by high-fidelity capture is that of code reversion, where software version control systems use exact representations of earlier states to allow the programmer to return to that state. Though both ends of the spectrum support certain techniques, the wrong level of fidelity can also stymie other techniques. Therefore the default approach of both capturing and presenting all detail for past versions may not be appropriate at all points during the creative process. Selectively choosing what to capture, or capturing all data but selectively choosing what to present to the user, may allow version control systems to support a wider variety of process behaviors.

5.4.5 Using Versions across Long Lifetimes

Inspiration and iteration may influence work across years or decades; a project though complete may resurface again to be continued, revised, or dramatically altered. Creative process cannot always be cleanly divided into individual projects. For several of our interviewees, history information and project versions had influence on the creative process far beyond the lifetime of the project itself.

For the Tapestry Weaver, reflecting on her past work revealed how long certain themes had been incubating in her work, and gave her inspiration for further evolution. For example, in her recent work, she has been playing with treating her weaving as a “canvas” onto which she sews other pieces of fabric. However she realized this is a much older idea than she had believed, when reflecting on prior pieces that she had kept available in her studio or had documented through photographs:

> **Weaver** [I had thought] that it is only in the past two or three years that I have been [doing] what I [call] ‘weaving a canvas’ and then stitching some things on top of it. And yet I did it there [on an older piece]. And I did it there. ...And that would be decades... later after it had stewed around for a while. Which is one of the reasons why I do like to have some of my things around me, because they continue to inform what I might want to do.

In addition to reflection, the Tapestry Weaver sometimes reworks projects from years before that were unfinished or unsuccessful, turning them into new or modified pieces. Similarly, all three creative coders looked back at prior projects and version histories, either to find and reuse specific components in a current project, or to inspire new pieces of art. These version histories are equally relevant to new projects as they are to the one they were created for, and retain their relevance even over long periods of time:

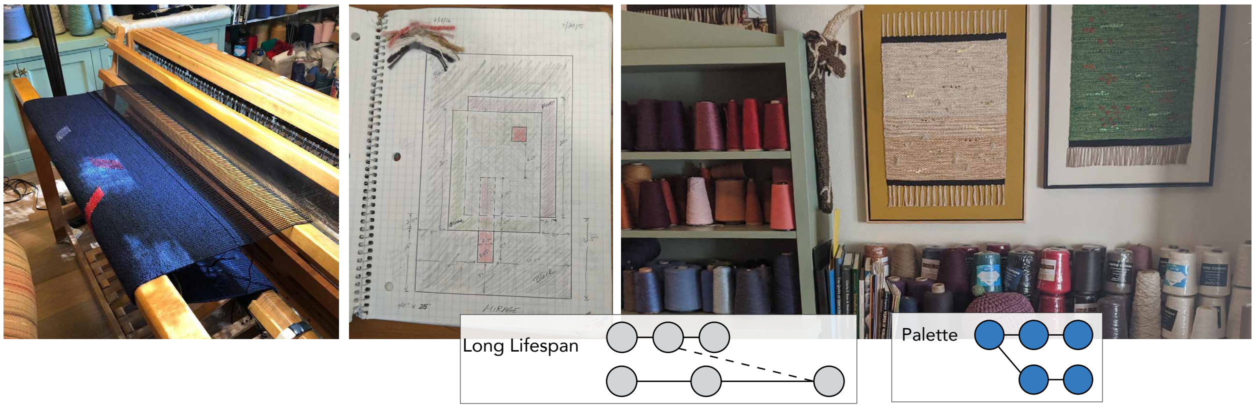

Figure 5.8: Long lifetimes of records. The Tapestry Weaver's studio contains in-progress work on the floor loom (left), notebooks of designs (middle), as well as completed pieces hung on the walls (right). These completed pieces act as a palette of inspiration and options for re-work, if she is dissatisfied with the result. Designing, making, and re-using pieces can occur over years or decades, resulting in long lifetimes of use.

> **Generative Artist** I would never push my company's production code from a year ago, but I might want to go back to an artwork that I did a year ago [to] explore it further.

In these cases, the long time frame can be a benefit in itself, allowing skills, techniques, and ideas to develop. The AR/VR Artist, Generative Artist, and Weaver all valued this growth over time, and valued the way their artifacts embodied these personal changes. As the Generative Artist described:

> **Generative Artist** As I'm maturing more and more, I can look back at my artwork, critique them but also... just have a better understanding [that] I can push them into this new direction, or maybe I can combine my new artwork [with] something from the old, and create something else new.

Reflecting on prior versions over time can reveal changes in the creator's understandings, concepts, or interests. For example, the Academic uses his old notes and free-writes to understand his evolving thought process. The Academic is an advanced graduate student in a technical field at a university in the United States, who has thoughtfully crafted his tools and habits to support his research process. Reviewing old notes not only reveals his growing understanding, but also encourages him by documenting his improvements:

> **Academic** A lot of research is coming up with the framing of an idea, about what makes it valuable, how it fits into the state of the art... Seeing that framing slowly change over time is helpful, both for recovering from false starts, and also to see that progress has been made in an otherwise very low feedback, very discouraging field of work.

However, version control systems are often focused on the project lifespan, supporting process behaviors within the creation, maintenance, and sunsetting of the project itself, but not intended for cross-project behaviors.

Software Engineer 3 discussed the same values that we see held by the Academic and Weaver when considering the potential of reflecting on old code. However, he did not engage in this kind of reflective review of old versions:

> **Software Engineer 3** I think my memory of how I solved problems before can inform my future decisions, but I don't reflect on my old code. I would like to, to some extent, but ...I'm not coming into contact with code I've written three, four years ago.

While VCS is often used to increase efficiency and productivity, it also has the potential to support the long-term development of the practitioner through reflection. Visualizations of version control data are one path towards supporting reflection, such as how the classroom tool Pensieve provides insight to students and instructors on individuals' approaches to writing code (Yan et al. 2019). Resurfacing specific entries in a reflective context, as we see the Academic and Weaver doing, may allow practitioners to see how they have grown in specific areas, or inspire them to return to certain themes, especially across larger time scales. Version control is uniquely situated to support such reflection, as it is already a repository of rich information about past process and content.

5.5 Discussion: Adapting the Paradigms of Version Control For Creative Process

Through the interviews with creative practitioners, we have seen myriad ways that version artifacts and history information support the creative process. Existing VCS features can be powerful tools for particular process techniques, and at the same time, they can be limiting for others. Here we discuss how these results can inform design decisions for version control systems, and propose Creative Version Control Systems (CVCS) as process-sensitive tools that foreground the roles version control systems play in creative process.

5.5.1 Creative Version Control: Supporting Creative Process by Modifying VCS

The mindsets and requirements of creative practice differ from the standard models and features of version control systems. Therefore, we cannot adopt existing paradigms of version control wholesale into new creative domains, or expect them to fully support creative process behaviors in domains that already use VCS. Instead, Creative Version Control Systems (CVCS) should be designed with supporting the needs of creative process as a central goal.

The Violin Maker discusses a compelling example of the failure case of adopting prior mindsets directly into a new practice: incorporating CNC machines into the violin making process. A CNC tool integrated into a digital version control system for a violin maker could use high-fidelity 3D scans to capture version information, and automatically return to old design versions by CNC carving new parts, with little labor from the artisan.

Yet to the Violin Maker, this is the wrong way to integrate a CNC tool into his process. Scanning a violin to capture a high-fidelity version of the design, then using a CNC to revert to that state, results in poor violins that are not adapted to the needs of the wood and cannot accommodate creative alteration. Since each violin must be made from unique material, each instrument requires its own touch:

> **Violin Maker** [You] have to have a method that's flexible, and that you can adapt to every piece of wood...What I want to do is have this method where the machine cuts just enough, what [an apprentice] would do for me.

Instead of reproducing the capabilities and values of standard version control for precise capture and easy reversion, the Violin Maker would prefer to leave space for adaptation to the individual piece of wood and creative variation in the design by reducing how much of the design the CNC cuts, and the level of fidelity captured by the version data. This approach to the integration of a CNC still imports the benefits of rapid manufacturing and offloading repetitive labor, while remaining sensitive to the needs of his creative process. By foregrounding the process needs of the creative practitioner, this more desirable design would be a CVCS.

The four themes discussed in Section 5.4: Findings represent a set of design choices for a CVCS that can affect the kinds of process behaviors it can support. These themes are a selection of behaviors we observed across multiple creative practices, but are certainly not the only possible design choices or relevant themes for all creative practices.

A creative version control system might support a **palette** of versions rather than a linear progression. To do so, it should consider providing **rapid, parallel access to versions** without fully resetting the state of the workspace, as discussed by the New Media Artist, Creative Coder, and Animal Behavior Researcher. In domains where outputs are separate from the state information, such as creative coding, the outputs should be **visually accessible and directly linked to the version state**, as explored by the Generative Artist and Tapestry Weaver.

Confidence and freedom to explore are essential across practices. However, VCS may place a **lower priority on rapid reversion** in order to gain these benefits. As seen with the Industrial Designer, Violin Maker, and Performer, easy reversion may not be a necessary capability: version histories provide these benefits even when additional labor is required to return to an earlier state.

Lower-fidelity records may enable variation, spontaneity, and adaptation, as valued by the Director, Performer, and Violin Maker. Similar benefits are found in low-fidelity sketches and prototypes, which allow creators to easily try variations (Buxton 2010), and leverage the ambiguity of imprecise representations to make space for interpretation and re-interpretation (W. Gaver et al. 2003; Tversky et al. 2009). Since software is plastic and can **dynamically change representations**, such tradeoffs need not be permanent: one stage of the creative process, such as early ideation or rapid improvisation, may require lower-fidelity presentations of version data and be willing to trade off easy reversion, while a later stage of refinement might display the full, high-fidelity records to enable easy reversion. Information visualization often leverages plasticity to adapt to the right level of representation (J. D. Hollan et al. 1997); version control systems may similarly benefit.

Making version data **accessible and visible across longer timescales and multiple projects** can support personal reflection and reworking of ideas, as seen with the Tapestry Weaver, Generative Artist, and Academic. Visualizations for reflection have been highly fruitful in VCS, across software development, writing, and education (Ball et al. 1997; Draheim et al. 2003; Zünd et al. 2017; Glassy 2006; Yan et al. 2019; Mahoney 2012; Park et al. 2017); such tools and frameworks can provide a groundwork for longer-term approaches.

VCS that could be redesigned to benefit from these approaches include VCS for code, but also version histories of collaborative text documents, spreadsheets, and design files. These tools are often used by creative practitioners, but currently rely only on similar paradigms to software VCS (Figure 5.2). Modifications to additionally support the paradigms of creative practice will better support the processes of creative practitioners. When tools better support their creative processes, practitioners may also be able to more fully integrate the existing collaborative benefits of version control into their workflows.

5.5.2 Material and Medium

The uses of version information in creative process are intimately tied to the material properties of the version, and the medium of the creative practice in which the version is utilized. The creative medium influences the choice of material for versioning; likewise, the material of the version influences the role it plays in the creative process.

In some cases, we see strong similarities with creative practices that share a medium. For example, the Performer and Director, who both work in physical performance, both value change and flexibility in their work, and choose lower-fidelity representations of version histories. As the Industrial Designer and Violin Maker both work in physical practices, they must recreate artifacts to return to earlier versions through labor-intensive processes. However, similarities between different mediums and differences within the same medium reveal aspects of creative process that are not dependent on any specific creative medium.

Software engineers and creative coders, though working in the same material, have radically different paradigms of creative process and the role of version histories. Though code and physical performance are different materials, VJ'ing, or live-coding visuals to accompany music, requires spontaneity and liveness in much the same way as a physical comedy show. The Physical Performer gains liveness by excluding the visuals of her performances from her version history; the Creative Coder uses rapid creation of parallel versions to allow him to pursue many different directions during a single performance, but only reuses a small selection of key modules between performances. Despite the different materials – bodily performance and code – the values are similar. The Physical Performer and the Violin Maker both use low-fidelity capture to make space for variation in their work, despite working in different mediums and on different timescales. There is much to learn by considering ap-

Theme	Illustrative Design Recommendations
Palette	- Provide rapid, parallel access to different versions without requiring a full reset of the workplace state. - Outputs should be visually accessible and directly linked to the version state.
Freedom	- Deprioritize rapid reversion in favor of supporting confidence and freedom to explore.
Fidelity	- Support variation, spontaneity, and adaptation. - Dynamically change representation to fit the needs of different stages of the creative process.
Timescale	- Make version data accessible and visible across longer timescales and multiple projects to support personal reflection and reworking of ideas.

Table 5.2: Themes and illustrative design recommendations for creative version control systems. These are neither a complete nor required set of guidelines, but were commonly used and needed among our interviewees.

proaches to version control across mediums and materials, as well as within them, and this work represents a step towards cross-pollinating across diverse creative domains.

We may also find value in considering creative process where version histories are mostly unused. Unique among our participants, the Ceramicist almost entirely rejects version histories in his work. The Ceramicist is an artist and ceramics studio technician and has been working in ceramics for 21 years. He collects and uses history information only minimally, and only as required for grants and show materials. In his day to day creative process, version histories are irrelevant: the knowledge of how to throw the base shapes in clay is embodied expertise, and the designs he creates are put together in the moment, linked by a single continuous theme. In a creative process like the Ceramicist's, external tools for version history are unnecessary.

5.6 Limitations and Future Work

While our interviews spanned a broad range of creative practices, this is not a comprehensive review of all version control needs and strategies. We have identified several fruitful approaches, but there may be additional insight to be gained from other domains. Additionally, VCS is deeply entwined with collaborative and social contexts, where we may find productive parallels for other domains: might history management tools for other creative domains find a parallel for "starter code", or share inspiration through public forums of history repositories?

Process is personal as well as domain based, and future tools may find adoption between domains as much as within them dependent on individual needs. Such needs may also vary based on context and culture. An office environment may have requirements for what information is captured, or value efficiency and accuracy over personal process. The behaviors we observed are tied not just to domain and individual, but grounded in context and culture as well.

In future work, it will be important to explore how to practically integrate these themes into digital tools. We intend to build tools that instantiate these themes and deploy them with creative practitioners in workshop settings. Such studies will also explore cross-pollination between disciplines and contexts: how do practices benefit when tools support helpful behaviors from other practices?

We also hope this work inspires other researchers to explore how to support creative process with version control across new domains.

5.7 Conclusion

In this chapter, we explored how creative practitioners in a wide variety of disciplines use version information to mediate and support their creative processes. Version control systems provide powerful tools for managing history and supporting collaboration. In our data, we see that creative practitioners use some of these features, and reject or appropriate others in service of their creative process: approaching versions as a palette of materials, gaining confidence to explore by capturing history, choosing varying levels of fidelity to capture version information, and reflecting and re-using versions over long time spans. Version control systems that are sensitive to these uses of version control information in creative process may provide large benefits to creative practitioners, and bring the collaborative benefits of VCS into creative workflows. We envision a future of widespread version control tools that are not just record keepers, but are collaborative partners intimately tied with creative practice, bringing benefits to software engineering as well as a diverse range of creative domains. Such Creative Version Control Systems will be sensitive to the paradigms of specific creative practices and foreground the value of version histories to process.

Studying version control systems has allowed us to explore the potential of process-sensitive creativity support tools in a cross-domain context, building on empirical data about existing practice. In the next chapter, we design and implement a process-sensitive creativity support tool for documentation and history-keeping in a design education context, building on the values and strategies explored in Chapters 4 and 5.

Chapter 6

Kaleidoscope: A Process-Sensitive Documentation Tool for a User Interface Design Course

Chapters 4 and 5 discussed strategies and values for history keeping and version control in creative process. In Chapter 6, we apply these themes to inform the design of a process-sensitive documentation tool for collaborative projects in a remote design course.

With this final system example, we primarily focus on the final research question:

R3: How can creativity support tool designers leverage process values and techniques to create computational tools that support process as well as output?

In the interviews described in Chapters 4 and 5, we saw how documentation and history-keeping can be used as creativity-relevant processes that support exploration, adaptability, and reflection and to increase motivation and self-efficacy, in addition to their role in creating long-term records for external use. From these insights, we design Kaleidoscope, a process-sensitive tool for documenting and interacting with design history in a user interface design course. Using a research through design methodology, we iteratively developed Kaleidoscope during a semester-long deployment in response to interviews, surveys, and student usage data.

We deployed Kaleidoscope in an upper-level undergraduate HCI and user interface design course at the University of California, Berkeley, with curriculum components structured to encourage learning about how documentation processes can be helpful to design. We explore how the insights drawn from expert practice (Pro-C creativity) in Chapters 4 and 5 can be introduced to students learning design (mini-c and little-c creativity), and discuss benefits and challenges of using expert process to design educational tools. These successes and challenges provide insights to guide future tools for design documentation and HCI education that scaffold process as an equal partner to execution.

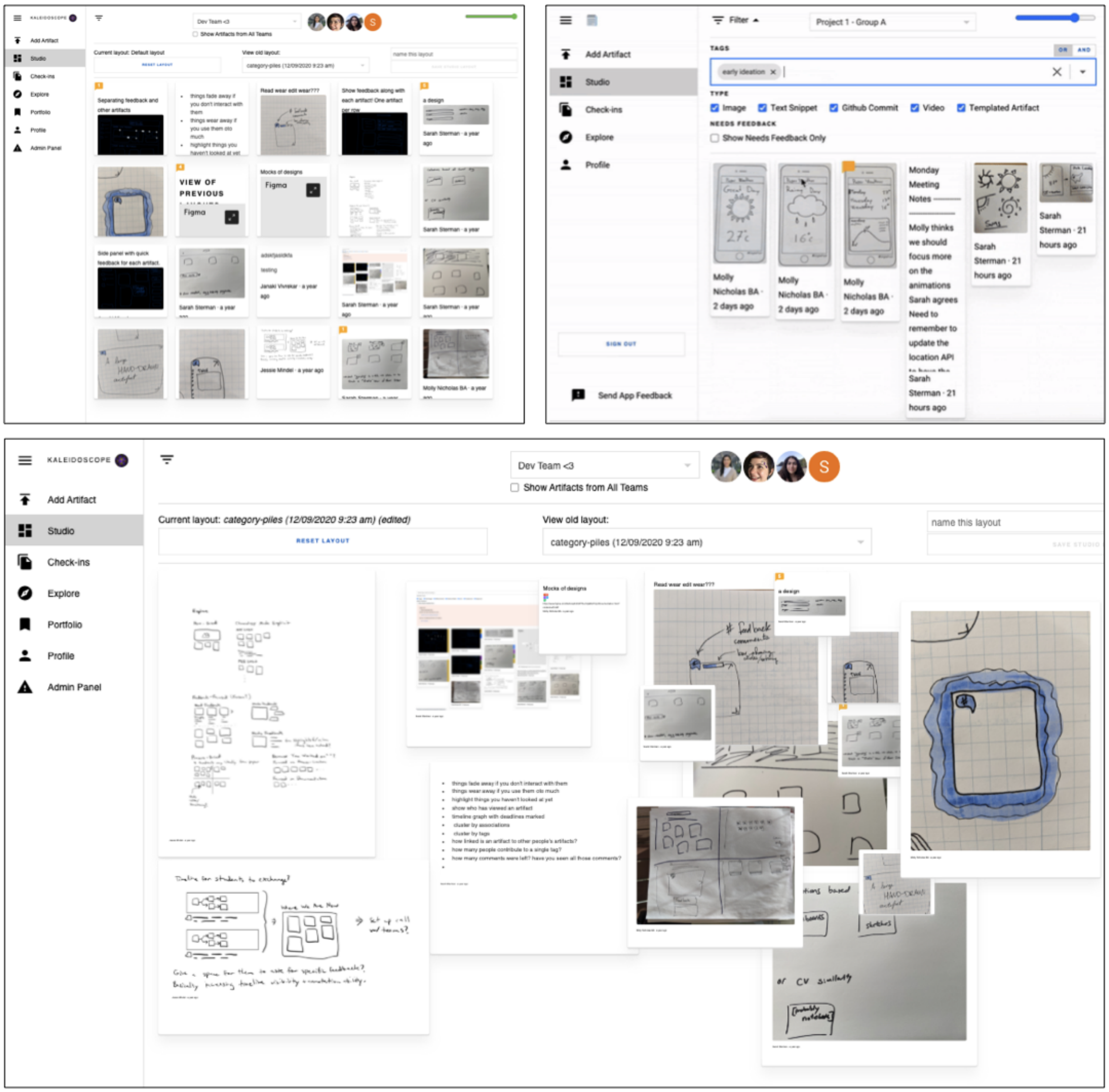

Figure 6.1: Kaleidoscope is a remote collaboration tool for student groups in a project-based interface design course. The "Studio Space" is the central place for group interaction, where groups document the history of their project with multimedia artifacts (top left). Artifacts can be filtered on tags, allowing students to look at specific parts of their process, such as "early ideation" (top right). Studio spaces can be organized with custom layouts (bottom). Other features support assignment submission, peer feedback, portfolio creation, and instructor visibility into student process.

6.1 Introduction

Design education is a growing area of interest among the HCI research community. Since HCI is an interdisciplinary field, teaching HCI requires covering a complex array of concepts from multiple domains. Essential in this mix is design process: many HCI educators teach some form of design as part of their HCI courses (Wilcox et al. 2019), and HCI can be seen itself as a fundamentally design-oriented practice (Fallman 2003). While there are many ways to teach design, and multiple interpretations of "design process," a common approach is to use project-based learning and a studio environment to give hands-on experience in iteration, critique, and collaboration (Vorvoreanu et al. 2017; Reimer et al. 2003). There is no single prescriptive structure for successful design process (Rivard et al. 2012), so project-based courses give students the opportunity to explore process for themselves, to figure out what works for them and for particular projects, and to adapt to changing needs.

At our institution, the University of California, Berkeley, such a course is CS160: User Interface Design and Development. Though facility with design process is a key learning goal of this course, projects are assessed by instructors based on the quality of individual assignment outputs. While these assignments are positioned at key points in the design process — for instance, turning in preliminary sketches, then turning in wireframes for a design — they capture only snapshots of outputs. Instructors only have access to these small pieces of students' process, curated by the students to be "successful" submissions. Moreover, students themselves have limited visibility into the structure of their workflows even as they perform them.

One leverage point to make process more accessible to both instructors and students is documentation tools. Tools have significant effects on how practitioners approach process (Dalsgaard 2017; Latour 1994). Documentation tools in particular are interesting for how they support not just individual tasks or post-hoc records, but are active participants in creative process, supporting iteration, branching ideas, and reuse of artifacts across the entire design process (Klemmer, Thomsen, et al. 2002; Kery et al. 2017; Sterman, Nicholas, et al. 2022). In user interface design courses, students learn how to use specific tools for particular tasks (e.g. wireframing, ideation, prototyping, etc.), but there is a gap for tools that support reflecting on the high-level aspects of process across the entire design journey. Documentation tools for design offer a unique opportunity to capture and reflect on process holistically while also supporting particular design skills.

In this chapter, we present a process-sensitive design documentation tool, Kaleidoscope, developed and deployed in an upper-level undergraduate user interface design course at UC Berkeley. Using research through design, we seek to understand how a process-sensitive documentation tool can support student design process, group collaboration, and critical reflection on personal process. This work responds to the call for more research in HCI education to provide empirical evidence from real classroom deployments (Roldan et al. 2021). Students documented over 3800 artifacts in Kaleidoscope – design sketches, notes, photographs of prototypes, code, Figma documents, etc. – and left each other over a thousand pieces of feedback. These artifacts spanned many mediums, creating a central repository for project progress and an infrastructure for feedback within and between teams. At the end of the semester, students generated final portfolios from these artifacts for the class showcase. Student interactions with Kaleidoscope provided unexpected insights into the role of documentation tools in a course setting and shaped the development directions of Kaleidoscope as it was continuously developed during the semester in response to student needs, usage patterns, and feedback.

We deployed Kaleidoscope in a fully remote semester during the COVID-19 pandemic. Since this course is usually taught in an in-person, studio format, this offered a chance to explore how a documentation tool might assist students in remote collaboration and provide not just an online replication of a studio environment, but utilize the digital format to add even greater depth and new interactions (Jim Hollan et al. 1992).

Kaleidoscope instantiates five key design principles: *collaboration, seeing the big picture, metacognition, curating the creative space*, and *making progress visible*. We discuss insights into how this tool supported student learning through feedback, reflection, visual display of project history, and flexible layouts, as well as challenges, including co-locating work and assignment submissions, tensions between creation and documentation mindsets, and lack of control over visual presentations. Kaleidoscope acts as an interpretive artifact for investigating process-sensitive tool design, where our vision of more concrete histories of, reflection on, and evaluation of process can be explored and critiqued in real world use.

These successes and challenges provide insights to guide future tools for design education, and for design process documentation. Kaleidoscope was designed and studied as a process tool for education, however supporting reflection and collaboration through process documentation tools also has relevance for practitioners outside of educational contexts.

6.2 Related Work

6.2.1 HCI Education and Studio Learning Environments

Recent scholarship in the HCI community has increasingly investigated how research can improve HCI education, for example exploring a research agenda for HCI education (Wilcox et al. 2019), integrating research with reflections on teaching (Rivard et al. 2012), and testing research theories in the classroom (Roldan et al. 2021). In this work, we use a Research through Design methodology (Zimmerman, Forlizzi, and Evenson 2007) to introduce a new tool for student learning into a project-based user interface design course to better understand how to support student reflection, documentation, and collaborative process in an online setting.

In a survey of HCI educators, Wilcox et al. found that the vast majority of HCI courses include design in the curriculum (92% of respondents) (Wilcox et al. 2019). We deployed Kaleidoscope in one of these such courses, which serves as both an introduction to HCI and to user interface design at UC Berkeley. This course is heavily project-based, a common format for teaching design through practice. Students complete several group projects during the semester, culminating in a large final project.

Studio environments are often essential to project-based design courses: they teach critique skills and reflection, enable learning-by-doing, and support peer interaction (Vorvoreanu et al. 2017; Reimer et al. 2003). Studio spaces make process visible through the physical presence of intentional artifacts and the detritus of process, which come together to ground learning and discussion (Klemmer, Hartmann, et al. 2006). Exploring how to bring studio interactions into the digital world, Koutsabasis et al. created a virtual studio in a 3D simulation environment where avatars can interact in group collaboration spaces (Koutsabasis et al. 2012), and found instructor awareness of student collaboration, real-time remote collaboration, and creative freedom to customize the group space as strengths of the virtual studio. In this work, we explore how to support the strengths of studio-based learning in a fully remote design course, using a custom tool for documenting and sharing design process.

This work was performed during the COVID-19 pandemic, which introduced new challenges to teaching and learning HCI. Roldan et al. report challenges as COVID interrupted their Spring 2020 HCI course, but also note opportunities for easy recording of online meetings to support reviewing and reflecting on design behaviors (Roldan et al. 2021). Markel et al. explore design recommendations for experiential learning in the context of the pandemic (Markel et al. 2020), and Benabdallah et al. and Peek et al. both discuss the challenges of bringing hands-on making courses to remote contexts (Benabdallah et al. 2021; Peek et al. 2021). We also sought opportunities with the challenges, designing Kaleidoscope not just to replicate features of in-person studios, but to provide additional capabilities around saving process history, searching and viewing multimedia design artifacts, and group collaboration.

6.2.2 Components of Design Process

The design of Kaleidoscope explores how to support particular components of the design process: documentation, reflection, and feedback.

6.2.2.1 Documentation

Documentation is an essential component of creative process. The tools we use affect how we work and approach problems (Latour 1994; Dalsgaard 2017), including tools for managing project histories. In domains from programming (Kery et al. 2017) to design history history (Klemmer, Thomsen, et al. 2002), the tools we use to document, visualize, and interact with history affect what and how we create. In in-person studio contexts, how past work is made visible and physical in a space captures history to shape creative process (Klemmer, Hartmann, et al. 2006). Documentation tools can also shape social and community norms, such as in Mosaic, an online community for sharing in-progress work that creates norms of feedback, reduces fear of sharing unfinished pieces, and supports reflection on process (J. Kim, Agrawala, et al. 2017). Information reuse is essential to design process, where one's own prior work or that of colleagues is a key resource for inspiration and problem framing, and designers keep many artifacts from the design process, and rely on visual foraging to make sense of collections of artifacts (Sharmin et al. 2009). Sharmin et al. also note the importance of keeping artifacts connected to their design process, but that this is difficult with existing tools (Sharmin et al. 2009). Lupfer et al. discuss how interfaces for design history curation can support process through multiscale spatial organization (Lupfer 2018; Lupfer et al. 2019). Annotated portfolios provide a way to capture a design history for a future audience, uncover underlying values, and communicate insights and learnings to a wider audience (B. Gaver et al. 2012).

Despite its importance, documentation can be difficult and underutilized. It takes time and effort, and workplace value structures can deprioritize documentation in comparison to the speed of progress or generating new outputs. Specific materials or components of the design process can be harder to document than others; da Rocha et al. explore the challenges and importance of documenting samples, noting their value for reproduction and communication, as well as the difficulties in interrupting a workflow to document samples and dedicating time to documentation (Goveia da Rocha et al. 2022). In Chapters 4 and 5, we explored documentation tools in creative process in greater detail. Kaleidoscope is a design documentation tool, intended to support reflection and collaboration by presenting a visual interface to design history and co-locating multimedia information sources with each other, along with feedback and discussion histories. We discuss challenges related to prioritizing documentation in a classroom setting and communicating its value to students.

6.2.2.2 Reflection

Reflection on design process is important for designers and students to improve how they work (Rivard et al. 2012). Roldan et al. introduce reflective activities into a studio design course (Roldan et al. 2021). These activities focus on particular behaviors during a participatory design session; we are also interested in supporting the role of reflection, with a focus on longer-term patterns of design cycles and decision making. Tools can help make process visible to students in order to structure discussion and reflection (Yan et al. 2019). Feedback also plays a key role in reflection: it can be an anchor for reflection, and becomes more useful to the student when structured reflection is applied to the feedback itself (Quinton et al. 2010). Kaleidoscope seeks to make the design process visible to students by collecting artifacts created across the entire design life cycle and with many tools into a single context, while also co-locating feedback on each specific artifact with the artifact itself while situated within this greater design context.

6.2.2.3 Feedback

Feedback is a key part of the student learning experience and the iterative design process. In the user interface design course we worked with in this project, feedback can come from course staff, either during project work or at assessment points, from group members within a project group, or from peers outside the project group. Feedback contributes to the iterative

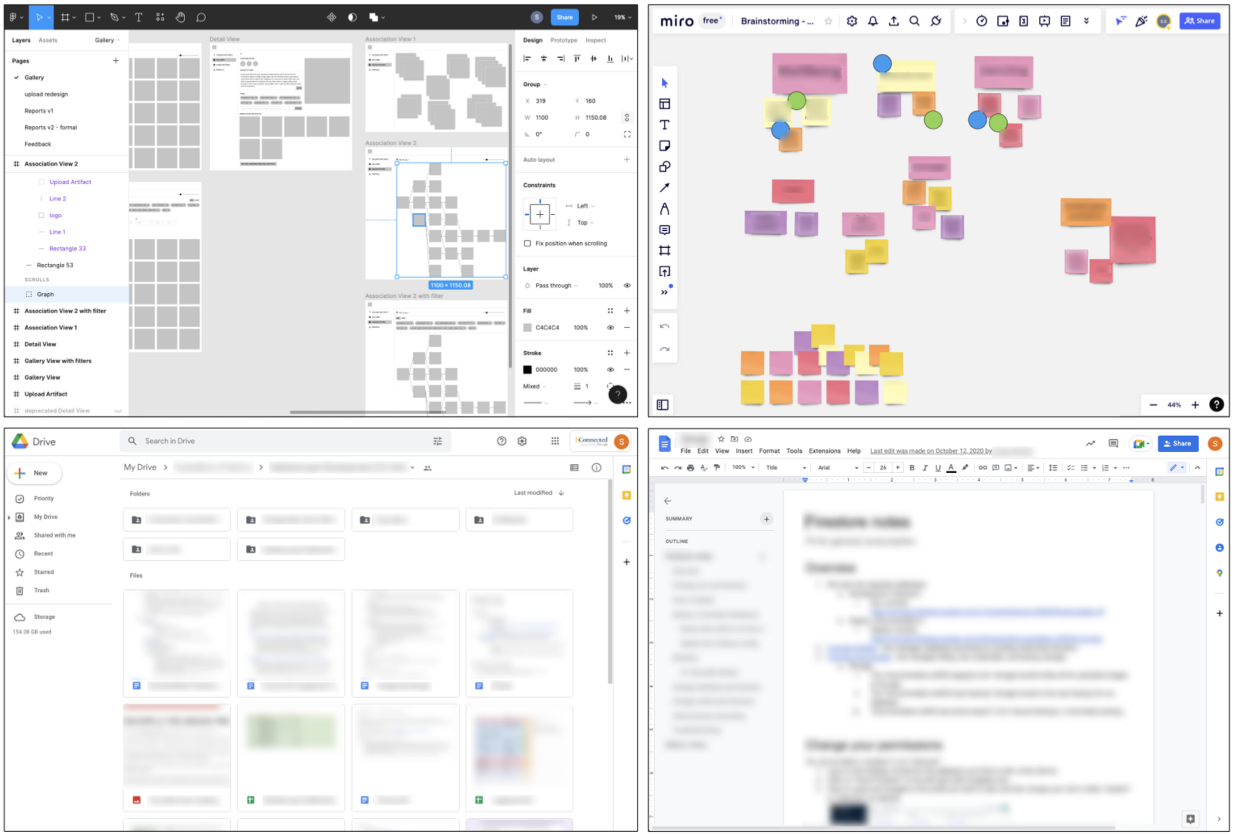

Figure 6.2: Students used many commercial collaboration tools during the course, including Figma for wireframing and design layouts (*Figma* 2022) (top left), Miro for brainstorming and remote whiteboarding (*Miro* 2022) (top right), Google Drive for sharing files (*Google Drive* 2022) (bottom left), and Google Docs for collaborative writing (*Google Docs* 2022) (bottom right). Images are examples of the tool interfaces and are not student work.

design process, but also to students metacognition around their own learning and process, in line with Boud et al.'s framing of students as active partners in the feedback process (Boud et al. 2013). Feedback and critique can be hard to scale; Kulkarni et al. design PeerStudio to provide scalable feedback in MOOCs by peers (Kulkarni et al. 2015), and Tinapple et al. design CritViz to support critique in large design courses, considering not just the logistics of critique but the social values of community, self-perception, and social accountability (Tinapple et al. 2013). Similarly, Kaleidoscope seeks to support positive community dynamics and create visibility into peers' design process to allow peer-learning, while integrating feedback into a more comprehensive studio documentation tool.

6.2.3 Digital Collaboration Tools in Our Classroom

Collaboration is essential to group work and successful design projects. Mercier et al. identify "creation of a joint problem space" as a key feature in successful collaboration in a design course, and emphasize the role of tools and shared artifacts in creating this space (Mercier et al. 2006). Kaleidoscope supports shared understanding by encouraging the central collection of all content related to the project, and acting as a shared reference for discussions and iteration.

Diverse collaboration tools have roles in the design classroom, in both in-person and remote offerings of courses. In the user interface design course we engaged with in this work, these include course support tools like Canvas (*Canvas* 2022), used for turning in assignments, hosting course media like PDFs of readings, and recording grades, or Piazza (*Piazza* 2022), a forum for questions and discussion. Students are taught to use Figma (*Figma* 2022), a current tool for design layouts and wireframing (Figure 6.2), and turn in video demos of projects by uploading to YouTube. During the pandemic, we also noted an increase in student use of other digital tools to support their group collaboration processes, such as Miro (*Miro* 2022), a digital whiteboarding application for brainstorming and Google Drive, Docs, and Slides for live collaboration and organizing documents (Figure 6.2). Students also relied on messaging and video calling services like Zoom, Facebook Messenger, and Discord to communicate synchronously and asynchronously during group collaboration. Kaleidoscope seeks to fill a specific niche by focusing on design documentation and metacognition around process, incorporating or working alongside these media rather than trying to replace any single one of them. We discuss below how Kaleidoscope related to these other digital tools in students' work.

6.2.4 Action Research and Educational Deployments

Field deployments can provide real-world data from a large population of users in the environment of intended use (Siek et al. 2014). In the educational context in particular, Roldan et al. emphasize the importance of implementing and studying HCI research recommendations in real classrooms (Roldan et al. 2021). In this work, deploying Kaleidoscope in a semester-long design course allowed us to see how students chose to use it in combination with other tools, how they used it over long-term projects and with different group dynamics, and to investigate Kaleidoscope in relation to the mindsets and stressors of the student experience.

In particular, we draw from the philosophy of action research to guide this project (Hayes 2014). In introducing a new tool into a classroom, we have multiple types of stakeholders: the students in the class, who have multifacted roles as learners, group collaborators, and designers; and the course staff, both the head instructor and the TAs who support the students through grading, mentorship, and lecturing. We engage with both the teaching team and the students as a participatory community in the iterative design of Kaleidoscope. Action research can provides first-hand experience with practical applications of ideas, however the effort required makes it less common lab experiments and other methods of research (Nachtigall et al. 2018). In the case of a design tool specifically introduced in a design class, we found it to be particularly appropriate to engage the students in the design and critique of the tool.

Within the frame of action research, we apply a Research Through Design methodology (Zimmerman, Forlizzi, and Evenson 2007; Zimmerman and Forlizzi 2014). Zimmerman et al. discuss four key components of Research through Design: *process*, *invention*, *relevance*, and *extensibility* (Zimmerman, Forlizzi, and Evenson 2007). In documenting the process of this research work, we will present a system description, details of interactions and data collection with students that led to system design decisions, and a thematic analysis of qualitative data from student interactions. Kaleidoscope presents invention through a novel multimedia documentation tool that supports remote design studio interactions, as well as course requirements. It allows students to investigate their own creative process at a meta-level, where prior literature and tools support specific features and detailed reflection. Kaleidoscope addresses questions of immediate relevance to the design community, as we continue to face remote teaching challenges related to the pandemic and broader cultural shifts towards online learning, and as the HCI community expands its interest in how to teach HCI and design most effectively. We hope that the community can extend the knowledge generated by this project by learning from the successes and challenges of this tool design to design future tools for creative documentation, consider new contexts for the role of reflection in learning design, and support remote learning in studio courses.

6.3 Methods

In this project, we engaged in action research through a Research through Design methodology (Hayes 2014; Zimmerman, Forlizzi, and Evenson 2007). Below we describe the course context, the design process with stakeholders including course staff and students, the eventual Kaleidoscope system, and the method of evaluation. The long-term use and iterative design of Kaleidoscope within a real-world course context allowed us to support instructors and students during the transition to an online format for the user interface and design course at our institution during the COVID pandemic, while also allowing us to generate research knowledge through the expression, evolution, and evaluation of our design goals in a real system.

6.3.1 Course Context

This project occurred in the context of CS 160: User Interface Design and Development, an upper-level undergraduate HCI and user interface design course in the Computer Science department at the University of California, Berkeley. This course covers user interface design, technical development skills, and HCI foundations; we will refer to it here as User Interface Design (UID). Between August and December 2020, this course was taught fully online for the first time, in response to the COVID-19 pandemic. UID is a project-based course, with approximately 100 students, in which students learn a design process incorporating needfinding, prototyping, and evaluation techniques. The course is structured around multiple design projects across the semester, culminating in a two month final project in which groups of 4-5 students design and implement a mobile application that focuses on equity and inclusion. Students learn Android mobile programming, as well as key HCI concepts for interface design and evaluation.

In standard offerings of this course, student project groups meet in-person to collaborate on design and implementation. The course also relies on in-person studio time, where students critique each other's work, test prototypes, and receive feedback. The remote offering of UID retained the project structure, but shifted all work online. Many students used Zoom and Discord for group meetings, Facebook Messenger for asynchronous communication, and Google Drive to collaborate in real time. Figma was a required tool for the course, which students used to brainstorm and create layouts and wireframes for prototypes.

This research was performed in close collaboration with course staff as key stakeholders in the design and use of a new classroom tool. Two members of the research team were also members of the teaching team for this offering of UID, one as a teaching assistant, and one as the lecturer. A third member of the research team was a former lecturer for UID, and two members of the research team had taken a prior in-person offering of UID as students. The remaining members of the teaching staff who were not directly involved in the implementation or evaluation of the tool participated in discussions around the tool's role in the course, their experiences using it in their teaching, and desires and needs for its design.

Prior to the beginning of the Fall 2020 semester, the research team developed a basic prototype of a documentation system for supporting collaboration and reflection. Throughout the semester, we continued to design and develop the system in response to its usage and feedback.

As the second key group of stakeholders, students provided feedback and suggestions to the research team on their experiences and needs, participating in a voluntary critique session, responding to surveys, and communicating directly with the research team through feature request, bug reports, and interviews. Kaleidoscope was introduced at the start of the semester as a documentation tool for group collaboration. In the How-To Guide on using Kaleidoscope, we describe it as follows:

> "While working on a project, designers often collect lots of images and examples as they build their vision for the final outcome. This tool allows designers to see everything collected in one place. This could help a designer to stay in touch with the original plan, try out new directions, and collaborate with others. This tool also lets designers look back at earlier iterations and see what's changed throughout the process."

The instructors demonstrated Kaleidoscope during a course section early in the semester, and encouraged students to integrate it in their design process, for instance to use it to share feedback and materials with their teams. The course required students to turn in certain assignments through Kaleidoscope; beyond that, there were no requirements about how students used Kaleidoscope in their process, and students created individual ways to integrate Kaleidoscope with other tools in their workflows.

Throughout the semester, we collected multiple types of data (See Section 6.3.4.1), investigating questions around the role of documentation tools in the HCI classroom, how to support remote studio environments, and how to encourage student reflection.

All research was approved by our IRB. Usage statistics and student critiques of Kaleidoscope were never included in student grades. The two members of the research team who were concurrent course instructors were not shown student interview data until after grades were submitted and did not participate in running interviews.

6.3.2 Initial Design Principles

Chapters 4 and 5 explored several specific ways documentation and history information play into creative process among expert creative practitioners. In this project, we wanted to explore how these strategies could be introduced to design students through a process-sensitive creativity support tool. Through discussions with course staff and the research team, we identified specific strategies from this work and from other prior work on education that might be relevant to the UID students. This synthesis resulted in the guiding principles listed below. We used these to inform the initial design and overall goal of the tool, with the understanding that we would be continually iterating on both the role of the tool in the course and the particular design over the course of the semester in partnership with students and instructional staff as the tool was used in practice.

We generated five guiding principles for our studio tool: metacognition, seeing the big picture, curating the creative space, making progress visible, and collaboration. Below we expand each of these original motivating principles, with example considerations and related theory.

Metacognition – *Reflecting on how we learn and work can be valuable to improving our process. Kaleidoscope should provide visibility into students' process so they can learn what works for them and what they might wish to change, by reflecting on their own process and others'.* In Chapter 4, we saw how embodying progress can support practitioner wellbeing and reflection; in Chapter 5, we saw how long lifetimes of records can support reflection between projects and across long periods of incubation. Metacognition and reflection has been suggested as important components of design education in other research: Rivard et al. propose reflexive learning as a framework for design education, emphasizing the value of critical reflection to learning design (Rivard et al. 2012). Roldan et al. explore how video can support structured reflection on student-led participatory design sessions in a design course (Roldan et al. 2021). Documentation tools particularly serve a role in metacognition; Yan et al. explored visualizing version control histories for reflection in computer science courses (Yan et al. 2019), providing unique opportunities for students to reflect on how they approached writing code.

Seeing the Big Picture –*Providing a high-level view of the project history can support design process, reflection, and understanding of progress.* In Chapters 4 and 5, we saw how access to artifacts from past stages of the creative process supported future work, in anchoring work to enable future exploration, maintaining an active palette of materials, and supporting reflection and motivation. Sharmin et al. explore the value of re-use of artifacts particularly in design activities (Sharmin et al. 2009); Klemmer et al. discuss the value of visibility of artifacts in studio and workshop contexts to enable communication and coordination as well as situated learning (Klemmer, Hartmann, et al. 2006). In work on multiscale design documentation, Lupfer et al. show the value of high-level views of design documentation to exploring and communicating ideas (Lupfer 2018; Lupfer et al. 2019). As a design documentation tool, Kaleidoscope draws on multiscale approaches to representing history, and should support visual foraging and building on older artifacts.

Curating the Creative Space – *The character of the studio space has important effects on designers' mindsets, bricolage practice, and feelings of ownership. Kaleidoscope should allow users to hide artifacts, draw attention to artifacts, and personalize the space.* In Chapter 4, we discuss how aestheticizing can create personal motivation around creative activities, by increasing the sense of value of an artifact and a desire to return to it. In Chapters 4 and 5, we also see how practitioners like the Tapestry Weaver deliberately curate their creative space to be surrounded by inspirational artifacts, either their own past work or others'. The studios described by Klemmer et al. have similar aesthetic and structural features, using the artifacts present in the studio to support peer learning, discussion, and critique in educational design contexts (Klemmer, Hartmann, et al. 2006). In constructing a design studio in a 3D virtual world, Koutsabasis et al. found the ability to construct and decorate their virtual collaboration space was engaging for student groups (Koutsabasis et al. 2012).

Making Progress Visible – *Student mindsets can have significant effects on confidence, self-efficacy, and perceptions of success. Kaleidoscope should allow students to see progress made on a project and have easy access to work they are proud of.* In Chapter 4, we see motivational benefits from embodying progress. In Mosaic, Kim et al. demonstrate how sharing works-in-progress can support productive mindsets around learning, improvement, and the value of process, as opposed to placing all value on final outputs (J. Kim, Agrawala, et al. 2017). Especially in a domain like design, where failure is an essential part of the design process (Rivard et al. 2012), growth mindsets (Dweck 2008) and valuing process over final output should be essential learning goals for design students.

Collaboration – *Working with a team is an important part of design, and is an integral part of the structure of UID. Kaleidoscope should be able to provide context for a decision to show another teammate, and allow teams to get feedback on the project as a whole or on specific artifacts.* Mercier et al. discuss the importance of a "joint problem space" for group collaboration, where members can concretize ideas and share context for deliverables and decisions (Mercier et al. 2006). CritViz is a system for structuring peer feedback in creative classes like a design class, and notes not only the value of giving and receiving feedback to better outputs, but also to creating a sense of community and teamwork (Tinapple et al. 2013).

6.3.3 Kaleidoscope System

Kaleidoscope is an online collaboration tool for documenting design history, supporting student reflections on their design process, and providing features for design education.

6.3.3.1 Studio Spaces

The central feature of Kaleidoscope is the “Studio Space,” where individuals or groups can collect and display artifacts from their project work (Figure 6.3). Each group has its own studio space for each class project; an individual can only see and edit spaces of which they are a member.

Users can upload *artifacts* to a studio space, where they are displayed as thumbnails. Artifacts can be images, text, GitHub commits, or links to other webpages, with special support for YouTube videos and Figma layouts. These covered the core types of information created for the class, with physical sketches and prototypes documented through photographs. Initially, studio spaces displayed artifacts in an automatically created grid layout; later iteration introduced a whiteboard-style free-form layout feature, where students could rearrange artifacts and save histories of layouts.

Artifacts can be *tagged* with free-text or suggested tags during upload or later on, allowing students to track particular design stages, assignments, or ideas. Artifacts can also be *associated* with each other, allowing conceptual groups to be formed between separate artifacts. Artifacts are displayed in the studio space, where they can be sorted and searched, and can be viewed individually on a *detail page*, containing the artifact, tags, description, title, and associated artifacts (Figure 6.4).

Detail pages also display *feedback* from group members, course staff, and other students. Artifacts can be kept private to the team and course staff, or made public for any student to view and leave feedback.

6.3.3.2 Course Tools

Certain features were designed specifically to support Kaleidoscope’s role as a tool for a course.

Check-ins are a special type of artifact, used for submissions of course assignments. A check-in template lists the requirements for the assignment, and students can select the particular artifacts to include in the check-in. Check-ins are not displayed in the studio, but can be accessed through a separate page that displays all assignment templates and past check-ins.

The *Explore Page* displays artifacts that groups decide to make public. Instructors can make artifacts submitted with assignment check-ins public, allowing them to curate galleries of student work: for example, collecting all low-fidelity sketches from an assignment and sharing this view with all students. In this way, students can see and learn from peer work, similar to how they would in a physical studio environment.

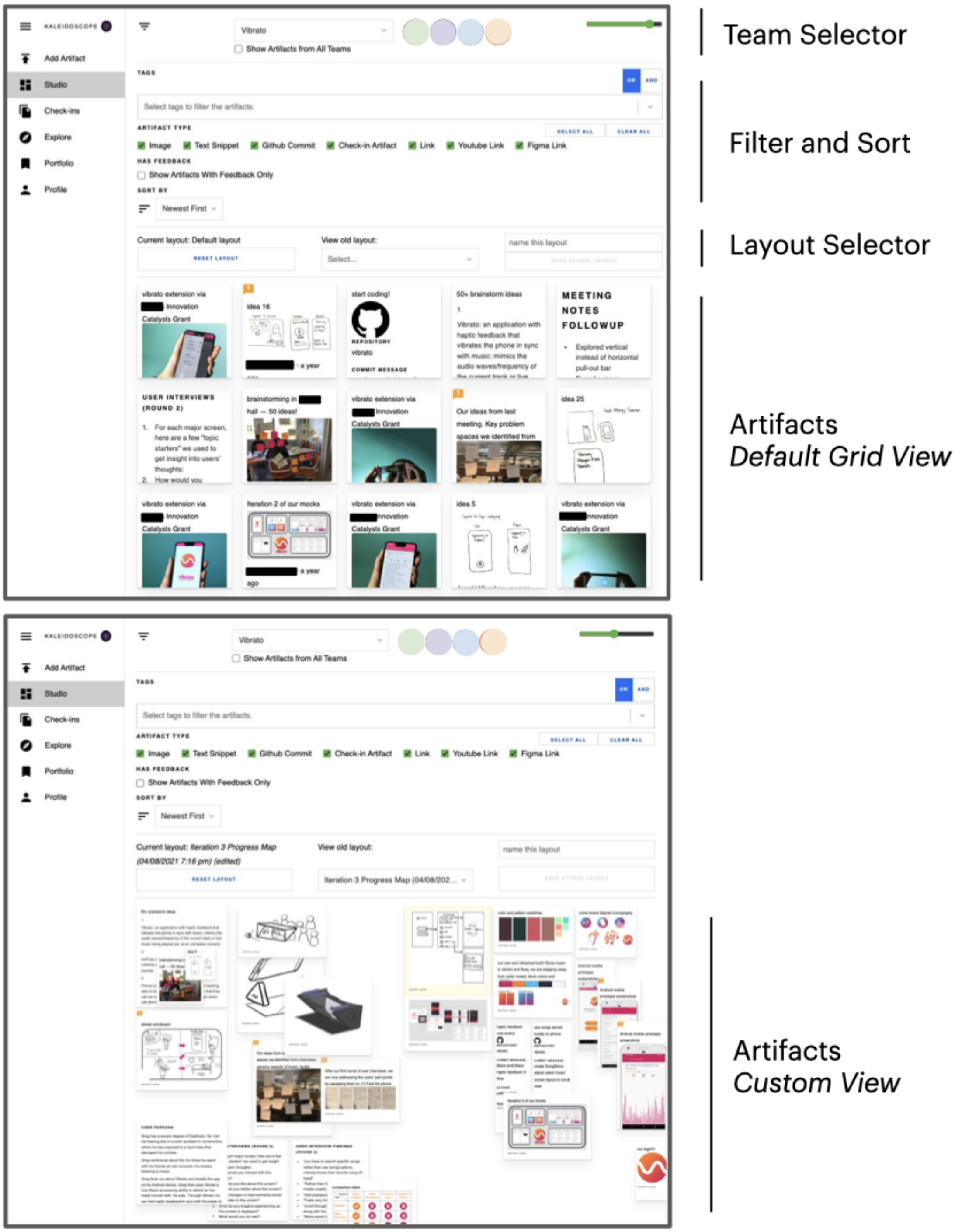

Figure 6.3: Studio Space. Top, a default view of a project's studio space, showing recent artifacts in a grid layout. Bottom, a custom layout in which artifacts have been moved and resized into conceptual groups, and saved as a named view. Three types of controls are available: choosing a project team to view in the studio, controls for filtering and sorting the artifacts shown in the studio space, and controls for saving and loading custom layout views.

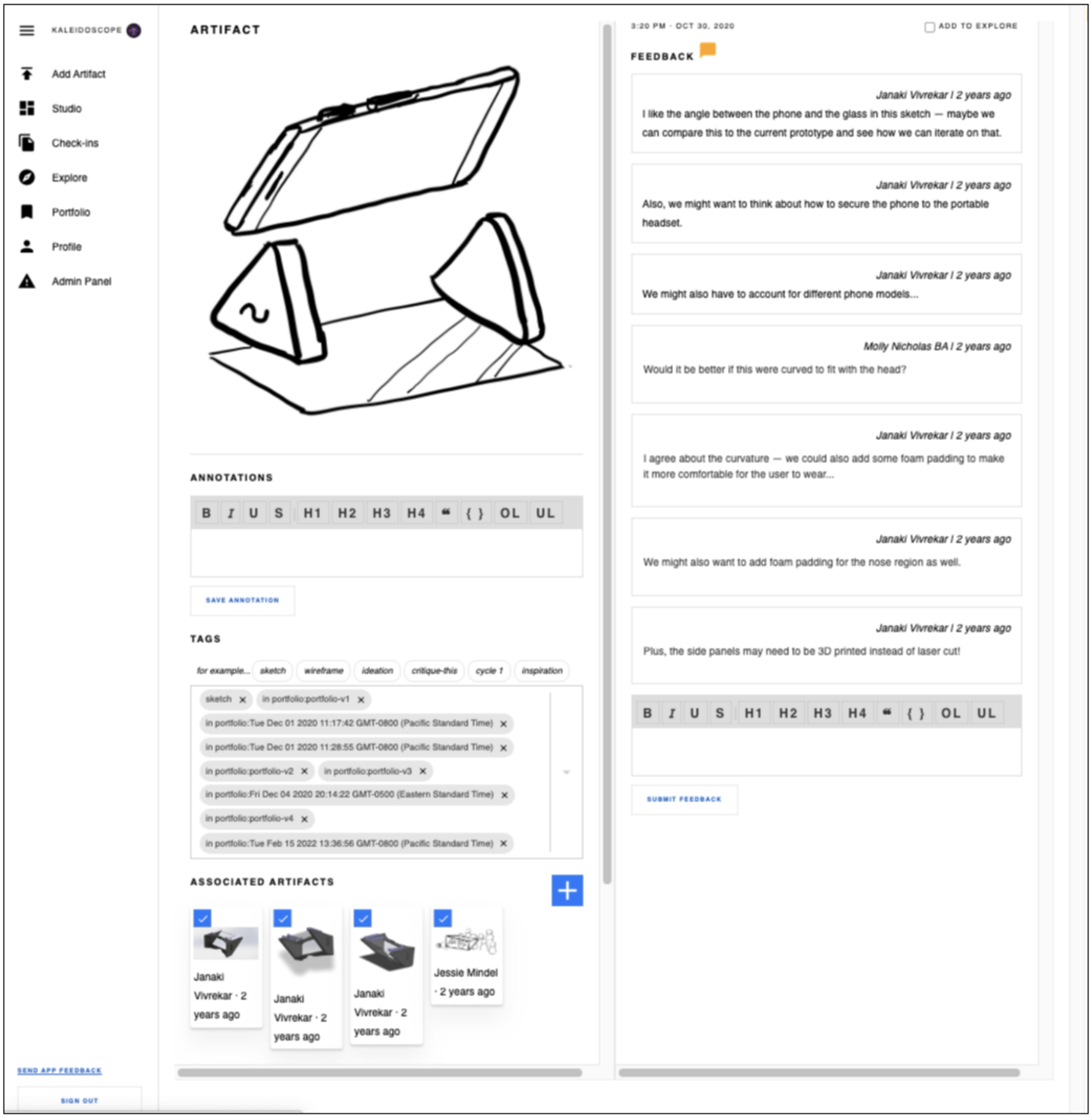

Figure 6.4: The Artifact Detail page shows additional information related to a specific artifact: the image artifact; an editable text annotation; the history of group discussion and feedback on this artifact; tags applied to the artifact; a tile view of associated artifacts that are relevant to this artifact.

At the end of the semester, students participated in a design showcase meant to give them a chance to publicly present their work. To support the virtual version of this event, and to help students put together a portfolio-style summary of their project, *Portfolio Pages* allows students to arrange artifacts in a public-facing layout (Figure 6.5).

6.3.3.3 Design Iterations

Over the course of the semester, the research team solicited feedback from students, spoke with course instructors, and monitored bug reports and feature requests from students, to iteratively develop the platform in response to student needs. We analyzed and discussed the feedback and student use behaviors as they were collected. We continuously updated the tool, adding new features and fixing bugs in response to student needs while aligning the tool more effectively with the design goals. Two major changes that were introduced include editable artifacts and customizeable layouts.

Initially, all artifacts were uneditable. Once uploaded, they acted as a static archive of the design history. Deleting artifacts was possible, but not recommended. However, students were frustrated by small errors in text artifacts that then had to be re-created to fix, and wanted to be able to work with teammates to update text artifacts after they were created. Partway through the semester, we introduced a rich text editor to the text artifact detail pages, allowing changes to text artifacts to be made at any point after creation.

The initial studio space layout was a column-based layout with tight-packing of the artifacts, running left to right in chronological order from most recent to oldest. While this allowed artifacts to take the amount of vertical space they needed to be visible, students found it messy and hard to find specific artifacts. There was also a desire for customizeable arrangements, to explore ideas and more actively interact with the design history during brainstorming and group discussions. We introduced *layouts*, a grid-based default view in which artifacts could be resized, moved, or hidden from a view (Figure 6.3). Layouts could be saved with custom names and timestamps, and easily reloaded from a dropdown menu.

Other changes included bug fixes, support for additional artifact types over time, and the introduction of the portfolio feature at the end of the semester.

6.3.4 Evaluation Methods

6.3.4.1 Data Collection

We collected data on experiences with Kaleidoscope in multiple ways during and after the semester, from both students and teaching staff. Data collected during the semester was used in the iterative design process to guide the direction of Kaleidoscope. As Kaleidoscope was integrated with an actual course throughout the semester, we had access to a breadth of data collection methods, including course assignments, reflections, and feedback surveys, as well as sources specific to the research project, including semi-structured interviews with

Figure 6.5: Portfolio Pages. At the end of the semester, students created interactive portfolios from their artifacts (demo portfolio at bottom). These portfolios were collected as part of a public showcase (top).

student volunteers. This breadth of data types allowed us to learn about how Kaleidoscope was used and received through multiple contexts throughout the semester.

Mid-semester semi-structured interviews (N=5).

Near the midpoint of the semester, the research team performed semi-structured interviews with individual students on their design process during the course, reflections on learning design, and the role of Kaleidoscope in process and learning (performed by non-instructor members of the research team). Interviews began by discussing where the students were in the course, what stage of the current project they were in, and how they felt that was going. After setting the stage, interviews transitioned to specific questions about personal and group workflows and their usage of Kaleidoscope. As semi-structured interviews, the questions evolved within and between interviews; a representative selection of guiding questions can be found in Appendix A.1.

Mid-semester course survey (N=34 students mentioned Kaleidoscope).

The teaching staff released an anonymous mid-semester course survey in which students reflected on the class overall, and gave suggestions on what was going well and what could be improved. The research team identified and analyzed responses related to Kaleidoscope. Questions which contained responses relevant to Kaleidoscope can be found in Appendix A.2.

Design reflection extra credit assignment (N=55). Near the middle of the semester, we released an extra credit assignment in which students reflected on their design process so far. This assignment was optional, however about half the students chose to complete it. Extra credit was given to all answers, with no evaluation of "correct" or "incorrect" answers. The goals of the assignment were: to describe and discuss your own creative process; make explicit subconscious behaviors and themes that affect your process; reflect on potential improvements to your process for future projects; consider how tools can support your learning, creativity, and reflections. While the questions did not explicitly reference Kaleidoscope, many students discussed its role in their process. The instructions for and questions presented in the survey can be found in Appendix A.3.

Kaleidoscope critique session (N=18). In the middle of the semester, we ran a critique session during which researchers moderated small groups of students in a discussion about their biggest frustrations with and wishes for Kaleidoscope. Students were given 5 minutes to individually add thoughts in a shared Google Doc, in response to a set of questions about their experiences with Kaleidoscope (Appendix A.4). Next, groups took 5 minutes to read others' comments and add any followups. The sessions concluded with 15 minutes of open discussion moderated by a single researcher, who took anonymized notes on student responses.

Post-semester semi-structured interviews (N=7). Post-semester semi-structured interviews with students on their design process during the course, reflections on learning design, and the role of Kaleidoscope in process and learning (performed by non-instructor members of the research team). Interviews began by discussing general reflections on the course, before transitioning to specific questions about their usage of Kaleidoscope. As semi-structured interviews, the questions evolved within and between interviews; a representative selection of guiding questions can be found in Appendix A.5.

Meetings with course staff (N=3 course staff, not including members of the research team). Throughout the semester, we held meetings with course staff to discuss their usage of the tool and their perceptions of student experience, and took detailed notes of the conversations.

Bug reports and feature requests. We collected bug reports and feature requests from students during the semester through a Google Form linked directly from the Kaleidoscope page, through direct emails, and Piazza posts.

Usage data. We collected all materials uploaded to Kaleidoscope, and logged interactions on the platform. Over the course of the semester, 149 users across 181 teams created 3268 artifacts, including 1063 images (33%), 1892 text artifacts (58%), 116 GitHub commits (4%), 89 YouTube videos (3%), 64 Figma layouts (2%), and 44 other web page links (1%) (Figure 6.6). 1077 individual pieces of feedback were left on artifacts. 553 check-ins were created for course assignments.

6.3.4.2 Analysis

During the deployment semester, the research team held weekly meetings where we discussed data collected so far, including student and course staff's experiences using the tool, and newly requested features and bugs. We used these meetings to guide the direction of the tool development and reflect on the tool design, role, and direction. After the semester, we performed a thematic analysis of the qualitative data from all the sources described in Section 6.3.4.1, transcribing the interviews and iteratively applying open coding to the entire corpus to seek high level themes across students' experiences with the tool.

We are specifically interested in analyzing Kaleidoscope as a research through design artifact within the frame of process-sensitive tool design. Therefore we focus our findings and discussion on interpreting the effects the artifact had on student experience and learning, including changes across the iterative development of the tool.

We present findings from the thematic analysis below. We do not report participant counts for particular themes, as our semi-structured and evolving interviews meant questions evolved as we collected data, therefore not every participant was asked identical questions.

6.4 Findings

6.4.1 Documentation Supports Reflection, Conflicts with Creation

As a documentation tool, Kaleidoscope's design began with an archival approach to artifacts, in which artifacts kept long-term without editing. While editing of text artifacts was introduced later in the semester, it was mostly used for minor, temporally proximal changes,

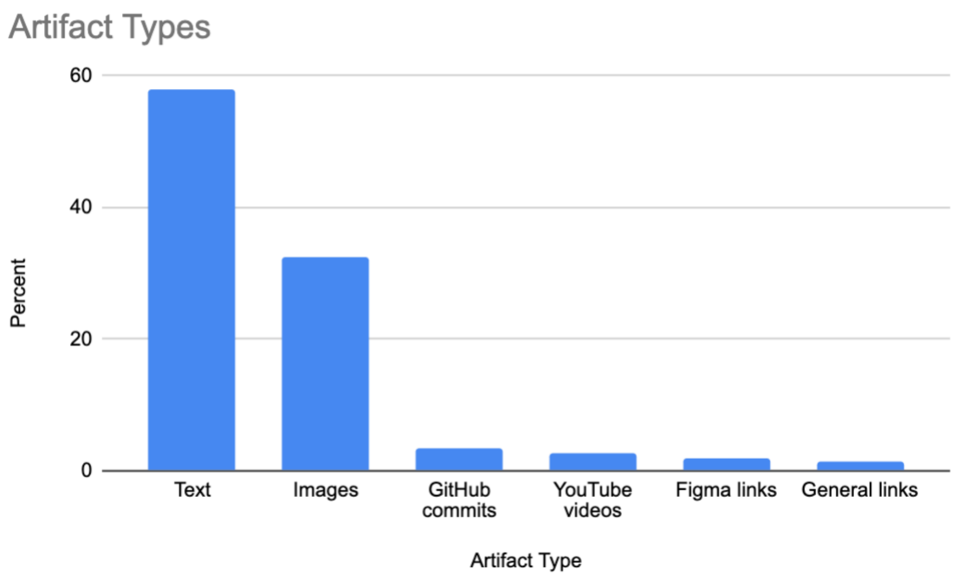

Figure 6.6: Types of artifacts uploaded to Kaleidoscope. 3268 artifacts were created during the semester.

and most artifacts remained static. This allowed the studio space to collect a history of past ideas and keep these visible to the team, showing how the project developed across over time and allowing students to reflect on their process at a high level:

Anon - Critique Session I tend to think of Kaleidoscope as timestamps of my creative thinking. It was great to see how my ideas were evolving over time.

Presenting these artifacts as visual tiles allowed students to quickly page in past context and stages of work:

S67 - Reflection Assignment It facilitates my thinking process... By reviewing Kaleidoscope, it reminds me of the designing process quickly.

Students were prompted to do an explicit reflection around their creative process midway through the semester. While the assignment never mentioned Kaleidoscope specifically, many students used Kaleidoscope to reflect on their project history:

S103 - Reflection Assignment [For the reflection assignment] I definitely took a look at my previous sketches in kaleidoscope. Which [at the start] did not seem like a great tool, but looking back really changed the way I looked at it. It almost feels like a version control for prototyping.

When creating final portfolios, students were able to use the history of the project collected in Kaleidoscope to reveal their design process and help their peers learn from their process:

S50 - End Semester Interview A lot of the artifacts that we added were actually artifacts that we already had... we wanted to include that step of the process to help inform other people's processes as well.

The artifacts in Kaleidoscope supported metacognitive reflection, providing a benefit after the artifacts had been created. However, there was a tension between the later benefits and the immediate labor of artifact creation. When students were creating content, they worked directly in other tools.

S47 - End Semester Interview I could have created an artifact in Kaleidoscope. But like, again, why do that when I want people to go to Figma and make edits.

Students added artifacts to Kaleidoscope most commonly for 1) assignment submissions, and 2) group discussion. Other parts of the project history were left in other tools, for instance snapshots of edits in Figma were rarely incorporated into Kaleidoscope. Instead, the artifact was added to Kaleidoscope only when it was considered "finished." Stopping to create intermediate artifacts required a change in focus from "creating" to "documenting":

S47 - End Semester Interview I would like to have like things more documented...but it's really hard because in the moment you don't know when you're going to change things...When I create things, I want them to be the final version. So I don't think like, Oh, I should document this right now, because it's either 1) it sucks, and I don't want to document it, or 2) it's good, and then it'll stay around.

Yet students expressed a wish for easy access to those intermediate histories after the fact, finding value in viewing multiple drafts of Figma documents in parallel, or frustration with the overwriting of state in Google Docs. Without these intermediate states, metacognitive reflection is harder; lower-effort or automatic capture of intermediate states in a central repository like Kaleidoscope may help support post-hoc reflection without interrupting the flow of creating.

While in Chapter 4, we identified Mode Switching as a valuable technique for deliberately changing mindset, in this case switching from creating to documenting modes interrupted the worfklow in a negative way. Yet changing to a reflecting mindset when returning to Kaleidoscope's history was useful. It may be valuable to decouple recording history and reflecting on history, so that documentation does not need to interrupt creation, yet reflection can be performed in an interface like Kaleidoscope.

6.4.2 Privacy and Visibility in a Shared Space

Teams developed personal structures for managing collaboration and project state, some relying on tools like Google Drive, and some on Kaleidoscope; many groups used a combination of multiple tools. Kaleidoscope's studio space was particularly beneficial to managing team state and communication, since it combined materials from many different sources along with design discussions:

S79 - Reflection Assignment It [Kaleidoscope] keeps all of our work together and we can always refer to our studio.

S32 - Reflection Assignment We documented every design we had. And we put almost all our design discussion in kaleidoscope. Whenever I need to look for something, I would first check kaleidoscope.

Students who didn't use Kaleidoscope found it more challenging to maintain an awareness of the team's state:

S117 - Midsemester Interview It's hard to measure progress because I think also people do things on their own and then they ported over [to a shared Google Doc] just like I did...So it's hard to see how people are progressing and what they're thinking or where they are in their parts of the project.

However, studio spaces created a tension between individual and team work, or private and public artifacts. Many students felt like they only wanted team members to see polished or completed artifacts, and held personal parts of the process back.

S47 - Midsemester Interview If I think that someone else is going to see it, it often hinders my ability to be as honest about whatever my ideas are or thoughts are.

Since other group members could see them, artifacts in the studio space felt more "permanent" (S47 - Midsemester Interview), and the inability to edit them made them feel "set in stone" (S42 - Midsemester Interview). Kaleidoscope therefore failed to capture evidence of the design process that students felt was in-progress or individual.

These student reactions led to many design discussions about visibility in the tool. The original design had assumed that group members would be comfortable sharing artifacts among themselves, but would desire privacy from peers outside of their group. Yet even within groups, students felt pressure to share only polished work with each other. This undermined the goal of Kaleidoscope as a complete record of process; to make a more effective shared record of progress will require careful sensitivity to the balance between privacy and visibility even among group members.

Concerns about privacy and visibility were also present in the feedback features. Feedback was one of the most successful and well-received features of Kaleidoscope: Students appreciated the parallel viewing of artifacts and feedback, the ability to rapidly see how many people had left feedback on an artifact from the main studio page, and the permanence of discussions, which otherwise could be lost in long chat logs. Kaleidoscope co-located group discussions, feedback from TAs, and feedback from peers with the project history, so that discussion and decision points were easily accessible and contextualized by the artifacts. In cases where groups did not use Kaleidoscope's feedback features, conversations were often buried in chat logs or scattered across document types.

TAs also appreciated being able to see student comments on the artifacts, allowing them insight into the group's process and discussions. Such discussions are often invisible to the teaching staff, as they otherwise take place in private or ephemeral channels such as group notes documents or messaging applications. While TAs chose to provide their own contributions to design discussions and positive feedback on Kaleidoscope, they noted the need for an additional, private channel for more critical feedback, and used our institution's Canvas platform for grades and critical feedback.

The ability to make artifacts public to other classmates for review and feedback helped students learn from each other's process.

> **S50 - End Semester Interview** There were the times that we would do the feedback for people's artifacts ...it not only allowed me to inform people about what our team had done and see if that could potentially help provide any additional help for that team or any additional inspiration, but also our team ourselves got inspiration from what other people had to say on ours...I really did value the time that I got to look at other people's portfolios [and] look at other people's artifacts.

We considered additional features to help students learn from peers' work, such as an Explore feature that would select three random public artifacts within a theme and encourage critique, but did not implement them during the semester.

Visibility makes many types of learning possible – reflecting on complete histories of your own team's process, learning from other students, and providing instructional staff insight into how the students are learning so they can provide better instruction. Yet fear of judgment and criticism reduces how much people are willing to share in a visible space, even knowing the goals of a complete archive. Addressing this tension will require careful design choices. One direction might extend the idea of low-fidelity versioning from Chapter 5, so that team members can see that certain artifacts have been created by other members, but not the details, or creating temporarily private sections of the studio so that individuals can work privately before sharing. However, resolving this tension will also require deeper investigation into the motivational and mindset aspects of why students are unwilling to share certain artifacts and reshaping the social and team structures that cause fear of judgment or criticism.

6.4.3 History Display Creates Sense of Achievement but also Overwhelms

The tile display of artifacts in the studio space allowed students to see their project at a high level. This ability to see artifacts collecting in studio space helped make progress on the project visible. The quantity of work done through the design cycle foregrounded progress as an accomplishment, bringing process to attention rather than just assignment milestones:

S50 - End Semester Interview And I also saw that with Kaleidoscope, seeing at the very beginning, you have your artifacts that you created with your team ...and then you start innovating and as you kind of look back at the check in artifacts or like the feedback that you get from people, you kind of see we're making pretty good progress and we've come a long way from where we started. And that's really cool.

Anon - Critique Session [Kaleidoscope is] used to help document the iteration process, which can often be really empowering for teams.

In contrast, the histories in tools like Google Docs are hidden, and edited or changed materials disappear unless explicitly sought out in the history. Students did not get the same satisfaction in progress or team awareness in tools like Google Docs as in the visible Kaleidoscope history.

S42 - Midsemester Interview I think the fact that you can see an artifact is kind of like a accomplishment...versus a Google Doc or Google Slides just a chunk of documents put together...It's kind of fulfilling and rewarding, you actually came a long way as a team.

Since creative design is an underspecified, complex task where it can be hard to see a path to "success" while deep in the process, making effort and progress visible to students can be an essential part of motivating students and building a sense of self-efficacy and forward progress.

S13 - Reflection Assignment It's nice to be able to scroll through and see our project's journey. Some of these things I've since forgotten so I love the visual aspect of Kaleidoscope that allows me to easily refresh my memory.

But the visual layout was also a challenge, especially initially when the layout was automatically generated. Many students found it messy and overwhelming:

Anon - Critique Session I don't really like the Kaleidoscope interface. I find it to be very messy.

S117 - Midsemester Interview When I first go into Kaleidoscope, I'm greeted by a wall of all my artifacts and that's a little bit overwhelming for me.

Some students preferred Kaleidoscope's Detail pages, where feedback and annotations were co-located with the artifacts. Instead of using Kaleidoscope for high-level views, one team copied links to Kaleidoscope artifacts into a Google Doc, as they found that easier to manage and search.

A common request during the early part of the semester was for more organization abilities in Kaleidoscope, for example a folder structure, to sort artifacts into conceptual groups and hide artifacts that were deemed no longer relevant. The introduction of flexible and saveable layouts partially addressed this need, but especially for students who characterized themselves as particularly neat or organization-focused, the lack of structure drove them away from Kaleidoscope. In order to gain the value of seeing the entire project at once, they also would need an underlying structure to hide or subselect artifacts.

6.4.4 Personalization and Aesthetics

The initial design of Kaleidoscope relied on automatic layouts, and had little space for personalization, despite the original design goal of curating the creative space. We intended to introduce flexible layouts later on in the semester, and this feature turned out to be commonly requested by students to support customization and organization.

Anon - Critique Session [I want to] position artifacts around and create a board/project of what you're currently working on. Then have flexibility to see an overview of your project and where it's going.

Anon - Critique Session [I want the] ability to drag/rearrange things so you can put the things that are more important on top, and maybe have the ability to resize.

The introduction of flexible layouts helped support active ideation techniques such as grouping concepts visually, as well as create a stronger sense of ownership over the studio space.

S47 - End Semester Interview [It's] fun to have a horizontal playground and not just like line-by-line, how it is in like a Word document or Google Doc.

At the end of the semester, students used the flexible layouts to create public-facing layouts for a final showcase.

S50 - End Semester Interview Going around and seeing everybody's portfolio was really, really cool, and seeing how everybody was able to customize it...we saw one team that kind of like a timeline, which we thought was really cool...a lot of people did a lot of different, really unique things with it that I hadn't really thought of doing beforehand.

Students wanted even more customization and personalization capability; for example to add purely aesthetic elements to portfolios, or to sketch on top of artifact layouts in the

Design Principle	**Kaleidoscope Features**	**Successes**	**Challenges**
Collaboration	studio space; feedback	central repository of team data; ability to collect multi-source artifacts; sharing peer feedback	lack of live collaboration; discomfort with making artifacts public to team; discomfort with permanence of artifacts
Seeing the Big Picture	tile display of artifacts; setting artifacts to public	visual display enables high-level views; peer learning about process	visual display can be messy, overwhelming, disorganized
Metacognition	archive of process history	support post-hoc reflection; understand process through documentation	tension between modes of ’creation’ and ’documentation’ reduces storing of history
Curating Creative Space	flexible layouts	customization of views; active interaction with history data	lack of personalization; lack of aesthetic control
Making Progress Visible	tile display of artifacts; studio space	see progress through artifact accumulation; see evidence of teamwork; see idea development	bugs and system limitations created frustration

Table 6.1: Summary of qualitative insights, organized by the design principles of Kaleidoscope, to inform future design process documentation tools for education.

studio space. These capabilities would not only support practical techniques like sketching during team meetings, but also create more of a sense of personal ownership over the studio.

Introducing such personalization and organization earlier in the semester might have also helped manage feelings of overwhelm associated with the tile view, allowing students to curate which elements were visible or hidden in particular views from the beginning.

6.5 Discussion

6.5.1 Designing Remote Studio Tools

Kaleidoscope was designed as a standalone platform to explore specific types of interactions, including co-locating feedback permanently with artifacts, visual foraging and views of past artifacts, and integration of documentation tools into assignment submission, portfolio creation, and group process. While some individual features of the platform can be found in existing tools, which are more stable and developed than a research prototype, Kaleidoscope brings these capabilities together to support novel interactions. For example, the brainstorming tool Miro allows flexible layouts and repositioning of text, images, and links, but does not provide detailed views of those artifacts to contain annotations, discussion, or other associations. Google Docs and Figma provide version histories inside the tools, but users cannot view those histories in a high-level, visual way to see the evolution of process.

Bringing these capabilities together opens the door for more active features around metacognition and revealing process. For example, access to all artifacts might allow abstracted visualizations of process histories, revealing when certain tools or mediums are more commonly used in design cycles, or allowing groups to compare their design processes with each other. In our classroom deployment we encouraged reflection through assignments external to the tool, but moments for reflection could be built into the tool as prompts or check-ins triggered by analysis of project histories.

As Kaleidoscope was developed iteratively during the deployment, it also allowed us to reveal key tensions and expectations between how we originally designed the tool and what students needed in their process. For example, the student desire for editing past artifacts was made clear because of the inability to edit at the beginning, revealing a necessity to co-locate creation and documentation capabilities.

A research prototype like Kaleidoscope requires a large amount of technical labor to build and support during a semester, but the lessons learned from Kaleidoscope can be extended beyond Kaleidoscope itself, so that future educators need not implement and support a custom tool. Process-focused histories could be incorporated into other design tools, used to inform larger products, or implemented manually by educators in an ad-hoc style. For example, if a course wished to quickly integrate a shared studio space to view project history, students could be encouraged to upload all their artifacts to a shared "infinite canvas" board as they worked, using a widely available tool like Miro. Check-ins might be approximated by sharing a template that can be copied to the group's board, and filled in with copies of artifacts. While such ad-hoc approaches will not have the full range of capabilities that Kaleidoscope explores, lightweight applications of the ideas explored here might be beneficial in rapidly importing these insights into HCI classrooms.

6.5.2 Initial Perceptions and Incentives

As a research tool under active development during the course, Kaleidoscope was significantly less stable and polished than tools students are used to working with. The research team kept a tight response cycle on addressing bugs, listening to student feedback, and incorporating new features, however Kaleidoscope had some severe bugs during its deployment, including a case where feedback was overwritten in the database after being submitted. While this was rapidly fixed, it undermined student trust in the system. Some students cited specific bugs or problems with the visual layout as reasons they used other tools rather than Kaleidoscope.

Anon - **Critique Session** There were moments where my project team and I thought about just dropping random thoughts/artifacts into our studio that made me realize how great [Kaleidoscope] could be as a collaborative tool. We never ended up doing so because it was just easier to do on Google Docs even if it was messier.

Beyond practical issues with the system, a second challenge arose with student perceptions of the role of the tool. Check-ins were developed as a way to make assignment submissions easier – if all the material is already in Kaleidoscope, picking specific artifacts to submit should be easier than exporting materials to assemble in another tool and then uploading that result to Canvas, a course management system. Moreover, check-ins on Kaleidoscope support easy sharing of artifacts for feedback and peer-learning, since artifacts in check-ins can be grouped together and made public by the instructors. However, the use of check-ins for assignments fostered an early perception among students that Kaleidoscope was a *submission* platform, rather than a tool for design work. Some student groups began to use Kaleidoscope only for submissions, importing artifacts only at the time they needed to submit a check-in.

The combination of bugs and hard-to-use interface aspects, along with the perception of Kaleidoscope as only a submission system, discouraged some students from interacting with it, even after the bugs and interface issues were fixed or improved. Once the early perceptions were established, they were hard to change.

S126 - **End Semester Interview** I think those initial weeks really colored a lot of our perceptions of what Kaleidoscope was possible of, and because we had already found alternative ways to work by the time Kaleidoscope start addressing those issues, it was just harder to then switch back.

Portfolios ended up being a highly successful feature at the end of the semester, where the motivation for having all artifacts and project history centrally available was clear and aligned with both students' intrinsic motivations for showcasing their work and course assessments. UID was many students' first exposure to design; the first time through the design process, students did not realize or appreciate the value of an early sketch or idea until they wanted to include it in an assignment or final presentation.

S18 - **Reflection Assignment** If we had to change the way we record information, I would put more materials into Kaleidoscope initially.

While this is a common and important learning experience, we may be able to encourage more early use of Kaleidoscope for recording all artifacts by reducing the perception of the system as a submission system, allowing artifacts to have multiple privacy settings, and incorporating more editing capabilities.

In introducing a research tool into a course setting, early student interactions should be carefully aligned with desired perceptions and uses of the tool. In our case, aligning with intrinsic motivations and authentic tool use should have preceded any assignment submissions with the platform.

6.5.3 Effects of Context on Creative Process

One final challenge that arose in the course setting is the different incentives around coursework and personal or professional work. Students are constantly under pressure to complete the next assignment or take the next class, with little institutional support for reflection or returning to old work. Some of the design principles we hoped to support with Kaleidoscope are drawn from literature around professional designers, and may have been less appropriate for the course setting. For example, one student expressed a radically different mindset around maintaining history between personal and course projects:

> **S117 - Midsemester Interview** For my personal projects [and] research I'm a little bit more cognizant of keeping things organized... so that if I'm stuck or if I don't know where to go in my research, I can just go back into those archives and try to spark something or remember what I did. But for group projects because it's more of like getting them [done] quick, and it sometimes may not apply to that my own interests, I take less care to keep those things organized.

Amabile's extensive research on extrinsic and intrinsic motivation in creative settings has showed a dampening effect of many forms of extrinsic motivation on creativity (Amabile 2018). The extrinsic motivators present in the course structures, including assignment grades and deadline, undermined attempts to prioritize creative process in the classroom. As part of the Kaleidoscope deployment, UID offered extra credit for reflective assignments, and encouraged documentation through the structure of assignments, however the greater environment of the institution and course expectations also affects students' mindsets and educational expectations. Tools alone cannot change behavior without support from the broader course structure and environment.

6.6 Limitations and Future Work

The development and deployment of Kaleidoscope in a real classroom context for four months allowed us to collect real-world user data, and learn from student needs as we iteratively designed the tool. However, the time pressures of the semester and the requirement to support particular course needs also limited the type of features we could release. Future work could explore how documentation tools like Kaleidoscope can more explicitly support reflection on process, perhaps through visualizations of group interactions and artifact creation, or prompts for specific types of reflection.

Kaleidoscope drew from the strengths of existing tools by interfacing with Figma, GitHub, and YouTube, but also competed with these tools for student time, effort, and attention. Future work might productively consider how to lower the amount of effort needed to document work, either by further integration with existing tools, or pursuing documentation layers within or on top of other tools, rather than as separate platforms.

While Kaleidoscope was deployed during a fully remote semester, it may be fruitful to explore how to document and reveal process during hybrid or in-person courses, either integrating a tool like Kaleidoscope into the in-person activities, or pursuing a hybrid-specific tool design.

Some students felt like reflecting on completed projects was an inappropriate use of their time, or felt like it had little value in the expectations they had for their education. There are a great deal of further questions to be asked regarding when it is appropriate to introduce discussions of meta-concepts around process to students, and how to align the incentive structures of the educational context to value reflection on past work rather than pushing students with constant new deadlines. Tool design can only go so far in the educational context; assessments, motivation, and learning goals must all be aligned to support desired behaviors.

6.7 Conclusion

In this chapter, we presented Kaleidoscope, a documentation system for design process. We deployed Kaleidoscope in an upper-level undergraduate user interface design course during a remote semester. Kaleidoscope displays artifacts generated during the design process in a virtual studio space, providing a shared repository for project groups to collect their work, document and annotate their progress, and receive feedback from peers and instructors. We report data from a variety of surveys, critique sessions, discussions, and interviews with students and course staff to understand how a documentation tool like Kaleidoscope can support collaboration, metacognition, making progress visible, high-level views of project histories, and personalization of a remote studio environment. We discuss key successes and challenges both students and researchers encountered with this tool, and how these insights might support other HCI educators in building tools which support students in understanding the many phases and dimensions of design.

Kaleidoscope is a process-sensitive creativity support tool, informed by the values and strategies demonstrated by the documentation strategies of practitioners across diverse domains of creativity. The design of Kaleidoscope focused on the experience of working, including motivation, self-efficacy, and strategies for performing design tasks, in addition to creating a useful repository of project data to support final report creation, post-hoc reflection, and assignment completion. This framing encouraged the development of companion assignments, such as the midterm reflection on creative process, and suggests future work to make process a tangible material. We envision the lessons learned from Kaleidoscope to support a future of design tools which holistically understand the design process wherever it happens, support student learning, sharing, and metacognition, and makes creative process visible for discussion, critique, and intentional modification.

Chapter 7

Conclusion

Computers are increasingly at the heart of modern work, whether in engineering, art, or design. As creative work and software systems overlap, creative process is becoming in large part computational process, using tools that draw their capabilities, values, and assumptions about ways of working from technological norms. Yet in creative process, there are values and behaviors that not only do not align with these expectations, but in some cases directly oppose them.

In this dissertation, I have presented four projects that explore how we might use an explicit focus on the values of process as a lens for developing computational creativity support tools that support the ways that people perform creative work. We have addressed three main research questions:

R1: What process values are present in existing creative practices?

In Chapter 3, we saw how prior approaches to literary style which assumed that precise categorizations of works into style groups were misaligned with the way writers and readers understood style. While effective for analytical tasks such as plagiarism detection, categorical approaches were reductive and uninspiring in creative contexts. We identified the tacit nature of style for most writers and readers, embracing the importance of interpretation and imprecision to allow room for personal meaning-making and the differences in how individuals experience literary style.

In Chapter 4, we interviewed a wide variety of professional creative practitioners, across multiple creative domains. We discussed values embodied in their process that seemed at odds to common expectations for tool use, including the usefulness of forgetting information instead of capturing it, deliberately introducing extra labor into a task that to enhance motivation and a sense of value, and the benefits of keeping failure and effort visible to improve self-efficacy and motivation.

In Chapter 5, we investigated version control systems, identifying key values in how version information is used in creative process, including the importance of adaptability over exact replication, reduced emphasis on the value of precision, and increased value on the future potential of each version as an active material in the creative process rather than as a possible final output.

> **R2:** How do creative practitioners instantiate these values in specific strategies and behaviors? How do tools, computational and otherwise, support or inhibit these strategies?

In Chapter 3, we saw readers and writers use comparisons between works to explain or converse about style. Prior computational interfaces for style presented analytical approaches to specific textual features, rather than addressing the holistic experience of style or encouraging interpretation.

In Chapter 4, we identified four strategies instantiated by multiple creative practitioners across domains to structure motivation and creative process: strategic forgetting, where practitioners choose not to record data in order to leverage the mind's natural forgetfulness to break fixation or filter ideas; mode switching, where practitioners deliberately move between tools or mediums with different affordances or levels of friction to change their mindsets about a task; embodying process, where practitioners create concrete records of intermediate efforts rather than only final outputs to enhance motivation and provide tools for reflection; and aestheticizing, where practitioners engage in extra labor to make an artifact beautiful in order to increase their own motivation for the task or future tasks.

In Chapter 5, we looked specifically at strategies used with version histories, identifying recreation and deconstruction as alternative techniques to reversion for returning to an earlier history state; palette interactions as a way to use versions in parallel as a creative material; the creation of low-fidelity records as a way to support future variation; and maintaining records across long lifetimes to enable influences between projects and incubation periods.

> **R3:** How can creativity support tool designers leverage process values and techniques to create computational tools that support process as well as output?

In Chapter 3, we designed a system for interacting with literary style via ambiguous visualizations, based on a neural net model of style comparisons. This tool prioritized interpretation and flexibility in individual experience, while providing a shared representation of style that could be used to communicate with others for discussion, with the computer for recommendations, and with oneself through reflections on the visualization. In the user study, we found that this tool encouraged unusual interactions with style as material and reflection about the meaning of style.

In Chapter 6, we presented Kaleidoscope, a documentation system for collecting multimedia artifacts across the lifetime of a collaborative design project. The design of Kaleidoscope drew on the values and strategies explored in Chapters 4 and 5 to support the design process, focusing on motivation, self-efficacy, and documentation strategies. Kaleidoscope was deployed in an undergraduate HCI course, where the tool helped students reflect on their own design process and see their work and effort as learning accomplishments.

These research questions come together in the concept of *process-sensitive creativity support tools*, which calls for a focus on the act of doing creative work, rather than a primary focus on creative output. In focusing on the human experience of creative process, we can expand our creative capabilities, gain new perspectives on our materials, and foreground human wellbeing and lifelong flourishing of creative expression.

7.1 Limitations

As Teresa Amabile notes, creative process is still incompletely understood (Amabile 2018). Without a complete model for the cognitive, social, and environmental underpinnings of creativity, this work relies on empirical studies of creative process to identify patterns of effective behaviors in creative work. Connecting cognitive science theories to these empirical observations can help us contextualize and understand the patterns we see, however the strategies and behaviors examined in this dissertation remain only a small piece of the bigger question of creative process. Future research in cognitive science, psychology, and empirical studies of creativity may help us develop a complete theory of creativity in the future, but we are likely still far off from that possibility.

While Chapters 4 and 5 address a diverse range of creative domains, this dissertation only engages with a small fraction of the many contexts of creative work. Even within specific domains, or the workflows of individual interview participants, the strategies and values presented here are by no means a comprehensive or complete analysis of all the aspects of process. There are many more strategies, behaviors, and values to be studied as we continue to expand our understanding of creativity, motivation, and human fulfillment. Individuals have unique techniques, perspectives, and experiences, which can enrich our understanding of creativity.

While this dissertation primarily discusses designing tools which seek to support creative process, tools also reciprocally shape process. Tool design should not only seek to address existing behaviors or values, but provide opportunities for growth and change. The interactive style tool, in responding to existing behaviors around literary style also inspired new ways of writing, such as seeking visually beautiful or strange styles as a creative exercise. Practitioners constantly adapt to new tools and appropriate available features in unexpected ways; process-sensitive tools should also seek to be open to these creative appropriations.

Frich et al. note that one of the challenges of creativity support tool research generally is the prevalence of novel tools that introduce exciting features or designs, but never proceed beyond prototypes or unsupported demos (Frich, MacDonald Vermeulen, et al. 2019), yet professional practice requires masterful and long term use of tools. The interactive style tool from Chapter 3 is one of these prototypes; tested in the lab, but unavailable for long term public use. Kaleidoscope was used in a 100+ person class at the University of California, Berkeley during an entire semester, and remains available for use at the time of this writing, however it will likely no longer be supported in the near future, as the development team of students moves on. Future work on process-sensitive tools may find benefits in integrating with widely available and accepted creativity support tools to study the effects of process reflection and strategies in long term, naturalistic use. I see designing novel systems and adapting widely available systems as complementary approaches: the first as a tool for provocation and re-imagining possibilities, and the second as a practical lever for having widespread impact.

7.2 Future Work

The framing of process-sensitive tools encourages a focus on effective and resilient ways of working. It recognizes the values that drive successful creative work can be unique and unexpected. Future work in this area can deepen our understanding of human creativity across engineering and artistic domains, and guide future software tools for supporting process in professional work, teaching process to novices and students, and reflecting and improving personal process throughout the many stages of a creative lifetime.

Here I suggest future research directions that integrate creativity theory construction with novel software design to shape technology, education, and communities.

7.2.1 Designing for Process in Novel Workflows

As we develop intelligent agents, novel digital and hybrid materials, and cutting-edge hardware, our focus is often on improved productivity metrics and novel final outputs; for example, how can we use a new digital fabrication tool to speed up fabrication and reduce waste? How can a better neural network create more naturalistic text or more photo-realistic images? These are important questions, and drive solutions to difficult problems.

The process-focused lens explored in this dissertation encourages us to ask a second set of questions as well. For example, how might a new digital fabrication tool respond to unique materials, or how a neural net for text generation might increase a writer's motivation, satisfaction, and fulfillment in their creative work? Together, these two lenses encourage us to continue improving both technological and human capabilities in synchrony.

New tools also open up possibilities for exploring new dynamics of creative process. While this dissertation has mostly addressed individual creativity, creative work is often highly collaborative. As we develop more capable AI agents, we must ask how they contribute to creative process. Is an AI agent a collaborator? Is it more like a new tool for supporting individual aspects of process, or a discrete team member? Are there new process values or strategies that can help us expand our creativity in partnership with AI tools? Recent research on collaborative teams, especially in design, have helped us understand how groups coordinate complex creative work, and explored such computational team members. Future work with a focus on process values may open up new considerations for the role of AI in design and other creative domains.

Developing and studying emerging tools will help us understand how creative practitioners are engaging with new materials and systems. At the same time, comparisons with established tools and workflows will help us understand when existing methods might be transferred into new contexts or when new methods can be developed, and how old and new tools are integrated in emerging work contexts. Co-design with expert practitioners may provide a fruitful method for these explorations. For example, to understand how digital tools might fit fluidly into analog and handed practices of making, we might join an instrument maker to develop novel software for CNC tools to support flexible iteration with templates, molds, and materials that current rigid workflows and version control tools make impractical.

7.2.2 Promoting Process-Aware Education

Teaching creativity can be challenging, as many of the structures of our educational system stymie creative process through the imposition of extrinsic motivators such as quick deadlines, grading singular outputs, and exams (Rivard et al. 2012). When we want to teach creative process, whether in a course focused on that topic such as design, or in a course that includes pieces of creative process among other content, such as a programming course, we must align course structures, incentives, and evaluations to value process as a learning goal, rather than output alone. But how can we assess process, either to evaluate it or provide effective feedback?

In computer science courses, we might develop process-sensitive programming and feedback tools to make coding, debugging, and design processes visible for critique and feedback. Visualizations might show how a student is approaching a problem; an AI agent might suggest alternative workflows when a student is stuck on a debugging issue. Rather than offering solutions to the problem, these tools focus on strategies a student might try. Such records of process may allow the creation of new types of assignments, with evaluation metrics based on self-reflection on problem solving processes, or explorations of different options. I hypothesize that early introductions of reflective skills and explicit representations of process will allow students to develop effective metacognitive skills and scaffold them towards expert ways of working. To test that hypothesis, we must also ask when and how students construct understanding of their own workflows and creative processes. What are the differences between how novices and experts conceptualize, discuss, and modify their own processes?

Through interviews, course observations, analysis of educational materials, and design probes across computer science and design courses, we can understand when and how to teach critical approaches to process. Such tools may help students learn specific aspects process earlier and more easily, and help nurture mindsets that value effort, learning, and pluralistic approaches to problem solving that make students grow into effective and flexible professionals.

Formal courses are not the only loci of learning. As we consider the values we want to enact in our classrooms, we can also consider the norms and values in our creative communities. Tools embody and afford certain processes, and therefore certain values. What values do open-source software, makerspaces, and craft communities hold in their creative process? How can careful tool design support, broaden, and transfer these values? Exploring successes and complexities within and across these domains will let us move towards a process-centric understanding of the role of tools as agents and mediators of values, and use novel tool design to encourage positive norms and reshape negative ones. For example, we might design tools that provide process visibility in makerspaces, to scaffold experimentation, resilience to failure, mentorship, and long-term engagement among novice makers.

7.3 Summary

Through contextual studies of creativity, this dissertation has presented insights into creative process across domains, both in the underlying principles that practitioners value in their work, and in the specific strategies and behaviors they use to structure their work and instantiate these values. I have highlighted key value inversions, where the principles of creative practice are at odds with the values embedded in common computational tools, as leverage points for designing process-sensitive tools. Finally, I have developed and demonstrated two process-sensitive creativity support tools that express key values in creative process, for literary style analysis and for documenting design projects. I envision a future where software tools embody and engage the messy, complicated, and deeply human aspects of creative work, propelling us to greater success, new possibilities, and lifelong engagement with creativity.

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Appendix A

Kaleidoscope Data Collection

A.1 Mid-semester semi-structured interviews

As semi-structured interviews, the questions evolved within and between interviews; a representative selection of guiding questions are below.

- How do you explore / track different ideas?
- What are your current tools in your design workflow?
- When do you feel most creative?
- Describe a time you revisited an earlier decision.
- Walk me through how you use Kaleidoscope.
- What types of documentation feel successful or unsuccessful? Useful?
- How has your experience of the system evolved over time?
- How has your design work or process evolved over time?

A.2 Mid-semester course survey

The midsemester course survey contained questions specific to many parts of the course. The subset of questions which contained responses relevant to Kaleidoscope were:

- What elements of the course should be removed/changed to help support you?
- We have worked to adapt many elements of the course to online/remote learning. What is working? Not working? What feedback do you have on the online experience specifically?
- Free form topics and feedback.

A.3 Design reflection extra credit assignment

The extra credit assignment instructions were as follows:

At this point in the semester, you have worked on several design projects, and are deep into your final team project. This is a great time to step back and think about the larger picture of what you have learned about design, design process, and your own experiences. This assignment is a chance to explore some of these ideas by reflecting on the work you have done.

Goals:

- Describe and discuss your own creative process
- Make explicit subconscious behaviors and themes that affect your process
- Reflect on potential improvements to your process for future projects
- Consider how tools can support your learning, creativity, and reflections

Extra credit will be given as long as you answer the questions thoughtfully; there are no "correct" or "incorrect" responses.

The questions presented in the survey were:

- Look back at the initial brainstorm you did for this project. How satisfied are you at the breadth of ideas and the directions you thought of? If you could go back and re-do your brainstorm, what would you change about how you approached it?
- Find at least two of your early sketches. What do you notice about them now that you didn't when you made them? (e.g. techniques, details, ideas that were or were not captured or re-used...) If you can't find any sketches, why not? Share links to the sketches you discussed.
- Find a decision point where your team chose a specific direction. Why was the decision made? Do you think it was a good decision, or would you change it with the information you have now? If you cannot remember why it was made, what do you wish you had captured?
- When answering the above questions, how easy or hard was it to find and understand your project's history? Where did you have to look to find it? If you were to change how you recorded information in the future, what would you do?
- What was the most fun part of the design process so far? What was the most difficult part?
- What part of the design process do you hope to improve most at?
- Have you noticed any underlying themes in your work? e.g. what tools do you like to use, or topics you like to design around? Were you aware of these themes before working on this project?
- How well do you feel your process is supported by your team's choice of tools? How well do these tools and documents support your reflections in this survey?
- For the rest of the semester or in your next design project, what new behaviors or changes do you want to keep in mind based on these reflections?

A.4 Kaleidoscope critique session

Students were given 5 minutes to individually add thoughts in a shared Google Doc, in response to the following questions:

- What was your worst experience with Kaleidoscope?
- When was using Kaleidoscope unpleasant and why?
- What do you think about the check-in feature?
- What was one time you tried to do something on Kaleidoscope and it didn't work as expected?
- What is one thing you wish Kaleidoscope could do?
- What do you think Kaleidoscope is for?
- What tool would you rather use than Kaleidoscope?
- Other comments?

Next, groups took 5 minutes to read others' comments and add any followups. The sessions concluded with 15 minutes of open discussion moderated by a single researcher.

A.5 Post-semester semi-structured interviews

Interviews began by discussing general reflections on the course, before transitioning to specific questions about their usage of Kaleidoscope. As semi-structured interviews, the questions evolved within and between interviews; a representative selection of guiding questions are below.

- What is the most important thing you learned in 160?
- If you reflect on your time in college doing design work, have you noticed anything about your own skills or process changing? Has how you approach problems or manage your work changed?
- What tools did you use for design and documentation work this semester?
- How did your group collaborate?
- Walk us through your group's studio space.
- Did you use the Portfolio feature? How?
- Did you use the rearrangeable layouts? How?
- Can you show us any particularly interesting moments in your process?
- What are you going to want to keep from this class?
- Do you have a personal portfolio? What is your workflow or documentation style for personal projects?