COLLABORATIVE MULTISCALE DESIGN CURATION:
SUPPORTING CREATIVITY IN PROJECT-BASED LEARNING

A Dissertation

by

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ABSTRACT

Project-based learning engages students in learning through making to help them develop contextualized, real-world skills, and exercise their creativity. At the same time, its creative, open-ended, and iterative nature make it difficult for students to comprehend how their project activities contribute to a connected design process. Incorporating practice from fields in art, we identify the process of how designers collect, organize, annotate, archive, and communicate about their process artifacts as *design curation*. This research investigates supporting project-based learning through a new medium of design curation, which is free-form and multiscale, as opposed to more commonly used linear forms, such as workbooks and project reports.

In free-form web curation, people create new conceptual and spatial contexts to discover and interpret relationships through visual thinking while assembling elements to form connected exhibitions. We combine this with multiscale design, which emphasizes differences of size and proportion, to create visual structures, relationships, and hierarchies. Our understanding of multiscale design practices comes from observations of architecture students, who juxtapose and transition between scales to communicate their design processes rationales. We investigate the multiscale design curation prototype LiveMâché, enabling student teams to collect and assemble elements of their design work collaboratively. Through a series of situated classroom studies, we show how this new medium transforms how students and instructors think about, organize, and present creative project work.

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1. INTRODUCTION

Project-based learning helps students develop contextualized, real-world skills [9]. However, the creative, open-ended, and iterative nature make it difficult for students to learn how their project activities contribute to a connected design process. Among the problems which hinder novice designers are fixation, depth-first thinking, and an unwillingness to discard concepts to search for alternatives [10]. Team collaboration compounds these difficulties with added issues of communication and organization [11]. This research investigates supporting team project-based learning through a new medium for organizing project work, which is highly visual and free-form, as opposed to more commonly used linear forms such as workbooks and project reports.

To support creativity and other work in project-based learning, we adopt *curation*, as signifier and signified, from practice in fields of art. Curation means the conceptualization and creation of a context—conceptually motivated and spatially organized—for purposes of exhibition [12]. Curation involves collecting, organizing (assembling), writing, sketching, archiving, and communicating about a set of artifacts. Since these are exactly the activities that designers perform throughout their design processes; we call what they do, *design curation*. We use this definition to identify existing methods of design curation such as how designers collect ideas in workbooks [1, 13], assemble inspiration in mood boards [7], detail their design process in annotated portfolios [14], and author visual exhibitions in pictorials [15].

This research investigates supporting project-based learning through contextualized studies of a new medium for design curation that combines free-form web curation and multiscale design. Free-form web curation is a prior medium for creating new conceptual and spatial contexts, in which people discover and interpret relationships through visual thinking, while composing content elements as a connected exhibition [16]. We extend the spatial contexts afforded by free-form curation by emphasizing multiscale design. *Multiscale design* uses differences of size and proportion to create visual structures, relationships, and hierarchies. Our understanding of multiscale design practice comes from observations of architecture students, who juxtapose and transition between scales as integral parts of their design processes (See Chapter 3.).

We combine free-form curation and multiscale design with new support for collaboration. In collaboration, participants must actively construct a shared context of meaning [17]. To create a shared context, participants being together artifacts and then work to debate and resolve their meaning. As part of these processes, participants need to maintain shared awareness. Dourish et al. describe shared awareness as "an understanding of the activities of others, which provides a context for your own activity" [18]. Just as we motivate free-form and multiscale spatial contexts to support ideation, so we motivate spatial organization to support shared contexts of collaboration and awareness. We introduce this medium, which combines curation and collaboration, as collaborative multiscale design curation.

In this chapter, we give an overview of sensitizing concepts fundamental to this line of inquiry. We synthesize these concepts as we craft a description of collaborative multiscale design curation. Next, we outline our main research methods, namely developing prototypes and gathering mixed-methods situated data to investigate transformational effects in real-world classrooms. And finally, we summarize our research contributions, which impact student creativity and thinking in project-based learning.

1.1 Sensitizing Concepts

We present a set of sensitizing concepts as lenses to understand and relate how multiscale design curation interfaces with different human cognitive processes. We describe concepts of visual thinking, human memory, and creative cognition that motivate this research. We then introduce concepts of curation that frame how we understand and support design project processes. Lastly, we describe some of the issues facing systems that attempt to support collaborative work.

1.1.1 Visual Thinking

Visual thinking begins with the perception of shape, and functions as the basis for active exploration, grasping essentials, abstraction, analysis and synthesis, comparison, problem-solving, combining, and contextualizing [19]. Processes of creating and experiencing assemblages stimulate *visual thinking*, in which perception, recognition, and reflection serve as the means for discovering and illustrating new meanings [19]. Psychologist Barbara Tversky shows how both abstract and concrete forms such as lines, arrows, maps and diagrams function as visual thinking aids [20]. Gestalt psychologists recognize pattern identification —through principles such as proximity, color, size, orientation, region, symmetry, continuity, and closure—as the fundamental ways to create visual organizations [21].

Visual thinking and exhibition have emerged as an essential method for disseminating research on human-computer interaction [15]. The *pictorial*, a recently developed ACM publication format, elevates the use images as the primary material for creating and articulating knowledge about interactivity [4].

Connect visual thinking to spatial thinking, for one way we understand spatial information is through vision. In spatial thinking, mental representations are used to encode the geographic properties of objects in the world [22]. Spatial thinking is not limited to physical geographies but can also be applied to abstract or imagined spaces. Often these spaces are understood through externalized visuospatial methods such as diagrams or maps [23] Ragan et al. investigated how different configurations of digital spaces support spatial thinking and affect cognitive abilities [24]. They argue that digital environments must provide meaningful spatial cues and groupings to help people form spatial encoding.

1.1.2 Working Memory Capacity

As the number of elements accumulates during curation, the harder it becomes to discover relationships among them. Humans possess limited working memory, which is the amount of information held in mind at once [25]. Psychologists find working memory capacity is 3 to 5 units of information [26]. These units could be a single datum, such as a word, or a group, such as a phrase. One mental process for increasing the working memory is visual chunking, which involves grouping elements visually to condense them into a single unit of meaning [27].

1.1.3 Creative Cognition

Creativity is the use of inspiration or imagination to produce original ideas or expressions. Ideation refers to the specific act of generating and developing these ideas. And although some specifics of creativity differ across domains, research has identified commonalities among how human cognition develops creative ideas and makes discoveries [28]. We approach creativity through the lens of creative cognition, which sees creativity as a family of multiple interconnected cognitive processes, e.g., visual synthesis, conceptual combination, and restructuring. [29, 30, 31].

Visual thinking plays a key role in many creative processes such as in visual synthesis, in which visual discoveries occur through mental processes of perception, pattern recognition, and extrapolation [32]. In processes of conceptual combination, two or more separate ideas are joined together, either in harmony or opposition, to form a higher-order concept [33]. Through the process of combination, any number of new ideas can emerge from existing ones. The combination can occur through different cognitive means. One such way is *relational linking*, in which concepts join into a complementary relationship. In *property interpretation*, a property of one idea applies to another. In the process of *hybridization*, component concepts cross-breed together.

Processes of conceptual combination are similar to that of developing emergent shapes in visual representations. Emergent shapes are new visual structures or forms which result from perceiving and interacting with visual representations [34]. Exploring emergent shapes is essential when performing ideation through drawing or sketching.

In cognitive restructuring, an idea transforms from its initial interpretation into something new [35]. Restructuring involves decomposing a concept into its components and then reassembling them in new ways. Externalization activities, such as sketching, writing, or rearranging, increases one's ability to restructure.

Shah et al. developed the pioneering C-Sketch (collaborative sketch) method for avoiding fixation and conformity effects [36]. Design team members first sketch ideas individually; then, the team exchanges sketches. Waiting to share their sketches prevents the ideas from others from limiting a participants' exploration of solutions. Mumford et al. show how groups that form common mental models are more likely to generate appropriate alternate solutions [37]. Divergence among individuals' mental models impedes mutual understanding. In time-constrained design tasks, such as in an architecture firm, teams must find a balance between individual and collaborative ideation processes. As we investigate collaborative design curation processes, we look at how they support individual and collaborative processes.

1.1.4 Curation

We situate the activities of collecting, organizing, archiving, and presenting design artifacts amidst art curation practices. In art, *curation* has become the conceptualization and creation of a context [12]. Curators find, collect, interpret, and visually arrange works in an exhibition space, to stimulate active engagement, give form to visual thinking, and produce cultural meaning.

Curation has emerged as a distinct framework of interaction and mode of discourse across disciplines. Curator Christiane Paul observes that curation requires a "Parallel, distributed, living information space, open to artistic inference—a space of exchange and presentation that is transparent and flexible" [38]. Curation has evolved from passively constructing a collection, to actively specifying and assembling new artworks for a particular exhibition; curators, such as Lucy Lippard and Harald Szeemann, adopt the role of the artist in addition to curator [12]. In recent post-modernist exhibitions, artists are invited to act as curators, helping co-create exhibitions [39]. The distinction between curator and artist becomes blurred.

Curation is not restricted to professional curators. Curation has also become a common activity for helping people make sense of the overwhelming amount of information and content available today [40] A plethora of curation sites have emerged, allowing users to tell stories through how the content they gather and how they assemble it. Others can come and rewrite the stories for new purposes in cycles of curation and recuration [41]. Journalists curate social media stories as part of their research [42]. Users on curation platforms like Pinterest engage in everyday curation collecting recipes, party planning ideas, home decorating inspirations, and much more [43]. People curate music playlists as forms of self-discovery [44].

As we talk about curation, we distinguish between the medium of the whole and the material of the curated elements. The *material of elements* defines the properties of the content that can be collected, and the *medium of assemblage* is the form in which elements can be joined [45].

1.1.5 Readymade and Self-made Artifacts

We associate curation with the notions of readymade and self-made artifacts. Marcel Duchamp is credited with developing the conceptual art construct of *readymade*: an everyday object, which is chosen and exhibited in a new context, with a new name, and thus has its meaning and significance transformed[46]. Readymade objects are found in the world and recontextualized through the act of curation. In contrast, we call artifacts that people create to be curated, *self-made*.

Dada [46] and Surrealism [47] launched the wave of artwork made by appropriating and assembling found objects. Creative curators fasten together readymade and self-made artifacts, in what we identify as processes of *assemblage*. Assemblage is a process of putting elements together, which visually and conceptually showcases the duality and tension between each element's original and resulting contexts [48]. This process of assembling an artifact becomes transformed, beyond an atomized thing or element of a previous whole, into a new element of curation. Creating and experiencing assemblages stimulate *visual thinking*: perception, recognition, and reflection become intertwined, in creative acts of forming and illustrating new meanings [19].

1.1.6 Free-form Web Curation

Manovich describes new media as having the principles of modularity, variability, and cultural transcoding [49]. They treat units of meaning as discrete and modular "media elements." These elements are variable in how they can be related to one another and how they assemble into larger scale compound objects. Transcoding is the process of converting an object into a new form of representation. In new media, this occurs as media elements simultaneously exist in both computational forms and cultural forms. We connect Manovich's principles to aspects of curation that we introduced above. The modularity of elements links to the readymade. The variability of arrangement is similar to the act of assemblage. And processes of transcoding are similar to the process of re-contextualization.

Free-form web curation was conceptualized as a form of new media—designed to support users in ideation by creating new conceptual, spatial contexts—in which they compose diverse content, as elements, to form a connected whole [16]. Through the flexible use of space, users discover and interpret relationships between elements using visual thinking [19], cognitive restructuring [35] and conceptual combination [33]. In *free-form web curation*, the medium of assemblage is a near-infinite 2.5D canvas on which users can freely arrange elements. The material of elements includes readymade media clippings, which come from outside contexts, such as web pages, in the forms of images, text, or videos, and self-made writings and sketches.

To help define *free-form web curation*, Kerne et al. looks at how people engage in *free-form web curation* in terms of their strategies, that is to say, their planned operations and courses of action [16]. In *free-form web curation*, involves six constituent strategies: (1) collecting content elements, e.g., clippings, diagrams, labels, embedded documents, images, and videos; (2) assembling them in an unstructured zoomable space; (3) shifting perspectives to see them in different ways; (4) sketching; (5) writing; and (6) exhibiting them as a connected set. These curation strategies are connected to creative ways of working in the arts, such as Dubuffet's *assemblage*, Higgins' *intermedia*, Rauschenberg's *Combines*, Warhol's *pop art*, Cage's *Imaginary Landscapes*, and Spooky's *rhythm science* [16].

Prior studies investigated the use of free-form web curation in different contexts with the IdeaMâché probe. One previous study looked at students using free-form curation for classroom presentations [50]. Another developed a pattern language that represents a range of forms in which students use free-form web curation to engage in visual thinking [8]. These visual patterns include *group*, connecting elements into distinct sets, *overlap*, visually layering elements to create relationships, *path*, assembling elements in linear or non-linear sequences, and *morphology*, assembling elements into a recognizable shape or form.

1.1.7 Collaboration

Collaborating with others has been shown to bring about social and organizational challenges [11]. Schmidt and Bannon describe how shared spaces can support cooperative work:

> Cooperative work is not facilitated simply by the provision of a shared database but requires the active construction by the participants of a common information space, where the meanings of the shared objects are debated and resolved, at least locally and temporarily. Objects must thus be interpreted and assigned meaning, meanings that are achieved by specific actors on specific occasions of use [17].

Design implications for supporting collaborative activities include the need for structure and flexibility, data portability, role identification, and alternate group interaction styles [51]. Collaborative systems often reduce the richness of communication, as compared to in-person experiences [52]. Systems often do not support many of the perceptual and physical abilities that people use to maintain workspace awareness, such as glancing and eye contact. Instead, systems often try to recreate these with technologically mediated mechanisms that are comparatively slow and clumsy.

Prior work has sought to understand how these challenges manifest within student groups [53, 54, 55]. Gokhale found that undergraduate students who engaged in small group collaborative learning in a traditional classroom setting performed significantly better on critical-thinking tasks than students who studied individually [53]. Kulkarni et al. recently found that participation in small group-based discussions in massive online courses led to increased participation in the class and improved grades [55]. Dennis et al. developed a multi-stage model of collaborative communication: exchange of information, followed by deliberation (conveyance), and development of shared meaning (convergence) [56]. They argue that collaborative tasks require multiple types of media. Gergle et al. found that remote collaborators working in a shared visual space rely more on visual than verbal communication [57]. Chung et al. use multiple shared displays to support collaborative visual sensemaking [58]. The multiple displays extend the visual space and thus extend the potential for spatial and collaborative opportunities. The proposed curation method integrates multiple media types, including images, text, video, sketching, and live media streams, into an unstructured, non-linear whole.

1.2 Collaborative Multiscale Design Curation

Our approach to addressing design curation in project-based learning is the new medium of collaborative multiscale design curation (CMDC). This medium is a synthesis of existing strategies of free-form curation [16] and newly developed strategies of multiscale design. In *collaborative multiscale design curation*, multiscale organization of heterogeneous elements supports users engaging in creative cognition processes and collaboration. Users collaboratively collect, assemble, sketch, and write representations of ideas in a near-infinite unstructured space. The flexible and variable use of space and scale support users in creating visual assemblages which help them explore relationships and multiply opportunities for creative synthesis. The mutability of curation elements supports externalizing processes of cognitive restructuring and conceptual combination. Through engagement in visual assembly over time, CMDC supports processes similar to *maps for design reflection*, which show trends and changes across a design process to stimulate retrospection [59]. The use of scale can create implicit hierarchies that support visual chunking. Through multiscale design, CMDC addresses problems with linear media—e.g., PDFs and slideshows—which, as they grow, relationships become harder to express and understand. We instantiate CMDC in the form of the prototype system LiveMâché described in Chapter 5.

1.2.1 Collaborative Live Media Curation

CMDC extends previous work on collaborative live media curation, which furthers the context creation abilities of free-form web curation, supporting not one, but multiple authors collecting and assembling simultaneously [60]. It focuses on the roles of communication and participation in collaborative curation. Support for participation comes from the shared conceptual and spatial contexts through the collection and assemblage of web content, similar to free-form curation, with additional streaming media elements such as webcam video or screen shares. Live media elements support new ways in which authors can inject their perspectives and voices into their curation contexts.

1.3 Research Approach

The field of human-computer interaction (HCI) research has moved beyond the study of usability and is increasingly engaged in improving society at large through research addressing the "wicked problems" facing the world. "Wicked problems" have no prior solutions and cannot be reduced, thus they require contextualized and iterative investigation [61]. To address the research of "wicked problems " Zimmerman et al. propose research through design as a methodology, building on the prior concepts, in which the design researcher focus on making a transformative artifact intended to exemplify how technology and design can change the world [62]. As learning scientists, Barab and Squire say researchers must "recognize the importance of local contexts [and] treat changes in these contexts as necessary evidence for the viability of a theory" [63].

The *primary research question* is to understand if and how collaborative multiscale design curation can support creativity in project-based learning contexts. When investigating complicated and interconnected phenomena, such as creativity and learning, controlled laboratory experiments are inadequate [64]. The open-ended and contextual nature of project-based learning activities leads us to adopt open-ended research methods, such as the probe. In HCI, probes are lightweight, simple technologies that can be deployed into real-world settings to explore contextually valid phenomena [65]. Technology probes are one such method, used to meet user needs, field test techniques, gather qualitative and quantitative data about usage, and inspire users and researchers to think about the technology's transformative potentials [66]. Technology probes are open-ended and co-adaptive in that users will adapt their processes to work with the probe, and they will use the probe in unexpected ways to fit their purposes [67]. A recent survey by Remy et al. examines the range of evaluation methodologies used in studying Creativity Support Tools [68]. They argue that longitudinal, in-situ studies are necessary to learn about creative processes. In this vein, to study team project-based learning, we move beyond the probe in terms of functionality, extensibility, and longevity.

Remy et al. also argue that the evaluation of Creativity Support Tools should move beyond the typical HCI evaluations of usability to more goal-oriented evaluations of creativity. In this research, our tool's goal is to support creative design curation among student teams. To evaluate this aim, we combine layered sociotechnical systems, cyber and human infrastructure, and multi-dimensional data collection methods, including observations, interviews, qualitative visual analysis, creativity metrics, and automated logging. For data collection and analysis, we take a mixed-methods approach involving qualitative and quantitative methods. Quantitative data includes the curations as semantic data and user operation logs. Qualitative data includes interviews with students and the curations as visual data. We evaluate the curations and their operation logs, as both quantitative and qualitative visual data, using a combination of evaluation methodologies: ideation metrics of curation [16] and visual grounded theory [8].

1.3.1 Measuring Creativity: Ideation Metrics

Developing empirical studies of creativity and ideation is challenging. Creativity involves divergent thinking tasks, in which there is no single correct solution [28]. Assessing human performance on these tasks is more complicated than convergent tasks, which have a clear solution. Typical quantitative metrics for convergent tasks are time and accuracy are not suitable for measuring creative ideation.

Building on Guilford's factors of creativity [69], engineering design researchers have measured ideation in solutions to design problems in terms of their Fluency (the number of ideas), Flexibility (the variety of ideas), Novelty (the uniqueness of ideas), and Quality [70].

We employ Kerne et al.'s ideation metrics of curation, which translates previous ideation measures for use with curation products [71]. In metrics of curation, Fluency measures the total number of curated elements. Flexibility measures the number of different information sources captured in the curated elements. And Novelty as the inverse frequency of the occurrence of an element across all curations in a set corpus.

In addition to the quantitative metrics described above, we also employ a range of qualitative data methods. Previous research adopts a social and subjective approach to understanding and supporting creativity [72, 73]. Several researchers have developed qualitative measures for the creativity and quality of design ideas via crowdsourcing subjective human ratings [74, 75]. Carroll et al. developed a schematized survey for factor-based self-assessment of creativity in user experiences [76]. Kim and Maher used protocol analysis to help human raters systematically compare collaborative design tools [77].

1.3.2 Visual Qualitative Methods

A central form of data in our investigations is the curations themselves, which we treat as visual data. We invoke visual qualitative methods [78], following other researchers who use visual evidence as a primary form of data [79]. Previous studies investigated visual data as material, questioning how they are seen, touched, and carried [80]. Often the materiality of visual data is addressed in terms of its physical characteristics [81]. In our work, we extend visual material to encompass digital media objects viewed through the web browser.

To derive understanding from visual data, we employ grounded theory methods. Grounded theory is a methodology for examining qualitative phenomena. It focuses on answering the question of "why" as opposed to "how" or "what" [82]. Charmaz articulates an empirical methodology for constructing grounded theory, which involves gathering rich data, iterative cycles of coding the data, categorizing the codes, and refining the categories into salient themes [83]. Much grounded theory uses field notes and transcriptions of interviews as the primary form of rich data [84]. Instead, we follow Konecki, who introduced *visual grounded theory*, which shifts the primary source of empirical material from textual to the visual [85].

1.4 Research Contributions

This research contributes to media of collaboration, creating more expressive and creative experiences. Students and instructors can think and work in new ways that further their capacity for spatial thinking, visual synthesis, and other cognitive components of creativity.

In Chapter 2, we examine *design curation* as how designers create, collect, and put together material to represent a design process. We discuss how a medium of design curation corrals designers into specific ways of working and thinking Understanding the implications of design curation media and their associated methods is necessary for effective design processes. The medium of design curation has a direct effect on both design processes and products. This interplay creates a reflexive feedback loop between designer and curation in which, to build on theorist Marshall McLuhan [86]; the medium becomes the method.

We derive a set of multiscale design strategies in Chapter 3 by observing the ways in which students use scale to explore, juxtapose, and synthesize relationships between their design components. We identify three multiscale design strategies: multiply, map, and shift perspective. In Chapter 4, we present a detailed investigation of how computer science students use the medium of multiscale design curation to collect, assemble, and report on their team-based design projects. From interviews with students, we find that their use of space and scale in their design curations is central to how they engage in creatively working together and reflecting on their projects.

In Chapter 5, we outline the needs of project-based learning tools and describe the prototype design curation system LiveMâché. Over three years, LiveMâché has been used in a variety of university design courses, enabling roughly 1500 students to create 3500 curations. From our continued support of these courses, we've refined our situated research practices. We generalize our approach as a new method, extending the technology probe, to engage in long-term investigations of situated and collaborative human activities, which we call sustained prototypes. LiveMâché, as a sustained prototype, enables us to investigate the importance of a cyberlearning infrastructure for transforming experiences in real-world classrooms. Finally, in Chapter **??** we discuss implications of our findings and propose future research directions.

2. Design Curation: A Review of Media and Methods

We study how the specific media forms that designers employ to represent their work affects their design thinking and processes. We hypothesize that choosing to use a particular medium can unwittingly or intentionally restrict how design processes are understood and how ideation is engaged, or it can open horizons. We ask the research question: do the media forms used to aggregate design work affect the process and resulting products, and if so, how? To develop understandings, we compare and contrast notable media forms used to represent design processes. We consider the implications of particular media for human working memory, visual and spatial thinking, synthesis and emergence, and ideation.

There are many ways to perform design [1, 87, 88, 89, 90, 13]. Most involve aspects of research, conceptualization, creation, and reflection [91]. Design processes rely on the creation, use, and communication of design artifacts, such as: conceptual and material studies and experiments, design proposals, and operational prototypes [90]. Artifacts help designers communicate concepts, define approaches, study end-users, and reflect on ideas [88]. Cross shows how different design methods employ artifacts in different ways, impacting a designer's ability to think creatively and rationally [10].

We formulate a subfield of design research which focuses on the media and methods that designers use to collect and present their artifacts [6, 1, 7, 87, 15, 88, 89, 90, 4, 13]. We liken these prior design practices to practices of curation, which according to art exhibition organizer, Paul O'Neill, is a means for re-contextualizing and exhibiting collections of creative work [12].

We introduce *design curation* to refer to the activities of creating, collecting and putting together material to represent a design process. Through these activities, designers create, explore, and communicate design spaces. Design curation refers to both the medium in which the artifacts are assembled and the activities of assemblage.In our definition of design curation, the medium and activities are interlinked and cannot be separated.

In this chapter, we compare and contrast notable prior design curation media and discuss their goals and how they influence design processes. They implicitly lead designers to subscribe to their underlying design methodology. We elaborate on the implications of thinking and ideation through our formulation of design curation, which manifests through the different media of design curation.

2.1 Methodology

For our review of design curation, we began with some notable design curation methods. From these initial papers, we collected more by chaining through citations and references. For each paper, we look for evidence of design curation activities: mentions of processes that involve collecting, gathering, assembling, organizing, annotating, or presenting design artifacts. We found 68 papers that matched these criteria.

Once we have identified a design curation media, we look at the specifics about how it is used and why. In gathering and assembling the papers of study, we began noting critical differences between the media. Through this process, we developed a set of questions we would work to answer with direct quotes from the papers. The questions include: what is the form in which elements are assembled? When does this assembly occur? What motivates choosing one element over another? Throughout our constant comparative analysis, these questions became facets that we use to distinguish design curation media from one another.

2.2 Facets of Design Curation Media

The facets of design curation media include: *Material of Elements*, *Medium of Assemblage*, *Roughness*, and *Authors / Constituents*.

2.2.1 Material of Elements

The *material of elements* refers to the intended types of artifacts that are collected. It captures the prescribed format of elements, such as images or text. Elements can be self-made, created by a member of the design team, or readymade, found, and taken from an outside context. Self-made elements include photographs of a prototype taken by a member of the design team or sketches of design ideas. Readymade elements include inspiration images found on the web or scholarly articles. In many cases, we found that a design curation medium can support a broader range of element types than prescribed by the associated research. We focus on the types of elements specifically prescribed or evident in examples.

2.2.2 Medium of Assemblage

The *medium of assemblage* captures the form in which the elements are attached to form a whole. The medium can be digital or physical or exist as either. A medium can be associated with a specific tool or application, or it can span multiple tools. The medium describes the set dimensions and boundaries of a design curation. It affects how the assemblage can be viewed and experienced.

We divide the structures of assemblages along an axis from non-linear to linear or, more colloquially, as boards to books. Books, or linear design curations, consist of elements ordered in a set sequence. They have a definite start and end. The authors can exercise more control over the viewing experience.

Boards, or non-linear design curations, there is no set order in which to view the elements. In non-linear spaces, elements are assembled to form composites, lightweight structures of two or more elements [92]. Viewers have more freedom to assign their interpretations to the relationships between elements.

2.2.3 Roughness

A design curation medium is intended to be employed at a specific stage of the design process. Some media are intended for initial design exploration. Others are intended to archive a complete design process.

The facet of roughness captures the extent of visual polish, legibility, and structure in the medium. We give dimension to this facet in terms of rough, polished, and mixed, for those mediums, which can be either. Roughness typically correlates with the phase at which a medium fits into the design process. Elements and arrangements created earlier in the process are more exploratory and lightweight than those that come later in the design process.

Roughness incorporates aspects of the flexibility of the medium of assemblage and the malleability of the elements. Rough mediums are more likely to emphasize iteration. Whereas polished mediums focus on communication and interpretation.

2.2.4 Authors / Constituents

Different design curation media are intended for individuals or design teams. A design curation media may be specifically intended for a specific skill level of designer. They may be intended for use only by experts, or perhaps they are intended for novice users. Often, design curation media do not specify a minimum or maximum skill level.

When possible, we assess the collaborative reach of a design curation medium. A design curation medium can be intended only for use within a design team or shared with project stakeholders, or perhaps, with the broader design community.

2.3 Design Curation Media

We present a selection of notable design curation mediums. We describe each medium using the authors' words when possible. Not all authors go into detail about the specific forms or material which compose the design curation medium. In those cases, we inspect example curations and infer their medium and materiality.

2.3.1 Design Workbooks

The design workbook consists of "design proposals and other materials drawn together during projects to investigate options for design" [1]. Generally, workbooks are considered flexible and open. They typically contain a range of possible proposals. Design proposals do not need to flesh out plans thoroughly, but can be as simple as a reference image or rough concept sketch [2].

Workbooks are linear documents of text and images, often assembled as physical books. They can also be created digitally as document of text and images (see Figure 2.1). Microsoft Word, Adobe Photoshop or InDesign are common software used to create digital design workbooks, usually as PDF documents. In either physical or digital format, the curated elements must be divided up amongst individual pages, and the pages themselves must be ordered linearly. However, within each page, the elements can be assembled non-linearly allowing for a less structured organization

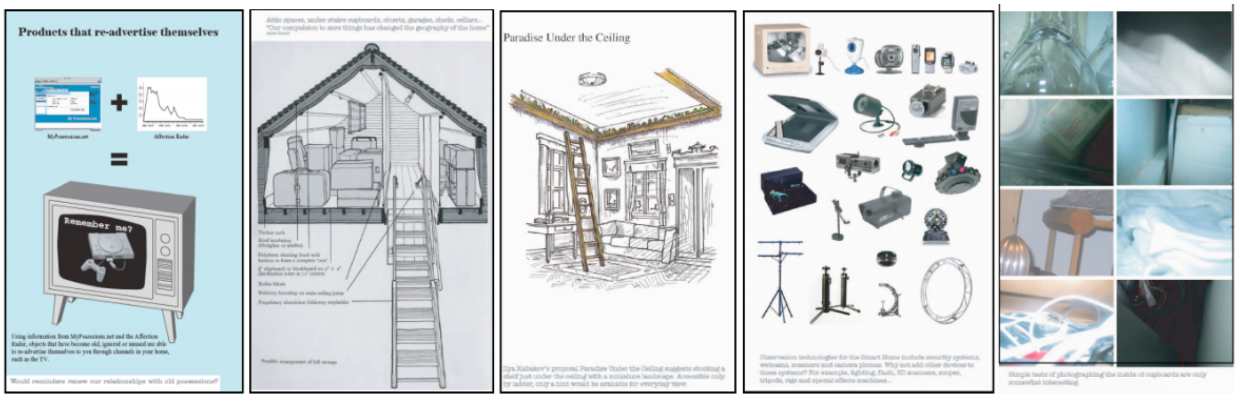

Figure 2.1: Workbooks are made up of pages containing combinations of writing, images, and sketches which could be arranged in more structured lists or grids or free-form [1].

such as in Figure 2.2).

Design workbooks are intended to provide an initial mapping of a design space. They are a medium for externalizing possible solutions. Workbooks are meant to be simple and easily appended to and modified. They are used to facilitate safe and relaxed creative exploration to encourage designers to try out more imaginative and risky ideas. They should allow designers to explore a large space of design possibilities quickly. The goal is to discover the fruitful areas of the emerging design space. Design workbooks are not intended for a specific skill level of designers. They are best employed during the beginning stages of a design process, such as in the conceptualization and ideation phases.

– *Material of Elements* - Readymade and self-made images, sketches, text annotations.

– *Medium of Assemblage* - Linear arrangement of pages of liner or non-linear arrangements of elements.

– *Roughness* - Rough.

– *Authors* - Solo or a small team.

– *Constituents* - Internal design team.

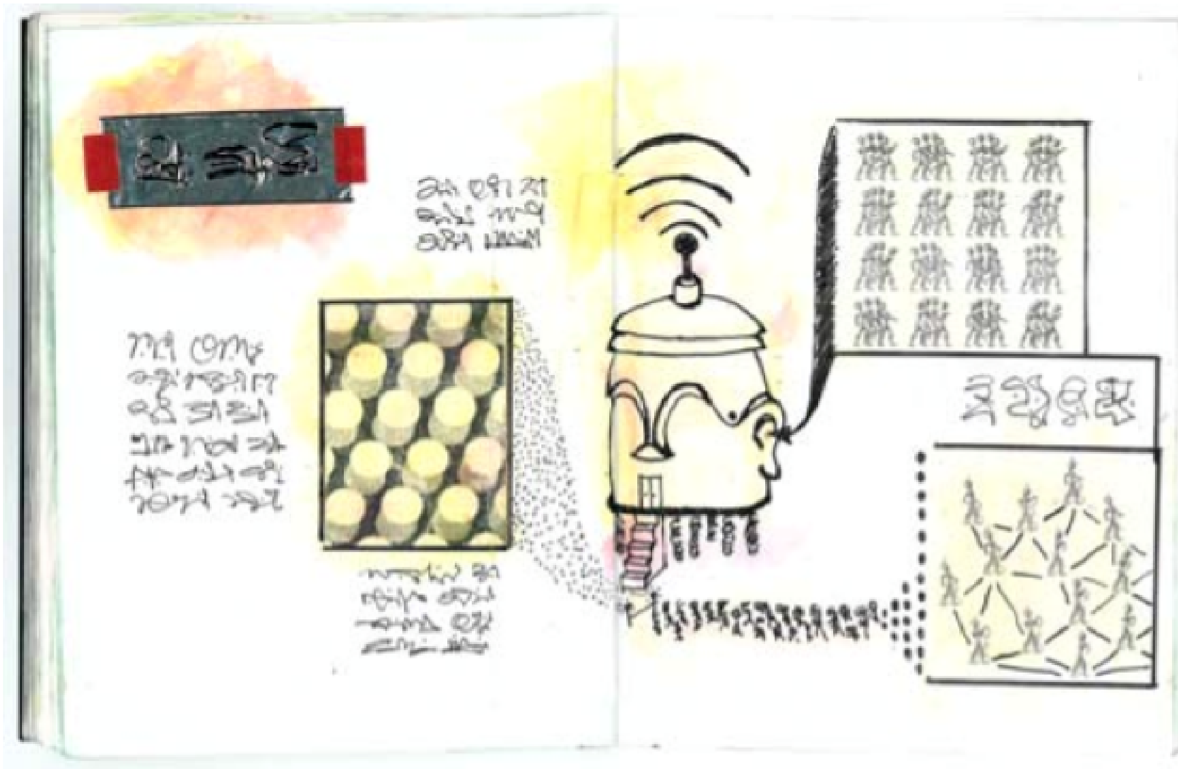

Figure 2.2: Workbooks can be digital documents such as PDFs or physical books with hand-drawn sketches and physically clipped images [2].

2.3.2 Annotated Portfolios

Annotated portfolios involve a set of design artifacts with added elaborations and captions in order to compare 'dimensions of design' (see Figure 2.3) [14]. Annotated portfolios link individual artifacts together to create a systematic body of work. Designers add written annotations to illustrate similarities and differences of the artifacts. The annotations make explicit the designer's interpretations of the relationships present in the collection. While the annotations should elaborate on and explain the design artifacts, the artifacts must inform the meaning of the annotations. Annotations can serve several different purposes, depending on the specific context and intended audience.

Annotated portfolios are not limited in terms of material forms of curated artifacts. Artifacts could include articles, diagrams, sketches, photographs, and videos of prototypes. In an annotated

Figure 2.3: An example page of an annotated portfolio. In the example, each image represents a situated study of a design prototype. The annotations label the different dimensions of user experience captured by the prototypes [3].

portfolio, each artifact is treated as distinct. The role of the annotations is to illuminate how the artifacts relate to one another to create a unified collection [3]. As a collection, the different aspects of the artifacts pool together to address broader, more general design ideas.

Similar to workbooks, annotated portfolios are typically a linear, paged document. However, the organization of artifacts and annotations in each page is flexible and often non-linear. Annotations and artifacts do not necessarily match up one-to-one. Flexible spatial arrangements create structures in which annotations can ambiguously apply to multiple artifacts. Annotated portfolios are less formal than typical scientific publications. The relaxed structure and emphasis on explicit explanation makes them a valuable tool for conceptual development and grounded, practical instruction. Unlike workbooks, which support designers in thinking and exploring, annotated portfolios explain and communicate design processes and outcomes [13].

Annotated portfolios provide explicit interpretations of the collection while still affording some variability and ambiguity. This ambiguity enables them to be both a descriptive and inspirational means for communication. Annotated portfolios help transform and abstract knowledge from the level of specific design ideas to more general implications or theories [93].

– *Material of Elements* - Readymade and self-made images, high-quality photographs, writings, and annotations.

– *Medium of Assemblage* - Linear with portions of 2D grids or free-form arrangements.

– *Roughness* - Polished

– *Authors* - Solo or a small team.

– *Constituents* - Exhibited to a broader audience.

2.3.3 Pictorials and Photo Essays

Pictorials are formalized publications in which visual artifacts (diagrams, sketches, photographs, collages) are elevated to be as or more important than the associated writing [4] They are intended to communicate design research understanding which cannot be expressed in words alone.

As a formalized publication format, they are limited in their medium of assemblage compared to workbooks and portfolios. They consist of formatted pages of text and images. Often the curated images are composites or collages such as shown in Figure 2.4. However, within the collages, the relationships are less ambiguous than other forms of design curation and typically arranged in a visual structure like a grid or list.

In the pictorial, images are “first-class exemplars of ... design”, they aim to “elevate the visual discourse in much the same manner that these contemporary thinkers have elevated the textual one” [15]. One benefit of pictorials is that they are well suited to designers who often prefer communicating visually instead of through writing [4].

We combine pictorials with photo-essays because of their similarities of medium and material. Like pictorials, photo-essay focuses on visual and material artifacts as the primary means for com-

Figure 2.4: Pictorials are research publications that focus on the visual. They often make use of grid arrangements to exhibit sub-sets of self-made images [4].

municating design work [87]. They use collections of images to illustrate design decisions and express aspects of the design, which could not be accurately captured in words.

- *Material of Elements* - Self-made text and high quality images.
- *Medium of Assemblage* - Linear sequence of 2D grids or free-form arrangements.
- *Roughness* - Polished
- *Authors* - Solo or a small team.
- *Constituents* - Exhibited to a broader audience.

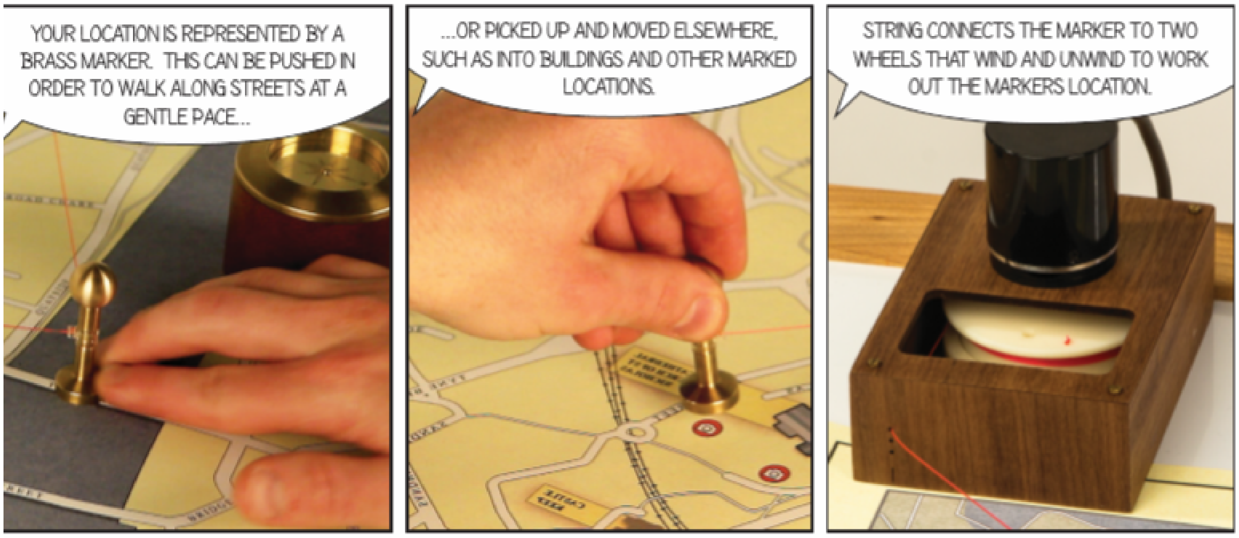

Figure 2.5: Comics are linear sequences of annotated photographs or sketches arranged in a grid or list [5].

2.3.4 Comics, Storyboards, Tutorials

Research through Design comics adopt the format of the comic book to tell design stories. They are typically linear grids or lists of visual elements with brief annotations or descriptions overlaid on top (see Figure 2.5). RtD comics work to describe the dynamic process of design through the metaphors of story and dialogue [94]. They capture the different viewpoints that went into the design process. Moreover, they describe the interactive and aesthetic aspects of the design outcome. As opposed to annotated portfolios, in comics, there is often a one-to-one relationship between the images and their written description or dialogue.

The medium of the storyboard is similar to that of the comic, and often comics contain one or more storyboards within them as composite elements. Storyboards are less detailed and rougher when compared to comics. Often, storyboards are employed as an exploratory design technique instead of comics intended to be published and exhibited.

We also place design tutorials in this category because of their similar linear structures of images with one-to-one dialogue. RtD tutorials are pedagogical tools that aim to communicate specific processes of design. Like annotated portfolios, comics and tutorials are beneficial for

Figure 2.6: An example big wall, with notes, sketches, and images physically tacked onto a wall. [6].

communicating because they encompass different ways of knowing. However, where portfolios are more ambiguous and open to inspirational interpretation, comics are more linear and consistent in their meaning.

- *Material of Elements* - Self-made images, photographs, sketches, and text annotations.
- *Medium of Assemblage* - Linear grids or lists of elements.
- *Roughness* - Mixed.
- *Authors* - Solo or a small team.
- *Constituents* - Exhibited to a broader audience.

2.3.5 Big Walls

In the medium of the big wall, individual elements of meaning (ideas, notes, references) are created and arranged on a 2D canvas (see Figure 2.6). Design researcher Jon Kolko lists “a big wall, a marker and lots of sticky notes” as the designer’s main tools used by designers [6].

Big walls are inherently physical as they are intended to be lightweight and seek to free the designers of the limitations of technology. Two principles define the big wall: 1) that content elements can be freely manipulated, and 2) that the entire curation can be viewed at once.

By arranging and rearranging the ideas on the wall, designers externalize their transformations in thinking. What initially begins as a divergent process of finding and gathering ideas becomes more organized as designers identify design dimensions and categorize their ideas. Big walls support processes of combination in which new meanings are discovered by spatially relating the discrete elements to one another. As designers engage in this process, the wall develops a more cohesive visual structure. The cohesive structure helps designers build a robust mental model of the design space.

– *Material of Elements* - Readymade images and text clipped from other sources. Self-made text annotations and sketches.

– *Medium of Assemblage* - 2D non-linear, free-form.

– *Roughness* - Rough.

– *Authors* - Small team to medium teams.

– *Constituents* - Internal design team.

2.3.6 Mood Boards

The mood board "consist[s] of a collection of visually stimulating images and related materials" [7]. Mood boards consists of an unstructured canvas on which designers are freely arrange their artifacts (see Figure 2.7). In digital mood boards, artifacts could be readymade images, text clippings, or videos from the web or self-made sources of inspiration. In physical mood boards, artifacts could be readymade magazine clippings, fabric swatches, or material samples.

Mood boards are intended to be used in the early stages of design. They help organize reference material to create spaces of inspiration and conceptual exploration. In the mood board, concrete and abstract elements are juxtaposed. Visual juxtaposition helps designers engage in processes of abstraction and combination.

Figure 2.7: This is an example mood board showing the messy arrangement of readymade images [7]. Elements are often randomly rotated when collected to help communicate the variability of possible arrangements.

Mood boards can be used as a visual aid to help ground discussions with people outside the immediate design team such as clients or stakeholders. They help align everyone's mental models and design visions, however, because of their free-form and often messy arrangements, they still allow for a variety of interpretations.

- *Material of Elements* - Readymade images and text clipped from other sources.

- *Medium of Assemblage* - 2D non-linear, free-form.

- *Roughness* - Rough.

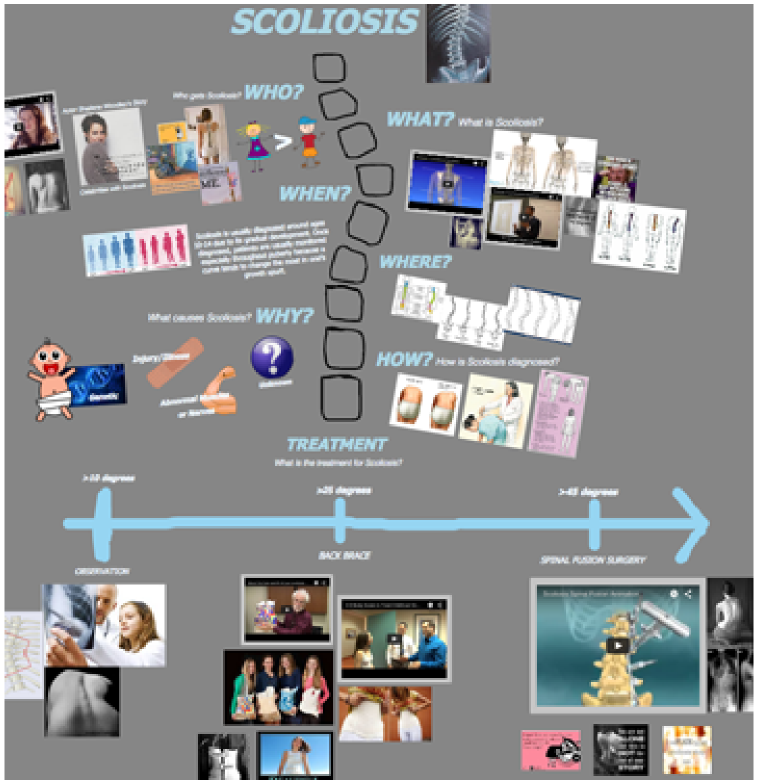

Figure 2.8: An example free-form web curation which contains readymade images, text clippings, and videos, and self-made annotations and sketches such as the abstract curved spine in the center [8].

– *Authors* - Solo or a small or medium team.

– *Constituents* - Internal design team and design stakeholders.

2.3.7 Free-from Curation

Free-form web curation involves collecting artifacts, assembling them in an unstructured space, shifting perspectives to discover new interpretations, and annotating discovered relationships through sketching and writing [16]. In free-form web curation, elements are collected from the web as readymades or created within the curation as self-made sketches and writings. Elements are freely arranged on a 2.5 canvas (see Figure 2.8). Through exploring different arrangements, free-form web curation supports visual thinking processes [8]. This exploration of arrangements is similar to big walls and mood boards, which likewise support combination and discovery through arranging elements. Unlike big walls and mood boards, free-form curation is not solely intended for use in the initial stages of design. Instead, it also encompasses processes of communicating and sharing the curation similar to annotated portfolios.

– *Material of Elements* - Readymade web clippings: image, text, video, document. Self-made writings and sketches.

– *Medium of Assemblage* - 2.5D non-linear, free-form.

– *Roughness* - Mixed.

– *Authors* - Solo or a small team.

– *Constituents* - Internal design team and exhibited to a broader audience.

2.4 Discussion

The process of developing a design curation is not just a matter of producing an artifact but also of conceptualizing the ideas within it. Design curations play essential roles, functionally and experientially, across all stages of the design process. Constructing design curations can provide value in turning from appreciating what is toward speculating about what might be.

People invest deeply in design processes. They have a stake in the efficacy of those processes and what they produce. These processes matter and are essential. The medium in which these processes take place affects thought, memory, creativity. In this work, we do not claim that one method is better than the other. Instead, we want to elaborate on how their difference can affect design processes and products. Designers should be aware of how their chosen processes can affect outcomes.

2.4.1 Constraints of the Medium

Design curations help explore and define design spaces. The medium of design curation can be thought of as a specific projection onto a design space. Think of the Earth's Mercator projection and how it skews the proportions of the landmasses near the poles. So do different mediums of design curation skew possible understandings. Designers should ask themselves, how might this design space be different if constructed in a different medium.

Design curations act as embodiments of methodological approaches to doing design. We look at the underlying design methodologies manifested in the medium. The different ways designers collect, organize, and present their artifacts affect how they think about and understand their processes. A particular design curation medium so impacts how designers work and think, to create a complementary method.

2.4.2 Media for Reflection

Reflection is an integral part of the design process. Reflection can come in many varieties. Schon identifies two types of reflection: "reflection on action", thinking about what you've done after you've done it, and "reflection in action", thinking about what you're doing while you are doing it [95]. All design curation media support "reflection on action"; however, they differ in the extent to which they support "reflection in action". Rough media, such as the mood board and big wall, embrace "reflection in action" as a primary encouragement for designers to rearrange their curated elements and reconsider their relationships with one another. Through the processes of assembly, designer and the emerging design space engage in cycles of "talk back" or conversation.

2.5 Medium is the Method

McLuhan said, "The medium is the message," meaning that the form of media determines how one 'speaks' and what one can express [86]. McLuhan uses the term *medium* in a broad sense; it is an environment for conveying content. We extend McLuhan's statement for design curation: the medium in which one organizes their design artifacts determines how the design process can be expressed. The medium encourages certain types of visual and spatial relationships and limits others. It pushes designers into specific ways of thinking and relating across their design artifacts. Exploring relationships, both within and between concepts and ideas, is crucial for fostering creativity and ideation. Thus we say, in design curation, *the medium is the method.*

The medium is not neutral. The power of media of design curation to influence thinking and ideation can easily be overlooked. They implicitly lead designers to subscribe to their specific, underlying design methodologies. Through our formulation of design curation, differentiate how different design curation thinking and ideation which manifest thought the different media of design curation. By relating these existing design curation media, we hope to assist practitioners in making more informed choices about which design curation method to use and support design researchers in developing new work on design curation.

3. Multiscale Design Strategies from a Landscape Architecture Classroom

Figure 3.1: In the studio space, students are assigned desks in clusters with their other team members. The desks were often covered with sketches and tracing paper.

We study design practices in a landscape architecture studio classroom (see Figure 3.1). The design studio classroom provides students with unique opportunities to engage in social and embodied collaborative activities [96]. Students define multiple problems facing a site, in conjunction with analyzing information scales spanning site, local, regional, national, and global [97].

Student designers synthesize analysis components, crossing a variety of contexts and scales, to develop sets of design proposals, both conceptual and schematic, which address encountered problems. They engage in a process intended to encourage them to enter into a dialectic relationship with the site and design dilemma. They must propose ultimate particular [98] solutions, which map directly onto the site, while at the same time analyzing these solutions in terms of larger contexts [99]. As their design evolves, students must shift their thinking across scales, to connect and relate their design to personal, civil, social, and environmental processes.

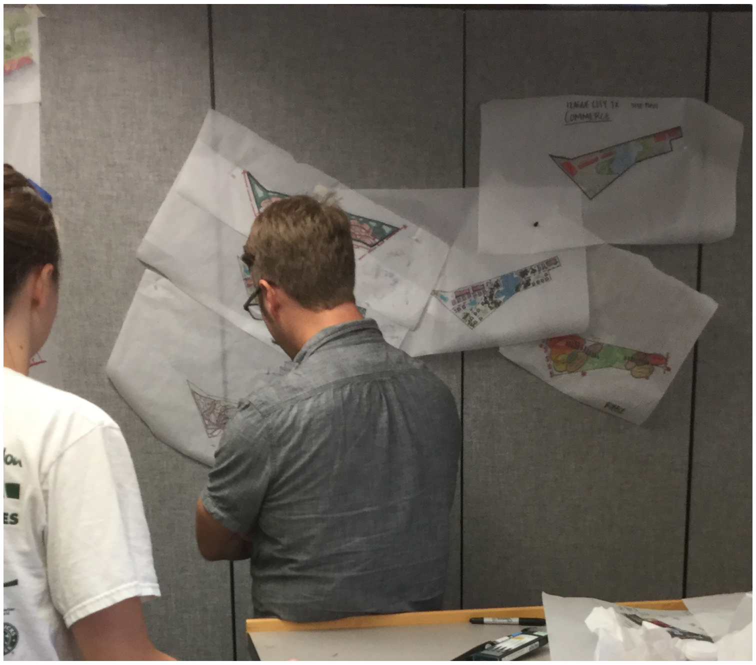

Figure 3.2: Students pin their sketches and drawings to walls to spatially organize them. In this picture, an instructor is talking with students about their sketches.

3.1 Methodology

Our understanding of multiscale design comes from study of an undergraduate level landscape architecture design studio course, Landscape Design III. The course had 3 instructors and 20 students. The students were divided into 6 teams, each with between 3 and 5 members. The course included some traditional lectures, but primarily focused on studio sessions, in which student teams worked on their projects alongside instructors (see Figure 3.2).

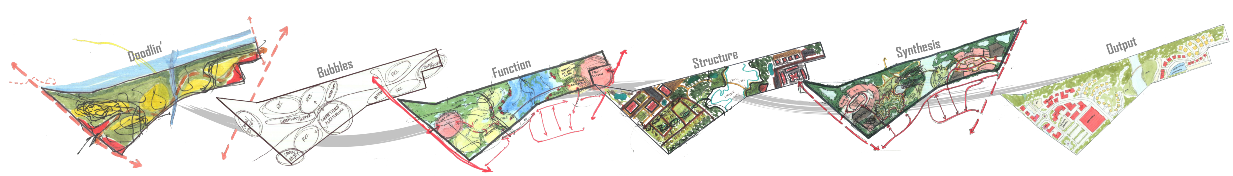

Figure 3.3: The figure shows the stages of Team ReSTORE's design process. From left to right, the labels read: Doodlin', Bubbles, Function, Structure, Synthesis, Output. This collection of images manifests the *multiply* strategy, using the repeated shape of the problem site to illustrate changes.

The course is structured around a semester-long project, in which all teams are given the same landscape site and design problem to solve. In Figure 3.3, Team ReSTORE shows the stages of their design process. They included this graphic in their final poster to show, as P4 states, “So you’re starting at the beginning and go through what we went through.”

During the semester of our investigation, the specific problem involved a 97-acre region in League City, Texas. The task was to design a development plan for the site, involving both residential and commercial properties, which addressed projected sea-level rise and increasing housing needs as shown in Figure 3.4.

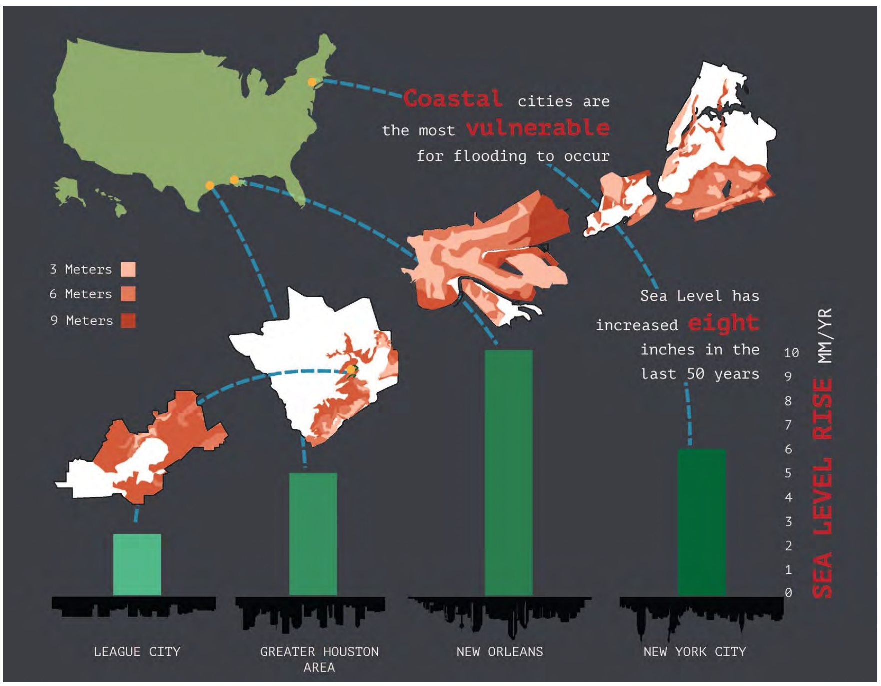

Figure 3.4: This infographic, created by Team FAD Visions, contextualizes the design task. The image introduces the problem of sea-level rise, comparing projected effects among different United States coastal metropolitan areas: League City, TX, New Orleans, LA, and New York, NY.

Over the course of the semester, each team defines the problems facing the site, analyzing information at the regional, city, and site levels. Next, they must conceptually and schematically develop a set of design proposals addressing these problems.

Our ethnography involved observation of the course, interviews with students, and analysis of their design artifacts. We observed 13 classroom / studio sessions, making notes and taking pictures of students working and interacting with instructors. Observation sessions were mostly studio work periods; others were lectures or student presentations.

At the end of the semester, we performed one-on-one, semi-structured interviews with 5 students from two of the teams: 3 from Team FAD Visions (P2, P3, P5), and 2 from Team ReSTORE (P1, P4). Interviews were analyzed using the grounded theory method of open coding [100]. Additionally, we collected design artifacts from these two teams. These artifacts were taken from different stages of their design processes. Using a visual grounded theory approach [85, 101], we categorized the artifacts based on their visual features. Based on the categories, we derived connected strategies, which we use to describing how people engage in creative practice in terms of their processes [16]. We identified three main strategies: multiply, map, and shift perspective.

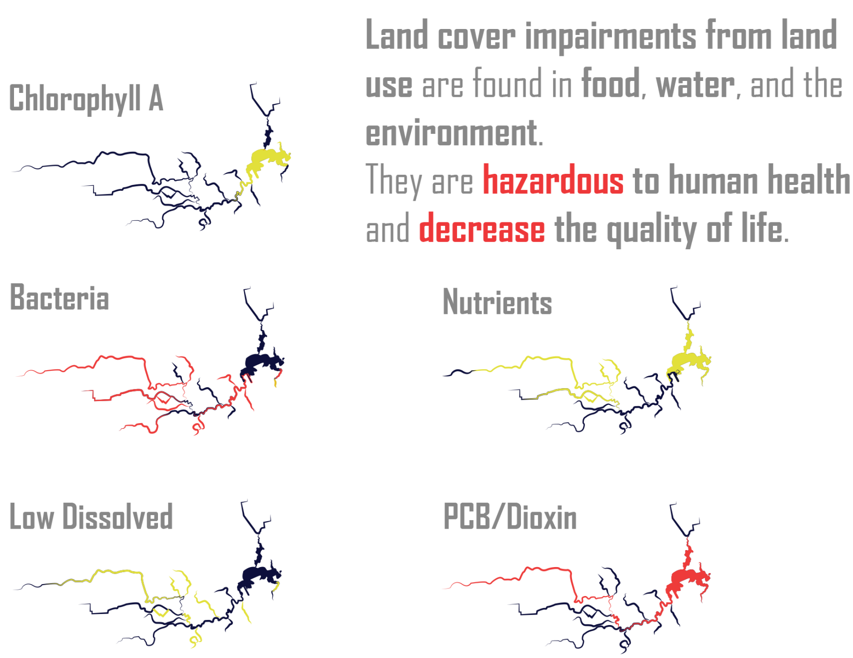

Figure 3.5: Multiples of the waterways in League City.

3.2 Strategy: Multiply

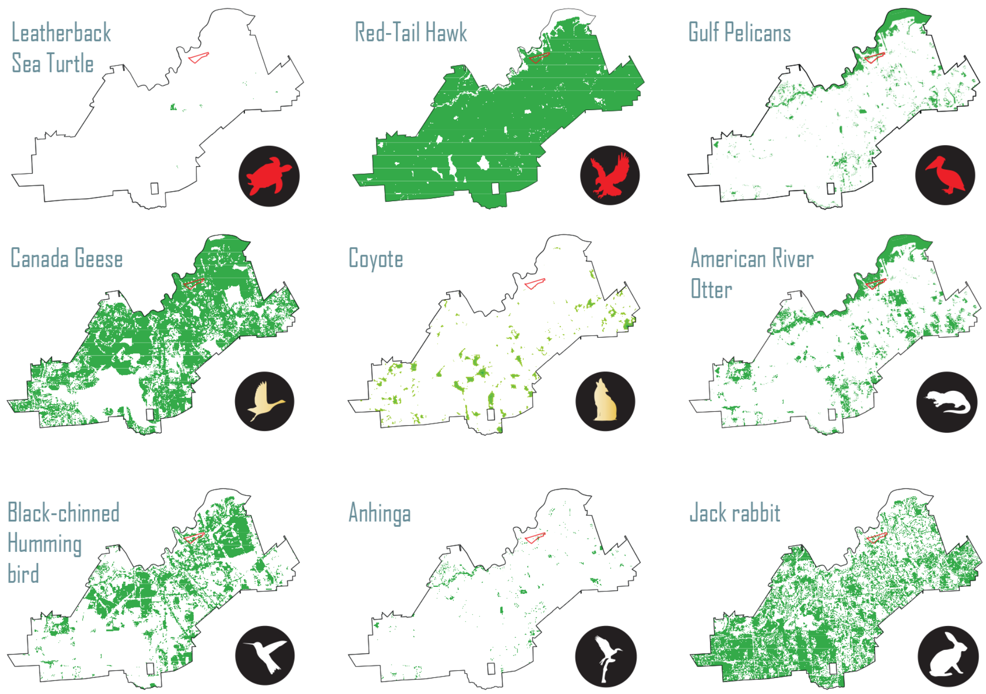

Figure 3.6: Multiples of League City, which show the different habitat regions of the area's native animals.

The Multiply strategy involves using repeated forms to connect information from different scales into a single, fixed contextual area and scale. These artifacts constitute small multiples. Small multiples support connecting information across scales by "visually enforcing comparisons of changes" [102].

The information presented in each multiple may be cropped to fit a target extent. The fixed scale of the repeated extent supports thinking about and comparing the different aspects of a design, without having to make mental scale conversions.

In Figure 3.5, the repeated shape is that of the waterways in League City. These waterways include the Gulf of Mexico, Texas rivers, and many smaller canals and regions. In Figure 3.6, multiples of League City, arranged in a 3 x 3 grid, to show some of the different animal populations in the area. The red animal icons indicate endangered species and the yellow indicate migratory species. Each of the species shown has different scales of habitats, especially the migratory species. Using multiples, the students were able to relate the different habitat scales to a single scale, that of League City. On each map, they have placed a small red outline that highlights the specific 97 acre project site.

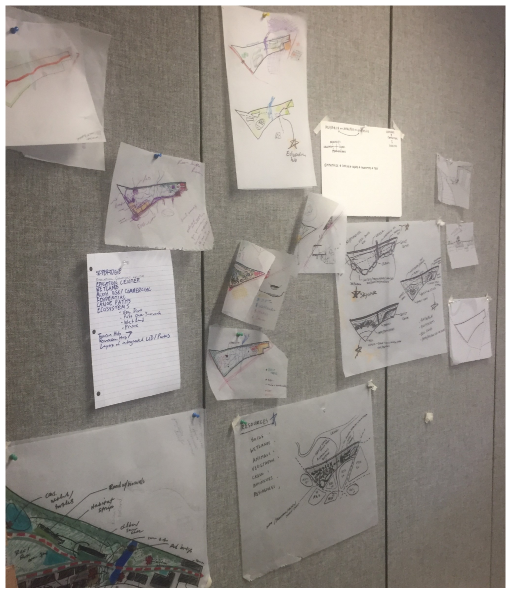

Figure 3.7: Sketches and tracings that have been pinned to the wall near one team's area of the studio.

Through this strategy, the repeated shape or silhouette encapsulates layers of information. Multiply thus draws on the stratification principle: "The city consists of a stratification of layers forming a consolidated entity" [103]. While presented information may address larger scale phenomena, such as animal migration or flood plains, repeated shape and scale ground and contextualize understanding.

Tracing paper is very common in the landscape architecture studio as shown in Figures 3.7, 3.8, and 3.9. Through tracing, students are able to quickly and easily duplicate shapes and diagrams. As P4 explains, "[Paper] more freeform and you're allow to explore different forms".

Figure 3.8: A team of students engage in sketching and tracing to help them communicate during a discussion.

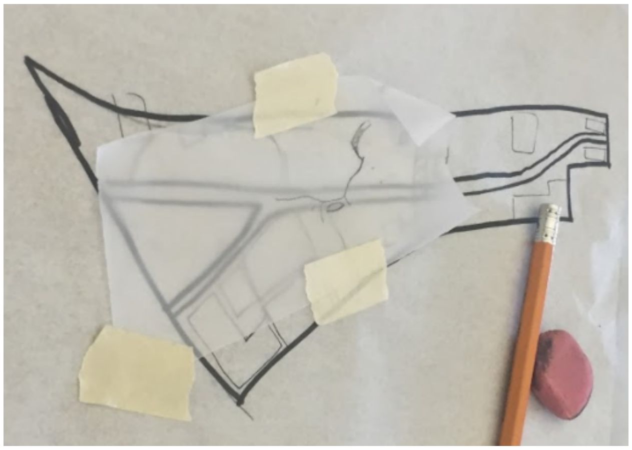

Figure 3.9: A piece of scratch tracing paper is taped on top of an outline of the project site.

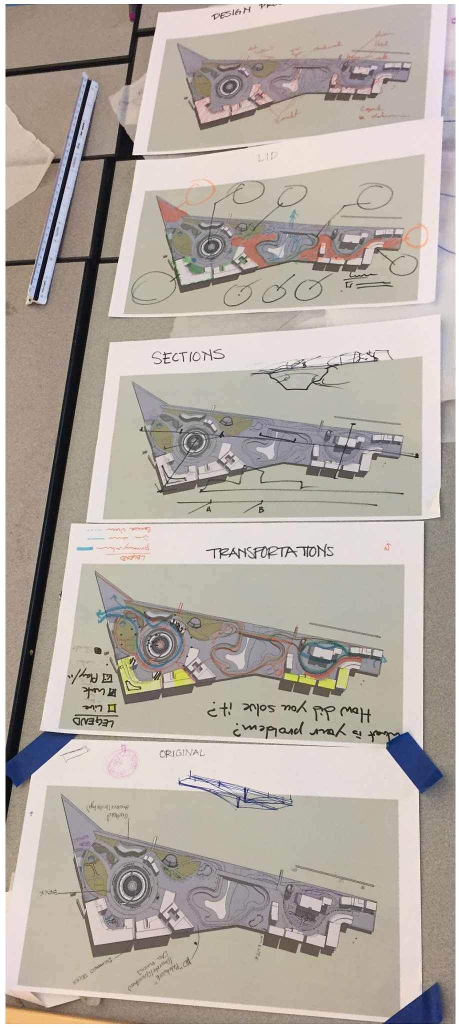

Figure 3.10: The students printed multiple copies of their site plan which they treat as multiples, annotating each one with to address different aspects of the design problem.

We also observed students printing multiple copies of an artifact and then sketching over and annotating each with different types or scopes of information (see Figure 3.10). The printouts on the right are labeled, from top to bottom, Design Problem, LID (low impact development), Sections, Transportation, and Original.

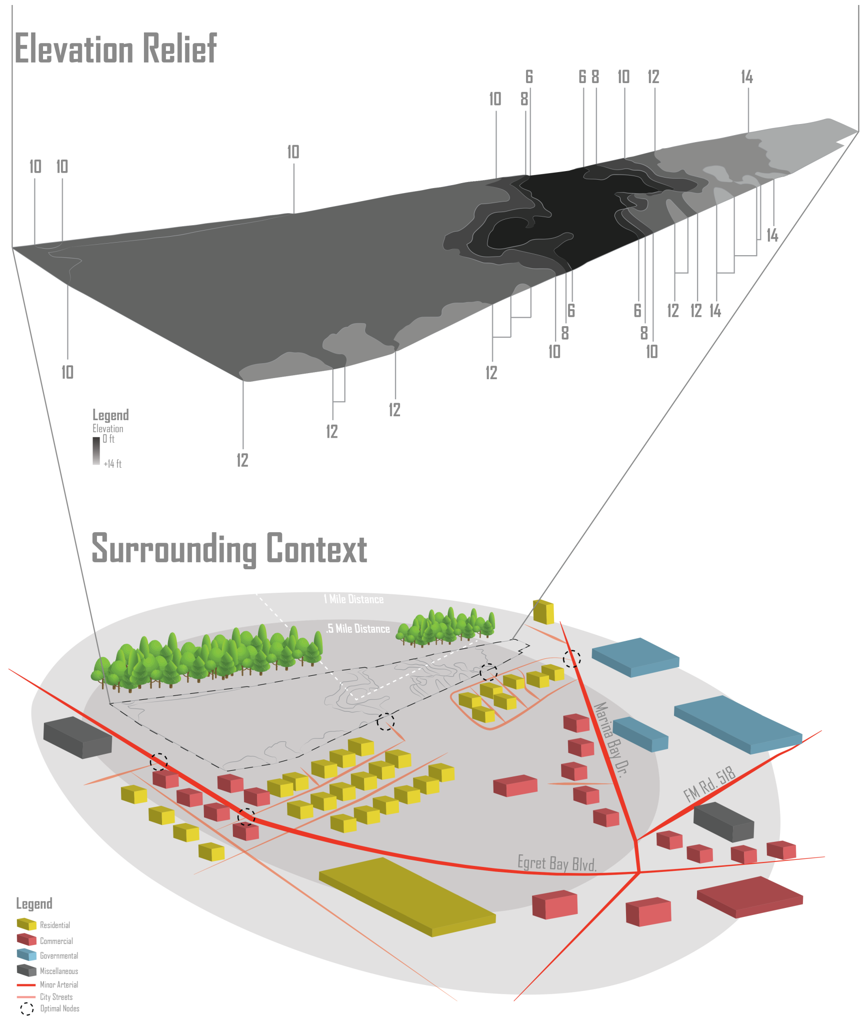

Figure 3.11: A elevation map is placed in relation to the context of the site through the callout lines which visually connect the shape of the elevation map to its position in the Surrounding Context map arranged below.

3.3 Strategy: Map

The Map strategy involves defining spatial relationships between representations. Mapping involves using visual techniques, such as layering or callouts, to connect the representations. Callouts are often lines or shapes, which relate one artifact into the space and scale of another artifact. Mapping facilitates connecting contexts of different scales through abstract visual scale transitions. Scale transitions can be in either direction, zooming out to show encompassing contexts or zooming in to show nested details. These transitions of scale are similar to the embodied experience

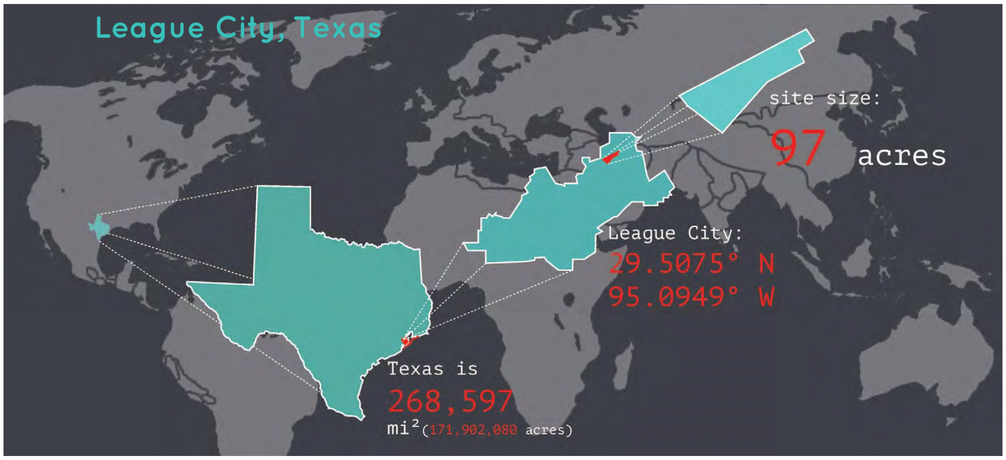

Figure 3.12: Team FAD Visions maps the project site in relation to League City, the state of Texas, and the North American continent. This mapping conveys both the relative scale and location of the site to the larger geographies.

of the city today, which Allen describes as, “Not so much the orderly progression of scales, as an experience of rapid shifts in scale and speed” [104].

In Figure 3.11, a map of the elevation is placed above an rendering of the team’s proposed site plan and the existing surrounding development. The dashed gray lines are used as callouts, to show how the Elevation Relief map fits into the Surrounding Context of the problem site. The Elevation Relief map is used to help them easily understand how to prevent sea-level rise and flooding from nearby development.

Figure 3.11 is a good example of how strategies work together. The shape of the specific site is multiplied, but each is shown from a different scale and perspective which are connected via the callout lines.

Figure 3.12 show three different geographic regions overlaid on top of a global map. Team FAD Visions has combined images of the state of Texas, League City, and the specific design site side by side to communicate transitions in scale. From left to right, they use callout lines to place Texas within the world map, League City within Texas, and the design project design site within League City. In Figure 3.13, Team ReSTORE does something similar. From top to bottom, they connect the site to League City and then to the world.

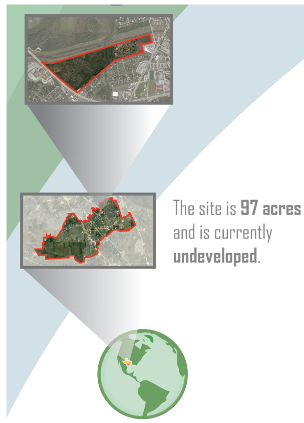

Figure 3.13: Team ReSTORE maps the project site onto League City, which is then mapped onto the world.

In Figure 3.14, callout lines connect the two perspective cross-sections on the left with their respective positions within the site map on the top right.

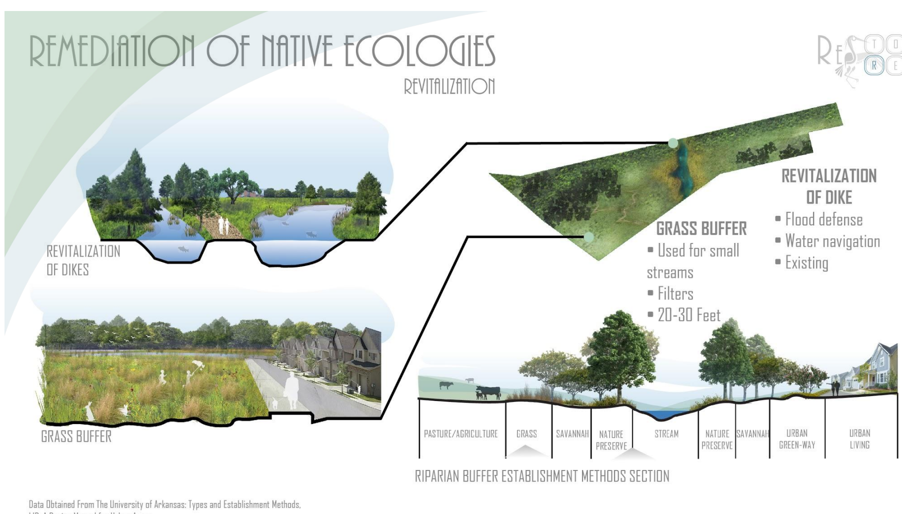

Figure 3.14: Two cross-section diagrams on the left are mapped to their locations within the site via the black callout lines.

Figure 3.15: Team ReSTORE uses 3D models and satellite imagery to create a mock bird's eye view of their proposal.

3.4 Strategy: Shift Perspective

The Shift Perspective strategy involves using views from different zoom levels and angles to gain a wider understanding of a context. We observed this strategy manifesting through models, either digital or physical, and through perspective renderings, such as birds' eyes, cross-sections, and ground level views. Shift Perspective is sometimes invoked in conjunction with the Map strategy to situate perspective views, among other representations.

Students create 3D models of the site using SketchUp and AutoCAD to see how their designs fit together within different contexts easily (see Figure 3.15. The models helped them see issues and other aspects that needed to be addressed that may have been overlooked before the model. In P2's words, "The [3D] model made us realize how big things were, [we needed to] scale things differently... Because we realized 'that's too big' or 'we need to make that smaller"'. P4 echoes this sentiment, saying "We put it to scale so that it wasn't just random anymore and that way we actually knew where stuff could go".

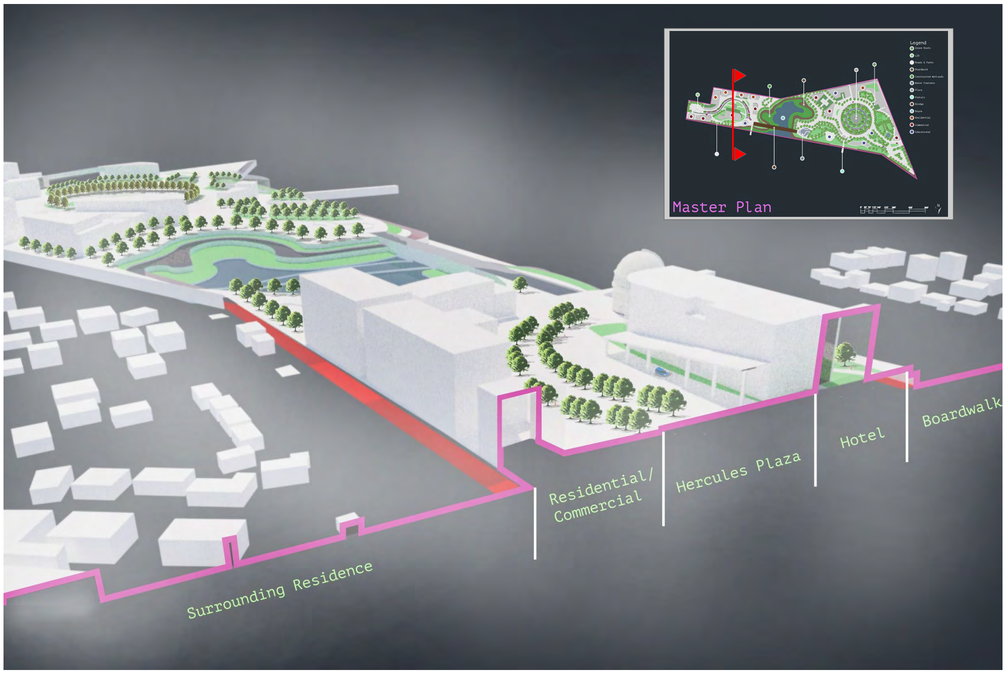

Figure 3.16: Team FAD Visions creates a cross-section using simple 3D models.

In Figure 3.16, Team FAD Visions is showing a cross-section view of their 3D model of their proposal for the site. They also included an overview image of the their “Master Plan” in the top right. The red line in the overview is a form of the Map strategy, connecting the cross-section to its location within the “Master Plan”.

Physical models manifest a form of the Shift Perspective strategy (see Figures 3.17, 3.18, and 3.19). They stimulate embodied cognition by situating participants relative to their 3D spatial forms [105, 106]. Experiencing the variability of relationships between designer and problem contexts has the potential to function as provocative stimuli [107], which can help overcome fixation. We also see students manifest other multiscale strategies within their physical models, further extending a model’s use as embodied, spatial metaphor [105].

In their physical model, shown in Figure 3.19, Team FAD Visions placed their design proposal as a removable section which stood on stilts above the model of the original version of the site. P2 explains, “We wanted it to show how the site changes”.

Other types of artifacts that students used to invoke the Shift Perspective strategy include cross-

Figure 3.17: Students created physical models of the design site and surrounding areas to help them visualize and understand the context.

sections and human level, detailed, renderings. Students used these artifacts to, “Give you what the topography looks like [and] show you scale-wise what a human would relate to” [P2].

These ground level renderings of residential and business development (Figures 3.20 and 3.22) demonstrate proposed solutions for dealing with excess water and flooding. When questioned about her process creating these perspective renderings, P4 says, “It depends on how much detail you want to put into it...I will zoom in, like micro, to try to fix stuff because I’m kind of a perfectionist.”

Figure 3.18: A close up photo of a physical which has been built by layering together boards which have been laser cut to match the team's 3D model of the existing terrain and buildings.

Figure 3.19: Team FAD Visions created a layered physical model, in which their proposed site is a removable section above the model of the existing site topology.

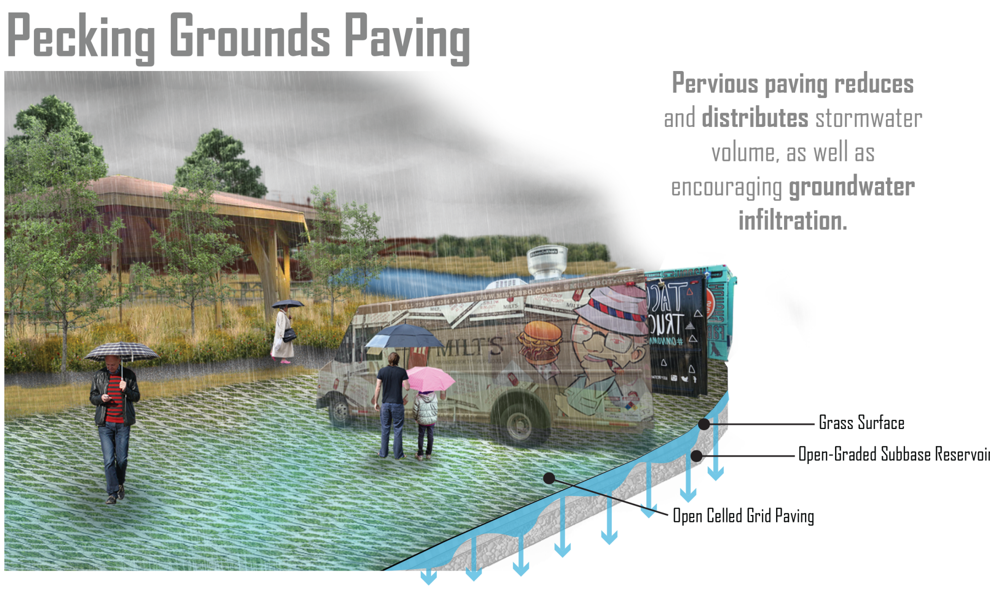

Figure 3.20: This human perspective image shows a specific park area which is part of Team ReSTORE's proposal.

Figure 3.21: These two cross-section perspectives by Team ReSTORE are scaled to show the entire length of the project site.1

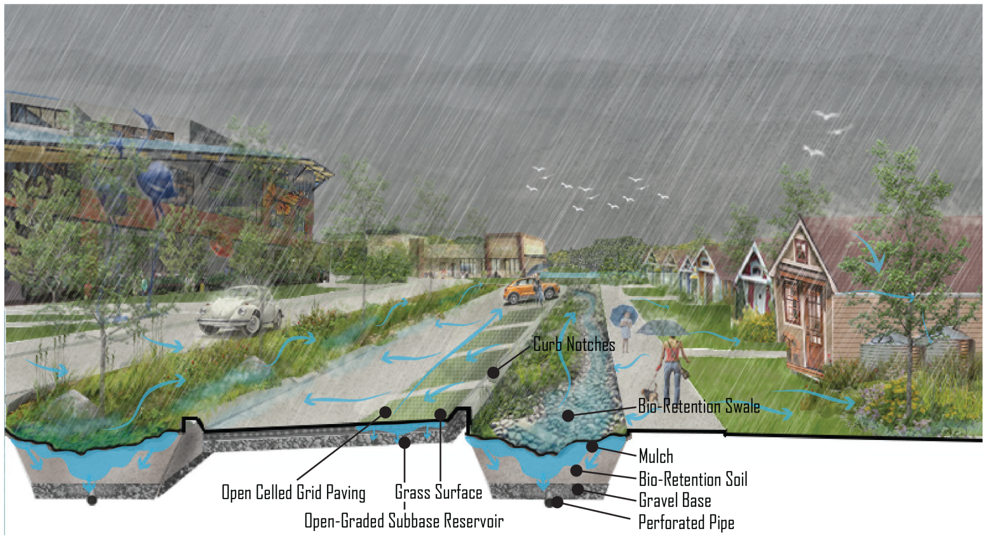

Figure 3.22: In this cross-section, Team ReSTORE gives a different perspective on how their proposal will address drainage and prevent flooding.

3.5 Multiscale Design Theory

Our work to formulate theory begins with understanding how student designers think about and deal with scale during design processes. We made observations, performed interviews, and collected and analyzed their design artifacts. From this data, we identified three visual design strategies that they used to deal with scale: multiply, map, and shift perspective.

The strategies are interconnected. They often appear in conjunction with one another. Students Multiply to explore and create different representations of a design context. They Map these, and other, representations together to connect and relate them. Through these mappings, they are assisted in Shifting Perspectives, and are therefore able to see the context through multiple vantage points. These strategies work together, helping the students understand the design context as a whole.

We synthesize these strategies to initiate a theory of multiscale design. Multiscale design theory seeks to understand the ways in which designers explore and define relationships across levels of scale and also how they juxtapose and synthesize contexts across representations: physical, geographic, and abstract.

Next, to abstract from our findings, we connect this new theory of multiscale design with prevailing theory. As mathematical biologist, D'Arcy Wentworth Thompson states, "The effect of scale depends not on a thing itself, but in relation to its whole environment or milieu" [108]. Architecture theorist Stan Allen claims,"Form matters, but not so much the forms of things, as *the form between things*"[104]. Another theorist, Corajoud, explains, "Crossing through scales is about controlling simultaneously and in the same way, the general and the specific, the close and the far" [109]. Multiscale design theory addresses ways in which design representations facilitate "crossing scales".

Architecture students work with and think about representations in a nonlinear manner across scales [110]. They need to present large amounts of information that often possess multiple relationships with other parts of their design. Prior theory contributes to our understanding. Ellin's understanding of the role of scale contributes to multiscale design theory, by shifting focus to, "Process rather than the product, relationship (or context) rather than isolated objects, and complementary rather than opposition" [111].

The practice of multiscale design strategies, in landscape architecture studio classrooms, contributes a model for future research, to explore new methods and interaction techniques supporting multiscale design. We hypothesize that Multiply, Map, and Shift Perspective strategies are not the only ways of seeing and doing multiscale design. Future work can then investigate to what extent the present theory is generalizable or context specific and how multiscale design is alternatively performed. These studies need to address various educational and professional design studio contexts.

4. Multiscale Design Curation: Supporting Computer Science Students' Iterative and Reflective Creative Processes

We investigate new media and methods to improve how teams of students create and organize artifacts as they perform design. Team design projects improve student retention, satisfaction, diversity, and learning performance [112]. Nevertheless, design is difficult to learn. Novice designers face creativity challenges such as fixation, depth-first thinking, and unwillingness to discard concepts to search for alternatives [10]. When students collaborate on teams, social and organizational challenges compound [11].

This research focuses on the processes of design curation to address the challenges facing design students. We define *design curation* as, the ways in which designers organize artifacts to think about, represent, communicate, present, and archive design processes. We frame these design activities through the lens of *curation*. Curation, in art practice, is a creative process of bringing elements together to conceptualize and create new contexts for purposes of communication and exhibition; works are found, collected, interpreted, and assembled, in an exhibition space, to stimulate active engagement [12]. We apply this art lens to prior practices and methods that involve contextualizing, presenting, and archiving design processes, which we identify as forms of design curation: design workbooks [1, 13], mood boards [7], annotated portfolios [14], and pictorials [4].

We investigate the research question, "How does free-form web curation affect student teams' iterative design processes?" We studied how teams of computer science students used free-form web curation to create and organize artifacts as they think about, represent, communicate, and present their design processes. *Free-form web curation* is a new medium that enables users to conceptualize and create new contexts—in which they discover, interpret, and represent relationships [16]. It supports students in creative engagement with prior work. Previously, we synthesized diverse artistic and scholarly practices, plus observed behaviors, to articulate creative curation strategies: collecting readymade and self-made content elements; sketching to relate elements and generate ideas; writing to label, annotate, explain, and interpret; assembling the elements in

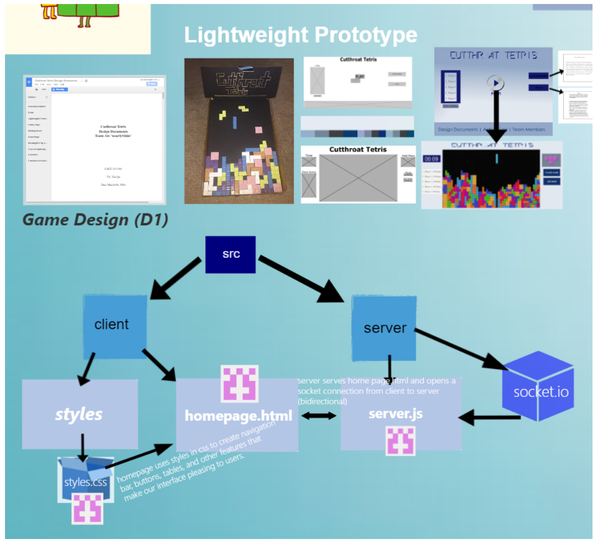

Figure 4.1: Design curation for an undergraduate team's multiplayer game project. In this view, we see their game design document, as a Google Doc, images of their lightweight prototype, wireframes, and system architecture diagram. Their design curation enabled them to assemble these different design elements in a shared zoomable space. [https://goo.gl/y2wPS5]

a zoomable space; shifting perspectives to view subspaces in different ways; and exhibiting, to present views of assemblages to audiences and users.

We choose to investigate students because we hypothesize that the effects of new media and methods would be more pronounced with novice designers. Novices are more open to trying unfamiliar design methods [10]. We performed two extended computer science and engineering classroom design interventions [63]. Undergraduate and graduate students used free-form web curation as their medium of design curation through 9-week, iterative, creative app design and development projects. Throughout the projects, student teams create specifications, wireframes, system diagrams, functional prototypes, and user study reports. They collect and assemble these project deliverables as self-made elements in their design curations. They use their curations to facilitate team collaboration and present to the instructors for feedback and grading (see example in Figure 4.1).

What is creativity? We draw on creative cognition: creativity involves human cognitive processes, e.g., conceptual combination and restructuring, remote and near associations, visual synthesis, and ideation [113]. In this chapter, we present interdisciplinary creativity research to investigate how students use new free-form web curation capabilities, in practice [114].

We argue that our study's computer science students lie in a spectrum between professional designers and laypeople. This spectrum is defined in the Four C model, in which creativity range from 'mini-c', personally novel to 'little-c' every day, 'Pro-c' professional, and 'Big-C', domain changing [115]. The student design work is a form of 'little-c', everyday creativity. Kaufman and Beghetto emphasize the importance of little-c for addressing common misconceptions of creativity, e.g., that only Big-C (or Pro-c) creativity matters.

Over the semester, we interviewed students and gathered their curations. We analyzed this data using grounded theory and qualitative visual methods. Our analysis shows that as the students use free-form curation to perform design curation, they (1) construct shared contexts of understanding; (2) communicate with team members and instructors; and (3) reflect on their iterative processes over time. Space and scale become central in how students engage in creative processes of contextualization.

4.1 Study Methods

This section describes our positionality, the courses involved in the present investigation, the project assignments, and our interview protocol and analysis process. We take a participatory approach [116], working with course instructors to integrate free-form web curation into iterative design and development project cycles. We performed a qualitative study to understand students' design processes, using a series of stimulated recall [117], semi-structured interviews. We interviewed 15 student volunteers about their experiences using free-form web curation for design curation. We analyzed transcripts using grounded theory methods [83]. We noticed that many students described similar processes for assembling their curations. We performed a visual analysis [78] on the final 27 curations to find the extent of structural similarities in curations across teams.

Using grounded theory methods [83], we coded and categorized student interview data. We identified the use of space and scale as the core theme across the main categories. We perform a visual qualitative analysis [78] of 27 final curations to further support the importance of space and scale.

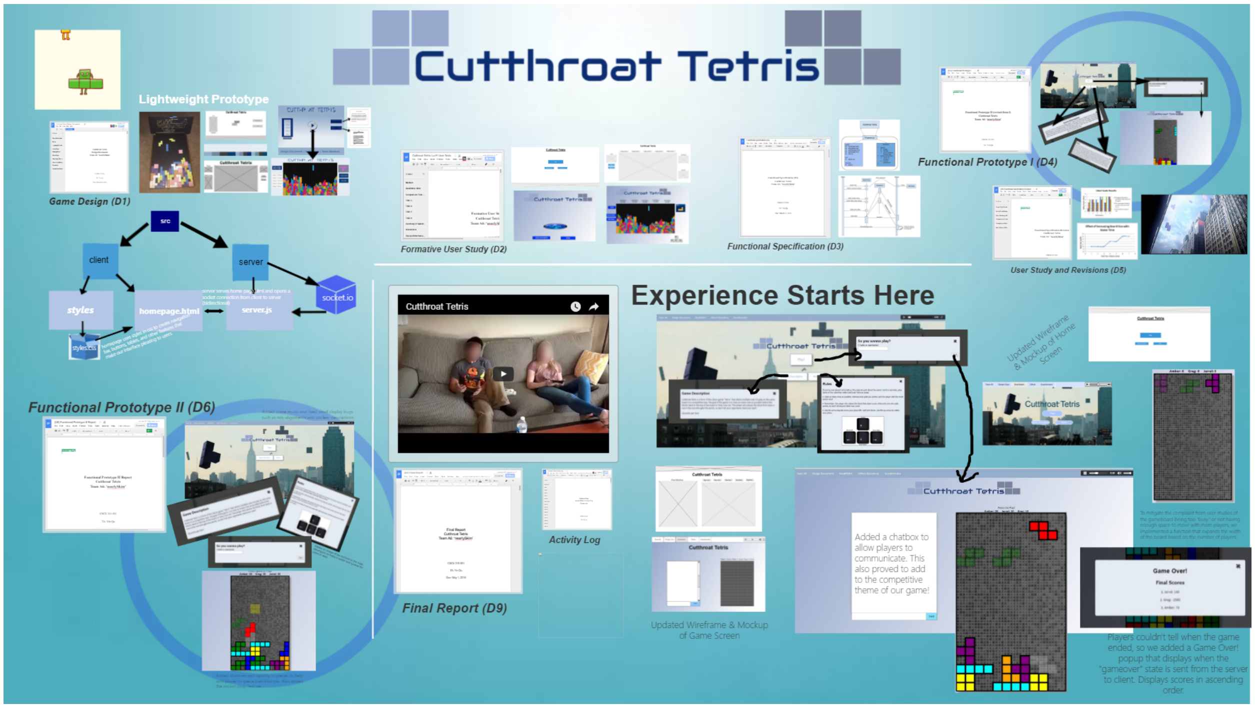

Figure 4.2: Final iteration of P12's team's design curation, for the *Cutthroat Tetris* multiplayer game. Two to four players collaboratively play Tetris in real-time on a shared game board, where each player controls a separate falling block. This final curation contains, within it, a series of 9 distinct deliverables. In this assemblage, the team gives visual emphasis to the most recent three. Under a central text annotation, "Experience Starts Here", we see the final Video, presentation, and report connected by spatial grouping. The curation uses 3 levels of scale to organize 116 elements. [`https://goo.gl/y2wPS5`]

4.1.1 Positionality

In qualitative methods, personal bias from researchers' experiences, backgrounds, and motivations should be minimized, but it is impossible to remove [118]. Thus, it is imperative for qualitative researchers to be upfront in declaring their position relative to their study [82]. Our approach to performing design interventions in education contexts instantiates the prescription of learning scientists, who advocate *design-based research*, which involves, "the production and testing of theory. . . [in order] to generate. . . design alternatives" [63]. Design-based intervention research requires evaluations that are no less simple than the phenomena being investigated, to generate evidence-based claims, which address theory [63].

Some authors of this chapter were instructors for courses the chapter presents. As instructors

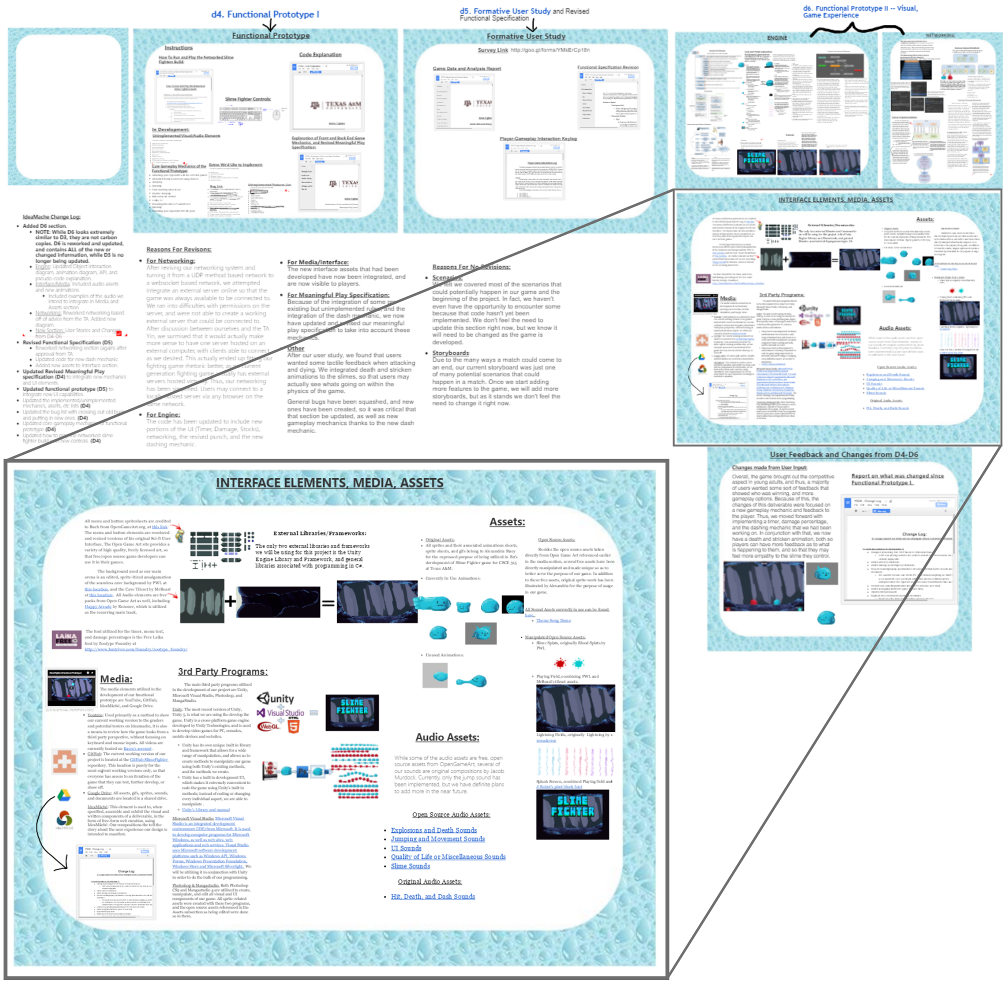

Figure 4.3: Overview of P8's team curation for their multiplayer arcade game *Slime Fighter*, with zoomed in view of the section labeled 'INTERFACE ELEMENTS, MEDIA, ASSETS' (bottom, left). Each of the blue bordered areas represents a specific weekly deliverable, which they arranged in an L shape, ordered left-to-right and clockwise. The 4 encapsulated sections along the right edge contain text and images for most recent deliverable. The text in the middle explains and connects the sections together and provides their design motivations for the changes made between deliverables. This nesting, as reported by P8, helped them have everything in one space. This curation organizes 213 elements using 3 levels of scale. [`https://goo.gl/NEAkyk`].

and researchers, our goal is to help students learn and self-actualize. Research and teaching grow intertwined. In this, we believe that expression and creativity, involving the combination of media and ideas, are inherently valuable. We developed the requirement for using free-form web curation as the medium for students to assemble their design artifacts, instead of as a linear document, such as PDF, the typical format. We did this because we believed that free-form web curation would

Course	Level	Duration	Teams	Curations
Programming Studio (Studio)	Undergraduate	9	24	150
Human-centered Computing (HCC)	Graduate	9	3	10

Table 4.1: Studied course contexts, each with the duration of the project in weeks, the number of teams, and the total number of curations created.

help students learn and grow.

4.1.2 Courses and Assignments

We performed design interventions [63] in two introductory courses during the Spring 2016 semester: *Programming Studio* and *Human-Centered Computing* (Table 4.1). Our design interventions take a technology probe approach. Researchers invoke *technology probes* to investigate experimental technologies, in real-life scenarios, to elicit contextualized experiences, and understand potential capabilities [66]. Through the interventions, a total of 102 students, in 36 teams, created 184 curations to organize, track, and present design projects.

Students used free-form web curation to organize artifacts into a weekly series of 9 project deliverables in each course. Central to the projects was designing a visual program [119], which communicates an envisioned user experience and conceptual models. Students' visual programs include wireframes and mockups. In a lightweight prototype deliverable, students created and tested a set of user experience scenarios.

Students were free to use any tools to create the wireframes, mockups, and other visual design artifacts. However, text documents—such as specifications and scenarios—were required to be submitted as Google Docs. Google Docs were used so that instructors could easily add inline comments and track changes. For each deliverable, students assembled and submitted their required design artifacts as a free-form curation.

For their curations, students used the free-form web curation probe, IdeaMâché (`https://goo.gl/9xHovW`). In IdeaMâché, content is collected through drag and drop, across tabs, in the web browser. The probe consists of a near-infinite pan-able and zoomable canvas and supports

Identifier	Course	Min.	Curation
P1	Studio	49	`https://goo.gl/GOJKXm`
P2	HCC	43	`https://goo.gl/aMuRzo`
P3	Studio	43	`https://goo.gl/XzkAIp`
P4	Studio	33	`https://goo.gl/Bu0f3K`
P5	HCC	35	`https://goo.gl/4hnQnJ`
P6	Studio	24	`https://goo.gl/ha2TeK`
P7	HCC	42	`https://goo.gl/32VcCo`
P8	Studio	38	`https://goo.gl/NEAkyk`
P9	HCC	40	`https://goo.gl/9dQkLd`
P10	HCC	43	`https://goo.gl/X8u94q`
P11	HCC	42	`https://goo.gl/fAYTPb`
P12	Studio	21	`https://goo.gl/y2wPS5`
P13	Studio	37	`https://goo.gl/RPUuRy`
P14	HCC	34	`https://goo.gl/su8cWb`
P15	HCC	29	`https://goo.gl/GAKBtw`

Table 4.2: List of participants showing their identifier, course, interview duration in minutes, and the link to their final curation.

continuous zooming across four levels of magnitude. All curated content, sketches, and writings are elements in the zoomable space, which are independently scaled and rotated. At the time of the study, the IdeaMâché web curation probe was the only system we knew to support embedding editable and scale-able Google Docs—along with image, text, sketch, and video elements—in a zoomable canvas.

4.1.2.1 Programming Studio

The undergraduate course, *Programming Studio*, is a project-based course with a focus on teamwork. The course is structured to teach students through engagement in a human-centered, iterative design process. They create and test prototypes, revise their designs based on user studies, and present their designs to instructors for feedback. In the extended project we studied, students worked in teams to iteratively create a multiplayer game. There was nine weekly deliverables, including a game experience design, functional prototypes, scenarios, storyboards, interaction de-

Course	Final curations	Mean elements	Left to right	Small to large	Nested older versions	Levels of scale
Studio	24	156.8	29.2%	33.3%	41.7%	3.08
HCC	3	121	25.0%	50.0%	58.3%	3.25

Table 4.3: Visual analysis evidence: mean curation sizes as number of elements, presence of particular multiscale curation techniques, and mean levels of scale, per course.

signs, user studies, and system architecture diagrams. Ninety students divided into 24 teams, each of 3 to 4 students. Figure 4.2 shows team *Cutthroat Tetris*'s final curation, which assembles all project deliverables. Figure 4.3 shows team Slime Fighter's curation, halfway through the project.

4.1.2.2 Human-Centered Computing

Like *Programming Studio*, students in the graduate course, *Human-Centered Computing*, used free-form web curation to assemble and present their project designs. The class of 12 students was organized into three teams of four to work on an open-ended project. Each team conceptualized, designed, built, and evaluated an interactive experience / application prototype. The project was structured as nine weekly deliverables, guiding teams through user studies and feedback from instructors. In the end, each team connected all the deliverables into a final curation, presenting a visual and textual story of the evolution of their app.

The suggested goal for the interactive systems was to support sensemaking [120, 121] experiences through the visual representation of semantic relationships among information resources. The project required that users be able to manipulate information parameters to weight, reorder, expand, and reduce, through processes, such as, "Overview first. Zoom and filter. Details-on-demand" [122]. Hence, student projects focused specifically on creating alternate representations of information, which could aid cognitive processes of understanding relationships among entities and properties. Student final projects included systems for visualizing and making sense of traffic accident data; visualizing and tracking progress in team-based projects; and visualizing web browser history in conjunction with user-curated content.

4.1.3 Protocol

There were 102 students, total, across both courses, 90 undergraduate and 12 graduate. We conducted 15 semi-structured interviews of students (Table 4.2). The 15 interviews cover 10 of the 27 teams. Interviews lasted an average of 36 minutes. We recruited participants via email. Participants were not compensated for their time, either monetarily or with course credit. They were informed that their participation would not affect their standing in the course or with the instructors.

Interviews employed stimulated recall, an introspective data elicitation method that uses visual artifacts [117]. The stimulus consisted of the curation that the student and their team had most recently worked on. Participants and interviewers viewed their curation on a shared display. Having the curation visible stimulated participants to remember thoughts and ideas that influenced their process, and helped interviewers ask questions targeted at specific visual and conceptual aspects of the creative work. Interviews were semi-structured, with an initial questioning route intended to elicit broad responses. Then, interviewers asked follow-up questions for specific details.

4.1.4 Analysis

Following a grounded theory approach, as we performed interviews, we transcribed them, performing multiple rounds of open and focused coding [83]. All researchers were involved in the coding process. Once four interviews were complete, each researcher independently open coded them. We then met to discuss the initial findings and update the semi-structured interview question route. For example, after noticing multiple participants addressing team dynamics, we added a specific question about team communication.

From the round of open coding, we collapsed our open codes into 6 initial categories: *process*, *project*, *getting resources*, *roadmap*, *visual style*, and *visual design*. These categories were used in the subsequent round of focused coding, over the next 7 interviews. After a round of focused coding, we modified our initial codes, adding a new code, *team*, and refining the code *visual design* into *layout*. Using these seven revised codes, we performed another round of focused coding on the last four interviews. Next, we collapsed remaining codes into three categories: *structure*, *communication*, and *process*. Subsequently, during theoretical integration [83], we renamed *structure* to *construct context*, shifting our framing from product to process. *Process* became *reflection*, to more specifically address student experiences. The categories share a theme around the use of space and scale.

4.2 Findings: Visual Analysis

In conjunction with the interview categories, we found that multiple student teams created similar visual structures. The apparent visual similarities between the curations led us to perform a visual analysis [78] of the students' final curations for each project (27 in total). We found that the three most common structural patterns are: *left to right*, *smaller to larger*, and *nested older versions*. These patterns extend previously observed patterns of free-form curation: *group*, *path*, *overlap*, and *morphology* [8]. *Left to right* and *smaller to larger* are new subtypes of the *path* pattern, which addresses how curation authors create linear and non-linear sequences through their curation elements. *Nested older versions* is a subpattern of the *group | nested* pattern in which groups of elements are scaled down so that they visually exist within a larger element or set of elements. However, *nested older versions* specifically refers to instances in which the nested elements are previous curations that were created earlier as part of an iterative process. We examined each curation, for evidence of these multiscale structure patterns, see Table 4.3.

For each curation, we also visually approximated the number levels of scale. We use levels of scale to describe how visually stratified the curation elements are along the Z-axis. Elements that exist on the same level of scale would be equally legible at the same viewport zoom. To approximate the levels of scale, we first zoom out until the entire curation is within the viewport. If there are elements at the viewport zoom which are reasonably legible, we count it as the first level of scale. Otherwise, we zoom in the viewport until the largest elements are reasonably legible, and count this as the first level of scale. Then, we zoom in until the next largest set of elements becomes legible and count this as the next level of scale. We continue as such until the smallest elements are legible. Table 4.3 shows the results of this analysis. The mean number of levels of scale for the entire data set is 3.15.

4.3 Multiscale Design Curation

Our derivation of understandings of how the use of scale can support design processes builds on our prior study of a landscape architecture studio classroom. We identified the design method: *multiscale design*: the use of space and scale to explore, juxtapose, and communicate relationships among design elements [123]. Multiscale design invokes human spatial reasoning to facilitate perception, understanding, communication, and creativity. Strategies of multiscale design are *multiply*, *map*, and *shift perspective*. *Multiply* is the repetition of form to anchor representations to the same scale. *Map* is the use of callouts or lines to connect representations at different scales. *Shift perspective* is the organization of representations at different viewpoints or scales to give context.

Multiscale design strategies from the landscape architecture studio [123] contribute to our understandings of computer science students' design curation processes. Specifically, we discovered that student design curations were constructed using the multiply and map strategies. The extent to which students use scale to organize and relate their iterative processes, as compared to prior studies of free-form web curation [50, 8, 16], led us to identify their practices as a new design curation method, which we call multiscale design curation.

Multiscale design curation involves collecting readymade and creating self-made design artifacts, and assembling them—as elements, in a continuous space, using levels of visual scale—for thinking about, ideation, communicating about, exhibiting (presenting), and archiving design process.

4.4 Findings: Interviews

Interviews with students revealed how they used multiscale design curation to: (1) construct shared context with their design artifacts; (2) mutually communicate, among team members and with instructors, through visual cues and mapping; and (3) reflect on their design iterations across deliverables.

4.4.1 Constructing Context

Multiscale design curation relies on an unstructured, zoomable space; with no templates provided. Students think constructively [124] about how best to structure their curations. Curation elements include all types of project deliverables, such as specification documents, scenarios, mockups, storyboards, system flowcharts, and links to functional prototypes. By thoughtfully assembling these design artifacts, using space and scale to create relationships, they create shared meaning [17] within their team and with course instructors. P2 describes his approach to assembling his team's curation:

> P2: I tried to position those [interface mockups] that followed those links and related to those spatially with where they are represented in the home screen.

As student projects evolved, the number of design artifacts increased. Therefore, the process of assembling their curations became more vital and challenging. Using visual scale was a common technique for students to mitigate the increasing complexity. P11 explains how one of his curations contained too much information compared to previous versions and how the previous organization provided a better overview.

> P11: This [curation] contains more information, but compared to other ones, I feel like you get more of a sense of what's happening, even without being able to read everything.

P9's curation was similar. He used a looping structure to create visual connections among elements across scales.

> P9: There is some sort of looping structure. . . between big arrows and small arrows, there's a huge difference between this one's size and that one's size.

Students often used sketching and spatial positioning to create a visual flow through their curations, showing their process in the order that made the most sense to them. This practice of using arrows connecting design elements across scales relates to the multiscale design strategy of *map*. This practice also instantiates the $path$ pattern of free-form curation [8]. P5 explains his approach to creating an understandable path.

> P5: To make the things easy for you to navigate, I chose this particular path. You start here, then the needs and requirements, then I show that the scenarios are inspired from the needs and requirements.

In some cases, students adopted a *left to right* structure, as P6 explains.

> P6: It's just kind of intuitive, going left to right, in the way that we read...from there it kind of turned into a spider...It is intuitive. Here's the data, left to right; here's the discussion left to right.

Not all curations were organized with linear paths. P4 used spatial structure to encourage viewers to explore the elements of his curation. He compares the unstructured flow of a free-form curation with the linear flow he associates with using Prezi, a popular zoomable presentation tool.

> P4: Because it's free-form and you can go anywhere...It doesn't really hold your hand and say, go here. I thought that was the point of a [free-form curation], otherwise we'd use something like Prezi.

P2 also adopted a non-linear layout, using scale to suggest paths to the viewer:

> P2: I was trying to avoid information overload and just give them a sizable chunk to think on and look at.

While some students enjoyed organizing their design elements in a free-form space, others did not. One student expressed difficulties overcoming the lack of initial visual structures.

> P12: It was difficult for me, not being a visual thinker. It was a little bit too free-form. I know that's part of the name, but it was difficult.

4.4.2 Communication through Visual Cues

Students used their curations to communicate among team members and with instructors. They used visual cues—e.g., sketching, positioning, and scale—to denote the significance of individual elements or their prescribed viewing order. Visual cues also assisted students in delegating tasks to team members. Through visual communication, they create a shared visual context [125], grounding their design discussions.

Many students reported that they delegated members to work on different aspects of a project, then came together as a team, to integrate them. They used design curation to help them perform articulation work [17], such as scheduling, allocating resources, assigning tasks, and dividing labor. While the specifics of these processes looked different, within each interviewed team, curation played a mediating role in the delegation of collaborative and individual work. P13 describes how his team learned to "flow [their] ideas together".

> P13: Once we started really learning how to share [the curation] together, and not just have it be like, "This is my part here. Here's your part," and separating it across. Once we had it being able to flow, we learned how to flow our ideas together.

Others combined individual and collaborative work. P1 remarks on how his curation facilitated collaboration in terms of "flow".

> P1: We all worked together to do the actual renderings and images. The diagrams were authored by my teammates and I incorporated them into the flow.

The students' curations were not only for them to manage and organize their projects but were also turned in, to the course instructors, for feedback and grading. Students were expected to incorporate instructor feedback in subsequent deliverable iterations. As part of this process, students developed best practices for communicating changes and other important factors to the instructors through their curations. P7 describes the importance of making it easy for the instructors to track their progress through the project cycle.

> P7: If I don't mark it, [the instructors] don't actually know which part is newly added and which is not.

Again, scale was a common technique for visually emphasizing aspects of the curation. P10 and P13 both remark on how they used scale to relate design components.

> P10: I knew that I had to make it smaller to keep the size of the entire thing. However, I couldn't make the scenarios smaller, or at least I think I shouldn't, because they're very important.

> P13: These big blocks are the ones where we really want your eyes to go first. Then this higher level architecture summary, in addition to the low level architecture summary, we had already discussed that in other deliverables, which is why they're not as big.

In addition to using implicit visual cues, some students used sketched arrows or embedded writing, as self-made elements to provide explanations in their curations. P9 states he had anxiety about making sure the instructors were able to understand his design. To alleviate this, he wrote a series of annotations to explain his design.

> P9: I used a lot of annotations, because I didn't know if they were necessarily clear from the arrows alone.

While curation required visual design effort on the part of the students, P3 observed that using free-form curation as the medium for project deliverables gave a new sense of understanding the design project as a whole.

> P3: Instead of flipping through 50 pages, you can easily scan this, and, if it's laid out nicely, kind of like this, you can easily scan through and find exactly what you're looking for.

4.4.3 Reflection through Visual Repositories

Students' curations functioned as visual repositories, in which they assembled content across iterations, and looked back, reflecting on their ongoing design processes. Sometimes a prior version was embedded as a subsection within the next curation. In others, they created organization and content distinct from previous deliverables. Through curation, they learned to function as reflective practitioners [95].

Throughout the project cycles, students were required to submit updated curations at regular intervals. Their curations could be newly created for each deliverable. Alternatively, students could use the same curation week to week, making adjustments and changes to incorporate new decisions and design elements. P12's team used the single curation approach.

> P12: This is the only [curation], we just appended on it the whole semester.

Similar to P12, P15's team also used a single curation for the duration of the project. Each week they would assemble new content into their curation, mostly leaving the previous organization of elements intact. His team developed a visual strategy for using space and scale to help create a flow between these different areas of their curation.

> P15: We were generally working from left to right in time. We'd zoom out and just make everything slightly bigger for the new week.

As projects progressed, curations' function as visual repositories grew. Students used older curations to reflect on their evolving designs. These older curations could be separate or subsections of an ongoing curation. P9 articulated how older curations served as a "time capsule", which helped him make design decisions.

> P9: I was still in the process of deciding how the interface was going to go. I guess it is kind of useful that I have all these different versions. It serves like a time capsule.

P8 explicitly describes how his team's prior curations, as repositories, supported their engagement in reflection.

> P8: I feel like the [curation] helped us have everything in one space, where we could just open it up and see. . . [if] we made a mistake. . . and we realized,"Oh, we need those back." I like being able to see the progression of the entire project.

Free-form web curation enables collecting and assembling multiple forms of content, such as images, text, videos, and embedded Google Docs. Students took advantage of this and used their curations as living repositories for their design documents. As P6 explains, he preferred having editable documents organized visually, as elements in their design curation space, rather than as icons in a shared folder.

> P6: Embedding Google Docs within the [curation] helped us have somewhere we can all see where we're at and where we are in the process.

Some students appreciated having all their design artifacts together in a continuous zoomable space. P8 found benefit in having his visual assets together (Figure 4.3, bottom left).

> P8: I had all of my assets in one place, instead of having to go though the hurdles in order to get a Google Drive that has this. I can just open the [curation] and see the assets that I'm using right now.

4.5 Discussion

We theorize that, in design curation, the medium in which elements are assembled inexorably affects how people think about, relate together, and work with the elements. Our extension of McLuhan's foundational principle—*the medium is the method*—emphasizes the strong connection between the expressive and interactive properties of a design curation medium, and how people perform design using it: i.e., how they construct knowledge, ideate, communicate, and learn. The act of creative expression extends beyond one's own mental and physical experience to include the media and systems that enable the expression. Expressive mediums and the systems that enable them are intrinsically connected [126]. We develop contributions addressing zoomable user interfaces, constructivism, contextualization in CSCW, premature formalism, and reflection through our understanding of multiscale design curation.

4.5.1 Zoomable User Interfaces and Multiscale Design

Hornbaek and Bederson define zoomable user interfaces (ZUI) as those that "organize information in space and scale, and use panning and zooming as their main interaction techniques" [127]. Multiscale design curation is congruent with this definition. ZUIs are appropriate for doing multiscale design curation but neither necessary nor sufficient. In many cases, ZUIs do not support creative expression. Some are intended for viewing, not authoring, such as digital map interfaces.

Photoshop can function as a ZUI, intended for powerful authoring. However, creating a Photoshop document begins with specifying its rendering resolution. We argue that this belies multiscale design curation, even though it does not preclude it. The inherent focus on rendering resolution promotes thinking on a specific scale, unlike arrangement across levels of scale, which we observed in student curations. As we see in Figure 4.3, rendering it at a single scale can become problematic. The scales and bounds for rendering are not known a priori.

Multiscale design curation is the result, not of an interface, tool, or system, but rather structural aspects of the zoomable spaces and the creative processes through which they create them. Multiscale spaces are fractal [128]. They can simultaneously show both overview and detail to facilitate spatial thinking and assist in navigating across scales.

4.5.2 Constructivism through Curation

Multiscale design curation instantiates a constructivist approach to design learning. The process is valued as more important than the final products. A constructivist perspective on learning states that learning happens over time as students engage in planning and revising cycles [129]. Students learn by making their own representations and defining their own organizational structures and flows [130].

We observe that the students' design curations support constructivist activities, such as collecting, organizing, discussing, and evaluating [131]. Throughout the project, students are required to create different deliverables, such as specification documents, mockups, and functional prototypes. Their design curation acts as a central space where they collect and relate all of their design artifacts. Multiscale design curation stimulates students to develop their own structures, because as P4 stated, “[it] is free-form and you can go anywhere. . . it doesn’t really hold your hand and say, go here.” We observed students working to connect elements together to form a cohesive story. P5 talks about how they “chose this particular path” through their team’s curation, because they thought it would be easiest for the instructors to navigate.

4.5.3 Contextualizing Cooperative Design Activities

Harrison and Dourish found that spaces serve as places, which provide opportunities for social interaction and carry social meaning, through understandings of behavioral appropriateness, practices of communities, and cultural framing [132]. We found that, even without live multiuser functionalities, the zoomable space of free-from web curation functions as a place that contextualizes a range of multiscale design curation cooperative activities, from organizational articulation work through collaborative creativity.

4.5.3.1 Articulation Work

Through assembling their curations, teams create spaces that instantiate shared visual contexts [125]. A shared visual context acts as a common ground for team interactions and communication. Shared contexts support the students in performing articulation work, i.e., the activities of a community that facilitate collaboration, such as scheduling, allocating resources, assigning tasks, and dividing labor [17].

4.5.3.2 Collaborative Creativity

Students used their multiscale design curations in ways that resemble the creative, collaborative practices observed in the physical design studio [96]. They mimic practices, such as using the space to divide up a design challenge among members. Students spoke about how they would structure their individual work areas near one-another in the curation space, to create shared awareness of each other’s work. Their use of space to contextualize real-time collaboration is consistent with our more recent investigation of live media curation, which extends free-form web curation, by supporting not one, but multiple users, concurrently collecting and assembling together, augmented by live audio/video streaming [133].

Multiscale design curation provides new support for collaborative creative processes. P13 observed that as their team learned to share the curation, they could flow their ideas together. P3 and P8 discovered a holistic sense of their team's design processes.

P2 observed, "[a curation] is just a blank slate where you position things how you wish." The structure of a curation develops over time, sometimes continuously, sometimes with discrete jumps, prompted by instructor feedback or new inspiration. The lack of initial structure, in conjunction with the ability to easily transform and restructure the curation, supported students in avoiding premature formalism [134], while helping them design for change [135].

4.5.4 Informal Structures and Chunking

As projects develop and the number of design artifacts grows large, using the zoomable interface, for organization and assemblage, becomes critical. While the number of elements in design projects grows large, human working memory capacity remains limited [136]. Students selected and scaled groups of elements, within their curations, to articulate and differentiate conceptual levels (See Figures 4.2, 4.3). As P7 says, "To do the process of making it make sense; we made different clusters." In this way, multiscale design curation supports visual *chunking*, to extend working memory [137], specifically by enabling participants to scale sets of design artifacts, as they engage in relating and connecting them.

The medium of free-form curation supports visual chunking through the use of space and scale, in ways which not possible with linear mediums for collecting and presenting design elements, such as PDF and slideware. The problem is that in these linear media, as documents get large, elements become distant, and so seeing relationships across elements becomes increasingly tricky.

Having design elements related together with their revisions was beneficial both to instructors and to students. Students reported that the multiscale design curations helped instructors, as well as themselves, track the ongoing design process. P7 said, "[the instructors] cannot remember each thing." The curations enabled viewing the entire design process in a continuous space. Viewing the curation as a continuous space contrasts prior design workbooks, in which design elements are assembled and related together, but across separate pages. P3 points out, viewing the curation is “easier than flipping through 20 pages.”

4.5.5 Reflection

Fundamental to multiscale design curation is an underlying methodology of design as a reflective process [95], in which designers draw from, connect to, and relate with, not only previous iterations or phases, but the entire design process history, as a whole. The medium in which design artifacts and aggregated and documented impacts the capacity for stimulation and reflection [138]. Multiscale design curation takes advantage of spatial positioning, which researchers show supports reflection [139], with a zoomable interface. Inspiration gets stimulated when designers organize prior visual material together, alongside their design solutions [140].

Through this assemblage of heterogeneous elements, multiscale design curation overcomes the fragmentation of design artifacts, which hinders reflection [141]. P8, who identifies as a “visual learner”, explains how the team curation provided “all of my assets in one place, instead of having to go through the hurdles in order to get [them in] Google Drive.” Having everything in one space enabled them to “See things through the deliverables.”

Students often assembled their next set of project deliverables in the same curation space as the previous. It was common practice to create a copy of the previous curation iteration and move its content within the next iteration, placing it to the side or at a smaller scale, manifesting the *multiply strategy* [123] of multiscale design. We call this pattern *nested older versions*; it occurred in 48.7% of the final curations. These previous iterations, nested within the current version, served as what P9 calls, a “time capsule”. This use of the *multiply strategy* by the computer science students differs from its use in landscape architecture. Architecture students *multiply* maps and site plans to make visual comparisons between conceptual layers. Computer science students use the *multiply* strategy to show changes across iterative revisions.

Students developed their multiscale design curations iteratively. They related and interconnected design elements across all phases of their project. We extend prior work on supporting reflection with curation, in which the assembled design elements function as *rich bookmarks*. Rich bookmarks integrate a visual representation with semantic information from the element’s source context [142]. Prior research shows that rich bookmarks support reflection and creativity in ideation tasks [142]. We find that they have similar benefits when used in collaborative and iterative design processes.

4.6 Conclusion

In art, *assemblage* is the process of fastening objects together. Assemblage highlights the duality and tension between the original and resulting contexts [48]. Over time, designers learn to navigate and understand the emerging landscapes of their abstracted design spaces [143]. Navigating abstract design spaces provokes them to engage in design synthesis, in which relationships among elements, rather than the elements themselves, become most significant [121]. Gaver states that this a core component of design curation, that assemblage in a design space supports the emergence of new ideas [1].

We observe students contextualizing their design artifacts —e.g. game rules, storyboards, user study data, and functional prototype code—across deliverables as curation elements in a continuous, zoomable space. The extent to which students used space and scale to create stratified structures of organization lead us to theorize a new design curation method, which we call multiscale design curation.

Multiscale design curation involves collecting and assembling of elements—in a continuous spatial context, across levels of scale—to understand, communicate, and reflect on a design process. A zoomable user interface facilitates. Open, unstructured space avoids premature formalism, supporting iterative design. Multiscale design curation is both process and product-oriented. It incorporates the curation strategies of collecting, assemblage, sketching, writing, shifting perspective, and exhibiting (presentation). Multiscale design curation supports creative cognition processes, such as association, convergent, and divergent thinking, synthesis, and emergence [113]. It provides a shared visual context that supports creative and articulation work in an integrated space. As one student puts it, multiscale design curation helped them "Visualize and convey transitions and relationships... [to] write a better roadmap."

This investigation represents a beginning, not terminal, point, in research on multiscale design curation. We have begun to develop theory that incorporates different disciplines' perspectives on thinking about and making use of visual scale. We still have much to learn about how new design methods and interfaces can support understanding, reflection, and collaboration, in diverse design fields, such as visual, information, interaction, and industrial design; architecture; and civil and mechanical engineering.

5. Sustained Prototyping Situates LiveMâché in Classrooms: Supporting Project-based Learning with Design Curation

Project-based learning places students in realistic environments to help them develop contextualized skills and knowledge. It engages them in high-level, open-ended activities with no correct answer or set methods [9]. Students must purposefully and creatively engage in iterative design processes [64]. While project-based learning is important to diverse fields, including engineering, architecture, business, law, social work, and education [112, 144], there is a need for technology to better support students in connecting their creative activities to learning [9, 145]. In this work, we present a prototype system, LiveMâché, and its associated design research methodology. Our sustained methodology supports us in investigating the use of transformational technology in real-world classrooms to understand such complicated and interconnected phenomena as learning and creativity.

To address design and ideation challenges in project-based learning, LiveMâché enables students to collaboratively collect, organize, sketch over, write about, share, and exhibit their project artifacts as visual assemblages. In this work, we see project-based learning activities as design curation. Students assemble inspirations, references, and examples; they recontextualize these to fit their specific needs and design choices; and they annotate and enhance their assemblages with their own artifacts; they create exhibitions to be shared within their project team and to their instructors and classmates. With this understanding of project-based learning activities, we develop the curation prototype LiveMâché to facilitate non-linear, multiscale organization as a means for supporting ideation and collaboration. It affords collaborative collecting, assembling, sketching, and writing representations of ideas into proximity with one another, creating relationships, and multiplying ideation opportunities afforded by visual assemblage.

Based on the open-ended and contextual nature of project-based learning, we build similarly open-ended research methods, such as the various approaches HCI researchers have taken to using probes. Probes are lightweight, simple technologies which can be deployed into real-world settings to explore contextually valid phenomenon [65]. Technology probes are one such method used to meet user needs, field test techniques, gather qualitative and quantitative data about use, and inspire users and researchers to think about the technology's transformative potentials [66]. Technology probes are meant to be open-ended and co-adaptive in that users will adapt their processes to work with the probe and they will use the probe in unexpected ways to fit their purposes [67].

Our research methodology is predicated on the notion that to understand the impacts of a system designed to support studying creativity and learning. Participants must be engaged in real tasks that matter to them. They must have skin in the game. Researchers must "recognize the importance of local contexts [and] treat changes in these contexts as necessary evidence for the viability of a theory" [63]. In studying LiveMâché, we began by following the technology probe methodology, but over time our method has morphed into something more. We go beyond the functionality and range of probes, with *sustained prototypes*, in which technology and infrastructure are iteratively created through cycles of contextual use across a range of deployments. To study team project-based learning, we move beyond the probe in terms of functionality and longevity. We aim to maximize the number of new learning phenomena that might emerge throughout a classroom intervention. While probes are meant to be as simple as possible, we require open-ended functionality to support a variety of unexpected activities. Technology probes are not intended to change during their deployments. In contrast, the LiveMâché prototype has been iterated upon to change and grow in response to new courses, instructors, and adaptions of practice. Sustained prototypes address the kinds of infrastructure needed to perform real-world classroom studies and gather meaningful data on collaboration, creativity, and learning.

To date, LiveMâché has been used in 15 university course instances from Fall 2017 to Spring 2020, enabling 1500 students to create 3500 curations. We first motivate the need for situated research when studying learning and creativity and argue for our approach to conducting situated research. We then present an overview of the technical components of the LiveMâché prototype. Next, we describe our methods for deploying and studying the system in classrooms. We present a range of data from the 15 course instances, highlighting differences in design curation activities across different design fields. Lastly, we discuss how technology, research methods, and pedagogy combine to support sustained, transformative research on complex, interconnected, and situated learning and creativity activities.

5.1 Project-based Learning & Curation

In project-based learning, students pursue solutions to nontrivial problems by asking and refining questions, debating ideas, making predictions, designing plans and/or experiments, collecting and analyzing data, drawing conclusions, communicating their ideas and findings to others, asking new questions, and creating artifacts [9]. Projects are central, not peripheral, to the curriculum. The projects push students to engage with the central concepts of a discipline [146].

According to Blumenfeld et al., for project-based learning to succeed, it must address "the complex nature of student motivation and knowledge required to engage in cognitively difficult work" [9]. Project work is directed to the application of knowledge. This is in contrast with problem-based learning, whose goal is more about knowledge acquisition [147]. Project-based learning helps students develop communication skills and teamwork experience [147, 145]. This research introduces *design curation* as a means for supporting students in focusing, thinking about, communicating, and reflecting on their iterative project processes.

5.1.1 Activities of Project-based Learning

Within project-based learning, new technology offers new possibilities for students to be creative. New technologies can broaden and stimulate how students engage in creative learning activities [148]. Projects involve students in a constructive investigation. They are student-driven. Students learn primarily by constructing knowledge and making meaning through iterative processes of questioning, active learning, sharing, and reflection. They learn to focus their attention and project efforts and monitor and evaluate their team members [149]. They learn to perform articulation work, which is the meta-activities that facilitate collaboration, such as assigning tasks and organizing work sessions [17]. To motivate the design of LiveMâché, we identify a set of collaborative project-based learning activities in Table 5.1. We relate each activity to strategies

Learner Activity	Curation Strategies	Operations	Data Method
Access Information Easily obtain information about subject matter topics, concepts, ideas. [9]	Collect.	Choose heterogeneous content as elements by drag-and-drop.	Curation Element Variety metrics: type, information source
Actively Structure View, manipulate, create multiple representations [9]	Assemble. Sketch. Write.	Free-form, multiscale assemblage [elements]. Embedded document elements.	Visual data. Patterns. Curation process data.
Manage Complexity Minimize mental details of artifacts [9, 64]	Exhibit.	Multiscale spatial organization [elements].	Curation Element Fluency metrics: range across courses
Work Together Share responsibilities, monitor collaboration [17, 149, 145]	Exhibit. Version.	Assign roles. Duplicate, transform, and share curations.	Curation working time. Cooperation Index.

Table 5.1: Learner activities of collaborative project-based learning. We connect each activity with their respective curation strategies, specific operations supported in LiveMâché, and forms of data which capture them.

of free-form curation and the associated operations supported in LiveMâché. We also connect each activity to the specific method of data, which we use later in this chapter to reveal how these activities manifest across design disciplines.

5.1.2 Curation as a Model for Supporting Project-based Learning

Curation is a means for framing and conceptualizing how people understand creative work and its contexts [12]. Curation emerged in art as a distinct mode of discourse and framework for interaction across disciplines. Central to curation is the creative act of re-contextualization.

5.1.2.1 Recontextualization: Generating Ideation

We associate curation with the notions of readymade and self-made artifacts. Artists and curators fasten together readymade and self-made artifacts in processes of *assemblage*. Assemblage visually and conceptually creates duality and tension between an element's original and newly formed contexts [48]. Processes of creating and experiencing assemblages stimulate *visual thinking*: perception, recognition, and reflection become intertwined in creative acts of forming and illustrating new meanings [19]. As artifacts and ideas become recontextualized, they gain new, emergent meanings, thus multiplying possibilities interpretation and ideation.

5.1.2.2 Ideation Strategies of Free-Form Curation

Students engaging in free-form curation invoke strategies—collect, assemble, sketch, write, shift perspective, and exhibit [16]—to perform design curation. Students *collect* diverse design artifacts to Access Information, represented with heterogeneous media: images, text documents, spreadsheets, sketches, and videos. They *assemble* the elements in a zoomable curation space, making design choices to create visual presentation, structure, and layout. They think critically to conceptually and visually relate elements, *shift*ing *perspective* to discover connections among individual elements and groups. *Sketch*ing and *writ*ing play integral roles in how they explain and relate design elements. They *exhibit* the resulting assemblages—to teammates, peer teams, and instructors—as curations. Each represents a team's current position in their design process, the path they followed to arrive there, and the emerging horizons of their design.

As part of this investigation, we identify a new strategy of free-form curation: versioning. *Version*ing occurs when students duplicate their curation, either in part or in whole. They set aside elements to create a view of their process at a specific point in time. *Version*ing activities support students in changing and evolving their curation over time [135] while maintaining a history of their process.

5.2 Situating Real-World Investigations: Sustained Prototypes

Computing keeps growing more pervasive in everyday life [150] and education [148]. This pervasiveness increases the divide between user experiences in controlled HCI laboratories versus situated, real-world contexts [151]. The divide confounds with the difficulties of investigating contextual phenomena, such as learning [63] and creativity [152]. HCI uses field deployments to study technology in context, but they are messy and uncontrollable [153]. Large companies, with widespread and robust infrastructures, can engage users in real-world use of exploratory technologies. However, it is difficult for academic researchers to investigate new and potentially transformative CSCW technologies in meaningful contexts. A manifestation of this problem is that as of this writing, only 4 of the 60 highest citation count CSCW papers focus on systems that the authors built [154].

When investigating complicated and interconnected phenomena, controlled laboratory experiments are inadequate [64]. The goal of applied design research is to impact participants while simultaneously generating new knowledge or theory [63]. Field studies have been used extensively in HCI for evaluating how technologies and participants can impact one another [153]. They can help understand behaviors in contexts of use, but they are messy, and their results cannot be controlled.

5.2.1 Probes

Probes and prototypes are vital to a variety of in-the-field, design-based research methodologies, because of their capacity to produce contextualized, real-world changes [65]. A probe is sent out into the unknown to make discoveries and report back its findings. Probes maintain an open and reflective methodology around the design of the probe and the connected study methods. Cultural probes [155], for example, are lightweight setups that are placed in real-world settings to inspire reflection and new ideas.

Technology probes resemble cultural probes in mission. However, they are more computational and robust in implementation and deployment [66]. The robustness of technology probes provides flexibility in where and how they can be deployed. Technology probes maintain focus on developing real-world insights rather than usability or long-term use.

During the first deployment of a new technology in a new context, all potentials of that technology are not known. Slow technologies are sensitive and responsive to unknown practices of use, which slowly manifest over time [156]. As users begin to experience and adapt to a new technology, they are expected to gain insights into how the technology can be better utilized or be inspired to engage in new activities that were not previously possible.

5.2.2 Sustained Prototypes

Design-based research demands evaluations that are no less simple than the phenomena being investigated, in order to generate evidence-based claims, which address theory [63]. The gap and phenomena our research addresses involve how to support design and ideation within student teams, working on design projects.

Through performing contextually situated research over the course of multiple years, we have developed a research method to address the need for CSCW research infrastructure. We introduce the method of *sustained prototypes* to provide a platform for investigating and transforming real-world practices of use, over time, adapting in response to new understandings, and growing to support processes that were not initially specified or expected. We combine layered sociotechnical systems, cyber and human infrastructure, and multi-dimensional data collection methods.

While sustained prototypes build on the previous probe methodologies: cultural probes [155] and technology probes [66], we choose the label *prototype* over *probe* because of the significant increase in functionality necessary for supporting a range of emergent collaborative, real-world activities. Sustained prototypes go beyond technology probes in that they should be equipped to go beyond provocation, they support sustained, real-world work.

Our approach builds on Shneiderman's "Multi-dimensional In-depth Long-term Case studies (MILCs)" [157], such as in data collection methods, users becoming expert, and longitudinal use cases. Sustained prototypes share MILC goals: "1) the refinement of the tool 2) general principles for the design of such tools 3) achievement of users' goals through the use of the tool" [157]. WE extend MILC, noting that sustained prototypes are designed to undergo cycles of refinement to adapt to the evolving user goals throughout multiple, long-lived deployments.

Sustained prototypes grow in technical functionality and cyber-human infrastructure over time. Infrastructuring involves the creations of new systems and roles for building and maintaining systems of working [158]. Human infrastructure refers to social and organizational structures [159]. Cyber or information infrastructure refers loosely to digital facilities and services usually asso-

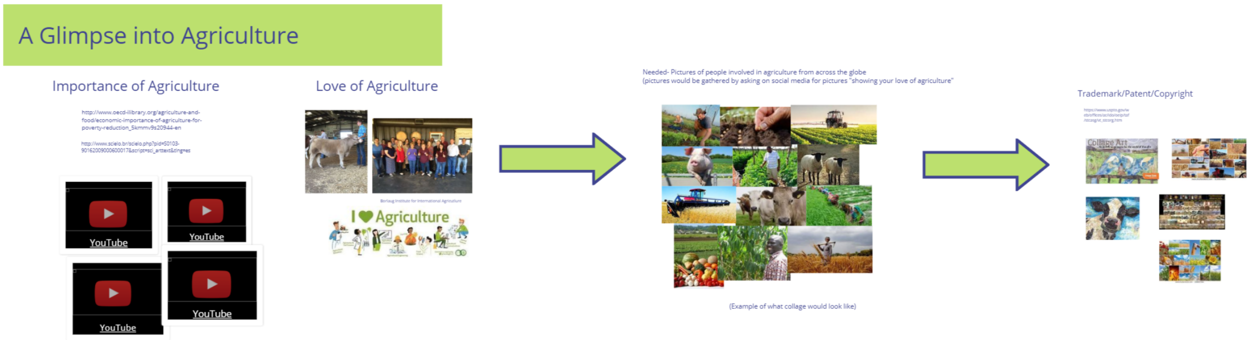

Figure 5.1: This shows a portion of an innovation curation from the course *Creativity & Entrepreneurship*. They collect YouTube videos and images and add their text annotations to present their agriculture tourism service in a sequence of element groups from left to right. Course: $Entp-2$. Fluency: 206. Visual Patterns: $group$ | $spatial$ and $path$ | $linear$.

ciated with the internet: e.g., computational services, help desks, and data repositories [158]. Growing infrastructure links with existing conventions of practice and becomes a part of existing structures, social arrangements, and technologies. It both shapes and is shaped by the situated conventions of communities of practice [160]. As the prototype becomes embedded in a context of use, both researchers and participants develop new insights into how the prototype can be utilized and iterated to better support existing activities, and entirely new activities.

5.2.3 Sustained Investigation in the Wild: Distinguishing Features

Sustained prototypes involve technology and infrastructure that are created iteratively, through cycles of contextualized investigation, across a range of situated deployments. They are open to unanticipated forms of use. They are designed as part of a participatory and evolving process. They serve to facilitate gathering data and feedback from participants. Sustained prototypes enable researchers to engage in continuous processes of data gathering and theory-making.

Like Hutchinson et al., in their explication of technology probes [66], we outline distinguishing features that sustained prototypes need for investigation in the wild:

Sufficiently Robust and Usable: Real-world use is messy. Prototype usage levels are variable. The system must be robust enough to withstand the demands of both every day and high-traffic use. In our case, students are using the prototype to complete and turn in assignments. This leads to a significant increase in demand during the hours leading up to assignment deadlines. Sustained prototypes need to be robust and usable, as compared to single-purpose probes. They must maintain a commitment to a stable and consistent user experience. At the same time, sustained prototypes are still tools for research. They are less functional than commercial products. They must maintain a delicate balance of development priorities, such that they are functional enough to affect real-world change, while not requiring exhaustive development efforts.

Open-Ended Functionality: Conventions of practice are expected to change as users and research adapt to the prototype. Changing practices iteratively reveal new user needs and requirements, which, in turn, motivate new functionalities. Sustained prototypes need to be modular with sufficient software engineering to support evolution and change. Similar to designing for hackability [161], prototypes strive to respond to unanticipated uses. Flexible software design patterns [162] and agile development practices [163] enables a prototype to be quickly built on, extended, and modified. With LiveMâché, the curation element structures are sufficiently modular to all us to easily implement new element types such as the embedded Google Doc elements.

Co-Iterative: Sustained prototypes need to be developed through ongoing collaboration with participants, in use-contexts. They rely on ongoing feedback from participants to remain sensitive and aware of emergent use in context. Logging and feedback mechanisms can help support this collaboration. In our case, we work with instructors and students to iteratively prioritize system capabilities and define student assignments. The need to understand ongoing use motivates developing instrumentation, such as dashboards, to visualize log data for developers, as well as participants [164].

Evolving Contexts: Sustained prototypes are not designed for a single context of use. Instead, they support a range of potentially overlapping activities, across multiple contexts. In our investigation, many of the courses were not part of the initial plan. However, they spontaneously arose from snowball sampling, when instructors or students would share the prototype with people in other courses or contexts. This leads to LiveMâché being used in additional contexts that are not part of this particular study. For example, it has been used in multiple literature courses and among student graphic design, animation, and game development clubs. Sustained prototypes adopt a hopeful attitude: if you infrastructure it, they will come.

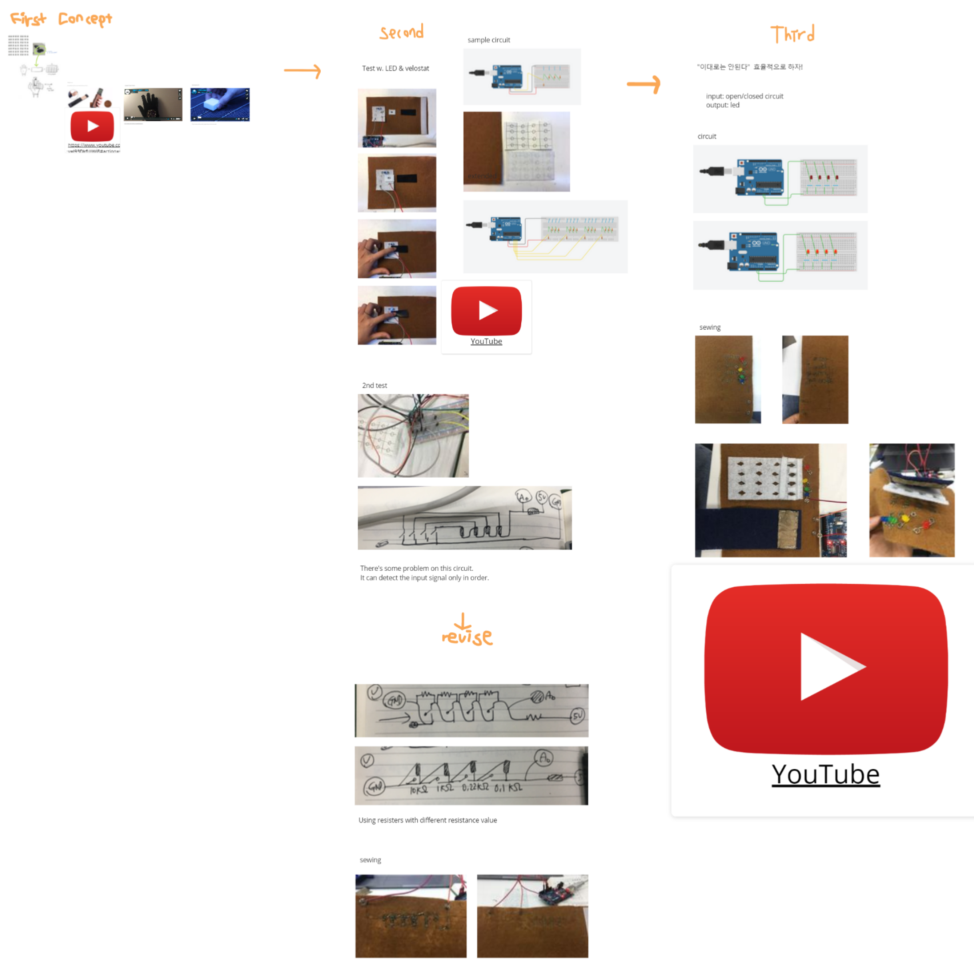

Figure 5.2: A design project curation documenting the student's design process of conceptualizing and building a wearable sensor. The curation is organized into three vertical columns. Each column corresponds to a specific project assignment deadline. Course: $InDe-2$. Fluency: 63. Visual Patterns: $group \mid spatial$ and $path \mid linear$.

5.3 LiveMâché

We develop LiveMâché to provide new support for collaborative design curation, which emphasizes the use of space and scale to organize and relate design artifacts and collaborative processes. LiveMâché is based on *free-form web curation*, a type of new media—designed to support users in creating new conceptual, spatial contexts—in which they discover and interpret relationships, while composing a variety of content elements to form a connected whole [16]. For example, Figure 5.1 is a student's curation in which they have assembled collected images and videos into a sequence to explain their idea for an agricultural tourism service.

A previous prototype, IdeaMâché, was used to study an earlier form of free-form web curation, which did not support real-time collaboration. Free-form web curation, as instantiated in IdeaMâché, supports students in thinking visually [8], creatively engaging with prior work [16], and reflecting on design processes over time [165]. LiveMâché extends previous forms of free-form web curation with the addition of *collaborative live media curation* which supports multiple authors simultaneously collecting and assembling together [60].

To meet the demands of the real-world use and to facilitate open-ended functionality, the LiveMâché web infrastructure is comprised of multiple interconnect services, data stores, and client application as shown in Figure 5.3.

5.3.1 Web Infrastructure: Storage, Services, Routing, & Interaction

To support situated project-based learning and curation activities, we implemented LiveMâché as a web application. Web applications can support a wide range of participants across different devices and operating systems. We organize the system's components in layers based on their general purpose: data storage, application services, routing, and user interaction. Our layers are similar to those of the Dexter Hypertext Model, which consists of three layers: Storage, Within-component, and Runtime [166]. In the Dexter Hypertext Model, the Storage layer consists of the structure and hierarchy of the data. The Within-component layer is concerned with the specific contents of the hypertext elements. The Runtime layer handles presentation and manipulation.

We alternatively reapportion the supported actions of the Dexter model in two ways. First, Dexter's *Runtime* layer is split between our Services, Routing, and Interaction layers to facilitate distributed, real-time collaboration. Multiple user clients can exist in our Interaction Layer, each communicates with a single set of services that handle synchronous, real-time manipulation of the elements. Second, we split the concerns of Dexter's *Within-component* layers across our Storage

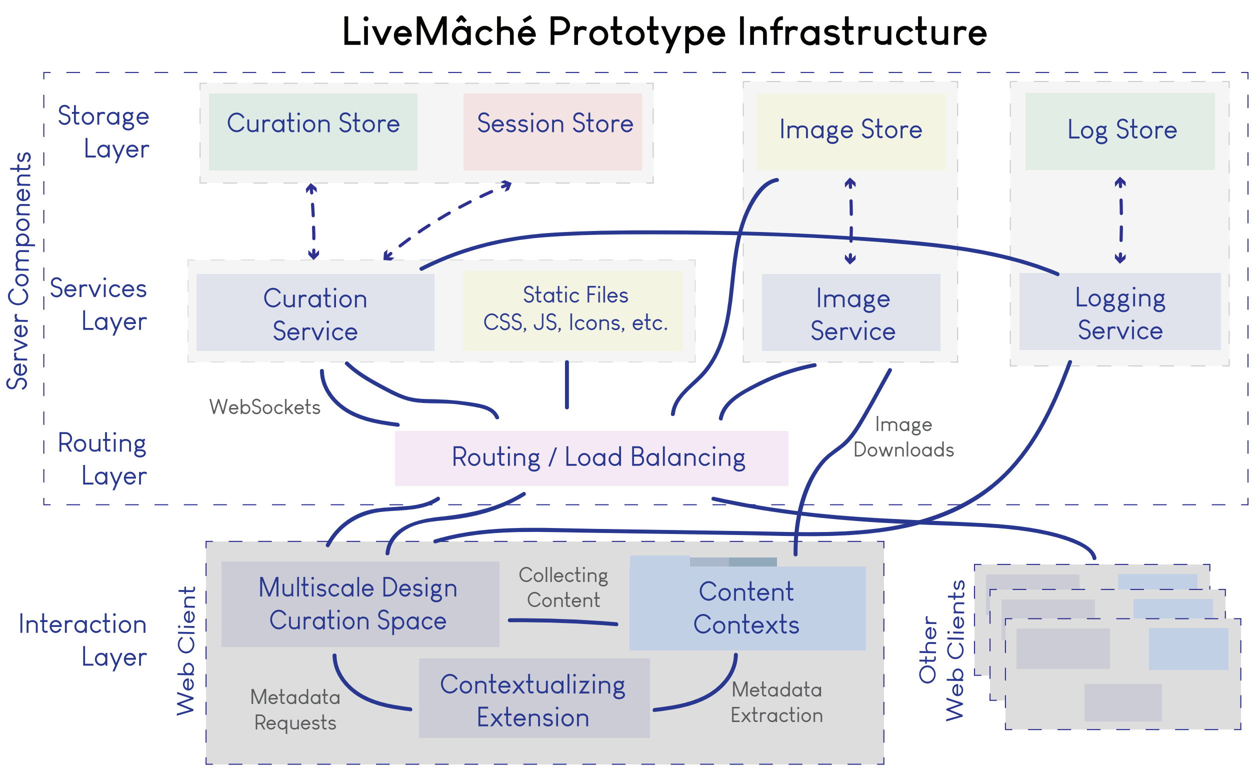

Figure 5.3: Overview of the LiveMâché system infrastructure. The system is comprised of multiple components, which we differentiate the components into layers: Storage, Services, Routing, and Interaction. The user interacts with the system through the Multiscale Design Curation Space. As users browse Content Contexts, typically web pages or local document explorers, they collect content, copying it from its source context into the curation space with the help of the Contextualizing Extension. Curated images are sent to the Image Service for processing and storage. Changes to the curation are processed through the Curation Service, which simultaneously updates the Curation Store and propagates the changes to the other web clients currently connected to that curation.

and Interaction layers to capture the specific context of curation activities from within a user's browsing session. A component of our Interaction layer is a browser extension that automatically parses the context of the collected elements as users engage in curation. Unlike the Dexter-model, LiveMâché does not contain an explicit node-link structure between elements, instead, elements are assembled in space.

5.3.1.1 Storage Layer

LiveMâché uses four different forms of data storage for curation data, session data, images, and operation logs. MongoDB is used to store editable documents data such as user models and curations, and the operation log data. MongoDB is well suited to emergent design research methods because of its flexible schema, which allows for easily adding new fields and relationships. This works well for storing the information-intensive work of spatial hypertext data which is, by design, highly volatile [135]. Session data, such as currently active users and their connection information, is stored in Redis, a lightweight in-memory data store. Lastly, curated images are downloaded to a simple directory-based storage system.

5.3.1.2 Services Layer

LiveMâché contains three services: the Curation Service, the Image Service, and the Logging Service. Each service runs multiple instances to handle the demand on the system. Each instance is independent of the others. Communication between them is handled through the Routing layer. The Curation Service handles user accounts and authentication, serving HTML, creating, accessing, and editing curations. The Image Service handles downloading, downsampling, and serving images which have been curated by users. It is necessary to download the images which are part of the curations because the sources are often lost or changed. The Logging Service handles saving and accessing the interaction logs. We designed our distributed services architecture in anticipation of future changes. As separated services, it is easier to upgrade or refactor the different technologies.

5.3.1.3 Routing Layer

In the *Routing layer*, a series of Nginx servers and proxies handle forwarding requests to their respective services and performing load balancing. The Routing layer also serves static files that can be cached on users' web browsers.

5.3.1.4 Interaction Layer

The *Interaction layer* is concerned with collecting, presenting, and manipulating the curation data, as well as connecting users with one another. In LiveMâché, this functionality is implemented as a web application that runs in a user's browser. In another sustained prototyping implementation, this is a Windows desktop application, *Emma*, which utilizes pen and touch as interaction modalities for early-stage visual design [167].

5.3.2 Storage and Services: Facilitating Studies

To support real-world usage, LiveMâché provides some basic functionality regarding user accounts, privacy, and feedback gathering. These functions are integrated into the Curation Service and Curation Store, which also servers as a user store.

5.3.2.1 Accounts and Privacy

Students create accounts within LiveMâché to manage and share their team curations. They can create an account with their email or through a Facebook or Google account. We include editable privacy settings for each in terms of visibility and shared access / editing permissions. Each curation has a Visibility setting, which can be set to either public or private. Public curations can be viewed by anyone who visits the curation's unique URL. Private curations can only be viewed by LiveMâché accounts which have been given explicit permissions by the curation's creator.

5.3.2.2 Logging and Feedback

We adapt and evolve LiveMâché through constant and reflective analysis of the system in practice. LiveMâché has integrated interaction logging and user feedback mechanisms. Both the client-side application and server send log messages to the Logging Service. The Logging Service has a simple API that allows us to aggregate, filter, and download the interaction logs as either JSON or CSV.

Another way we learn from the participants is through a user feedback mechanism integrated into the LiveMâché web application. From the application, users can submit a feedback message directly to the research team. Along with the user's message, the feedback form automatically includes information about the user's device and current curation properties.

5.3.3 Interaction: Multiscale Design Curation

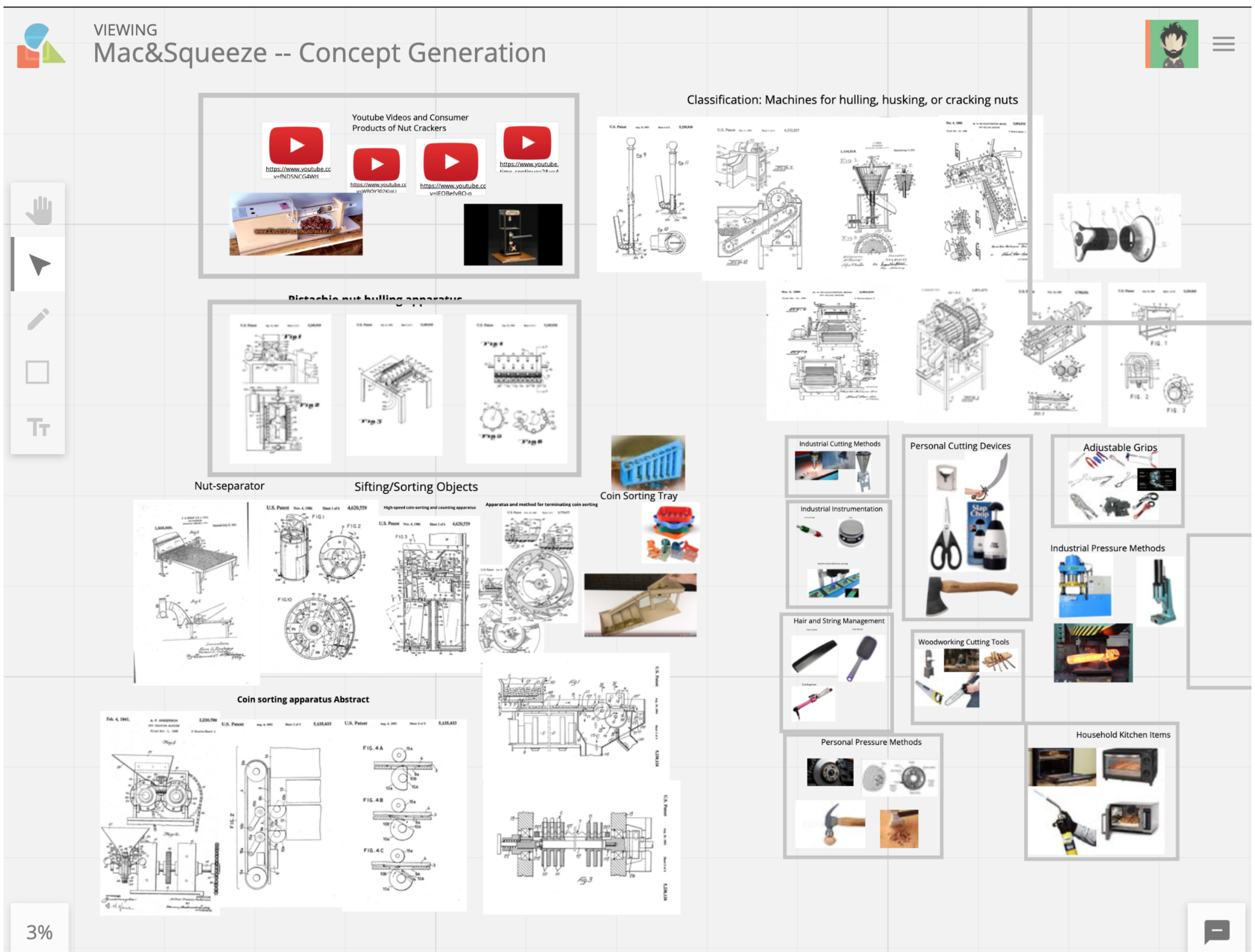

Figure 5.4: The LiveMâché web application viewing a curation created by a student in *Designing Engineering System*. The curation's title is in the top left and underneath is the toolbar. The current active users and drop-down menu are located in the top right. The student has collected a variety of patents, images, and YouTube videos as part of their concept exploration. Course: $Mech - 2$. Fluency: 110. Visual Patterns: $group \mid spatial$ and $group \mid nested$.

The LiveMâché system includes features and components specific to supporting creative design curation activities and lets students create active structures of information. LiveMâché supports multiple users working simultaneously to visually and conceptually organize, annotate, and sketch elements across a range of scales in a 2.5D zoomable user interface ZUI. Content is *collected* into the curation as elements through drag-and-drop operations. Elements can be freely *assembled* in the near-infinite zoomable space. LiveMâché supports the transformation operations: position, scale, rotate, and anchor. Elements can be layered along the Z-axis, going in front of or behind overlapping elements. Each element can change the opacity of each element to create interesting visual syntheses. Users can *shift perspective* of the zoomable space via panning and zooming their viewport.

In addition to manipulating elements, LiveMâché supports integrated *writing* and *sketching* operations. Created writings and sketches support the same manipulations as other curation elements. To help support users in authoring intricate curations, LiveMâché has undo / redo functionality for all the different element operations. The different types of operations can be accessed via the toolbar shown in Figure 5.4.

5.3.3.1 Multiscale Curation Space

LiveMâché elevates the use of multiscale space as a cognitive strategy for supporting re-contextualization, synthesis, exhibition. A zoomable user interface (ZUI) uses the traversal of scale as a fundamental interaction technique [168]. The use of visual scale supports human working memory through visual chunking [27], which involves grouping sets of elements to represent higher-level concepts. Using a ZUI for curation enables users to engage in strategies of *multiscale design*, in which designers use scale to explore, juxtapose, and communicate relationships among design elements [169].

LiveMâché utilizes a virtual camera system to support a zoomable user interface and multi-scale design activities. Elements are rendered onto a specific camera layer based on their element type and Z-order. The camera layers use CSS3 transforms to translate and scale the elements together. Each users' web client has an independent virtual camera system to view the curation. The

LiveMâché web client includes an overview map, rendering a miniature view of the entire curation and the user's current viewport position and scale.

To increase system performance, LiveMâché uses refinement processes similar to previous ZUIs [168]. As images are uploaded to the Image Service, a series of down-sized versions are created based on diminishing powers of two. When a user completes a zoom operation, the application updates the image elements to render the specific sized version, which is closest to the current scale. For embedded elements such as YouTube videos or Google Docs, the embedded visuals are only rendered when the element meets the minimum size; otherwise, they are rendered as representative icons.

5.3.3.2 Collecting and Contextualizing Content

Curation is fundamentally an act contextualization [12]. Each collected element serves as a bridge between the elements assembled in the curation, and the original context from which it was taken. The element functions as a *rich bookmark*, maintaining a reference to its original source [142].

In project-based learning, students need easy access to information in many different forms. LiveMâché features lightweight drag-and-drop interactions. Users can drag content from the web or their local machine and drop it onto the LiveMâché space. LiveMâché will parse the available data flavors from the dropped content, text, HTML, and URIs, to create one or more curation elements. HTML sterilization is performed to protect against unwanted or harmful scripts or embedded content which could be injected into the LiveMâché client. Newly created elements are scaled relative to the current viewport. LiveMâché supports element types, including images, writings, animated GIFs, sketches, shapes, embedded YouTube videos, and embedded Google Docs.

To capture data about the source context of collected elements, LiveMâché incorporates a Contextualizing Extension. Implemented as a Google Chrome browser extension, the Contextualization Extension injects source information into clipped web content during a drag and drop interaction. The extension allows us to capture various metadata about the source context such as the location, page title, and page description [170]. The extension runs within the user's web browser.

Metadata extraction is executed locally without having to transfer any user data to an external service.

5.3.4 Interaction: Real-Time Collaboration

LiveMâché was designed to support real-time collaborative activities. Such systems should include structure and flexibility, data portability, role identification, and alternate styles of group interaction [51]. LiveMâché is a collaborative application supporting users in real-time curation activities. Users can share their curations with other LiveMâché users. The creator can assign other users specific roles. Each role has an associated set of permissions that determine the available operations users can perform within that curation. Currently, in addition to *creator*, LiveMâché supports of the roles: *viewer*, can see and browse the curation, *commentator*, who can also participate in text chat, and *editor*, who can create and manipulate elements in the curation.

LiveMâché uses the WebSocket protocol to connect user clients in real-time. When a user first accesses a curation, an active session is created and stored using Redis. The session data contains specifics about the curation, the connected users, and their permissions. The real-time manipulation events are sent from the web client to the application server, updated in the Curation Store and propagated to the other connected clients.

5.3.4.1 Presence & Awareness

LiveMâché utilizes a variety of techniques for visualizing presence and creating shared awareness. Shared awareness is "an understanding of the activities of others, which provides a context for your own activity" [18]. When users first access a curation, they are assigned a unique color. Their color and user avatar are shown to other connected users in the top right of the interface, see Figure 5.4. To help support collaboration LiveMâché includes integrated text chat along the right side of the interface.

As users create or manipulate elements in the curation, other users see the operations occur in real-time. LiveMâché uses an element-level locking mechanism, which prevents users from simultaneously manipulating the same element. When a user manipulates an element, the element becomes outlined in that user's color tho show who is responsible for the manipulation. If the manipulated element is off-screen, an activity indicator is displayed on the nearest screen edge similar to the Halo visualization [171].

5.4 Methods: Interventions and Data

Our investigation of supporting project-based learning involves the use of LiveMâché in a variety of university design courses. In these courses, students use LiveMâché to create and edit curations that support their design projects. Our deployment protocol includes: working with instructors to integrate LiveMâché into existing pedagogy, presenting the prototype to students, providing technical support to students, helping instructors collate and evaluate student curations, and data collection. We take a participatory approach, working with instructors and students as co-designers rather than as subjects [116]. Students and instructors help us conceptualize new functionality and assess the priorities of different usability and system performance development efforts.

5.4.1 Course Interventions

We first identify a potential course and invite the instructors to become part of our ongoing research efforts. We explain our research objectives and demonstrate the prototype to potential instructors. If interested, we work with them to identify ways to integrate curation activities into their project-based learning curriculum. Potential uses of curations in student projects span a range of purposes, including initial design explorations, documentation of implementation details, and presentation of outcomes. Figure 5.4 shows an example of a design exploration curation from the course *Designing Open Engineering Systems*.

After deciding on how LiveMâché can be used to support their students, we offer to visit the course to give a workshop on using LiveMâché. The workshop includes an interactive demonstration of the prototype and an overview of our research on curation as a design method. The workshop can take between 20 and 40 minutes, depending on the course schedule. When we demonstrate the features of the prototype, we explicitly show the integrated feedback mechanism.

We make sure to reiterate to students that, should they need help with the prototype, they should contact the research team and not the course instructors. We want to reduce the burden on the instructors to teach the students a new technology.

We provide students access to LiveMâché similar to a closed-beta. In order to create an account, students must enter an access code. Unique access codes are assigned for each course intervention. The access codes allow us to associate users and their curations with specific contexts of use. However, once a user has created a LiveMâché account we do not control or limit how they use the prototype. During the workshop, we encourage students to feel free to use LiveMâché for whatever purposes they please. We hope to encourage them to experiment with prototype in new ways. In a few cases, students have asked us to provide access codes for them to share with their classmates in other classes or with their student organizations.

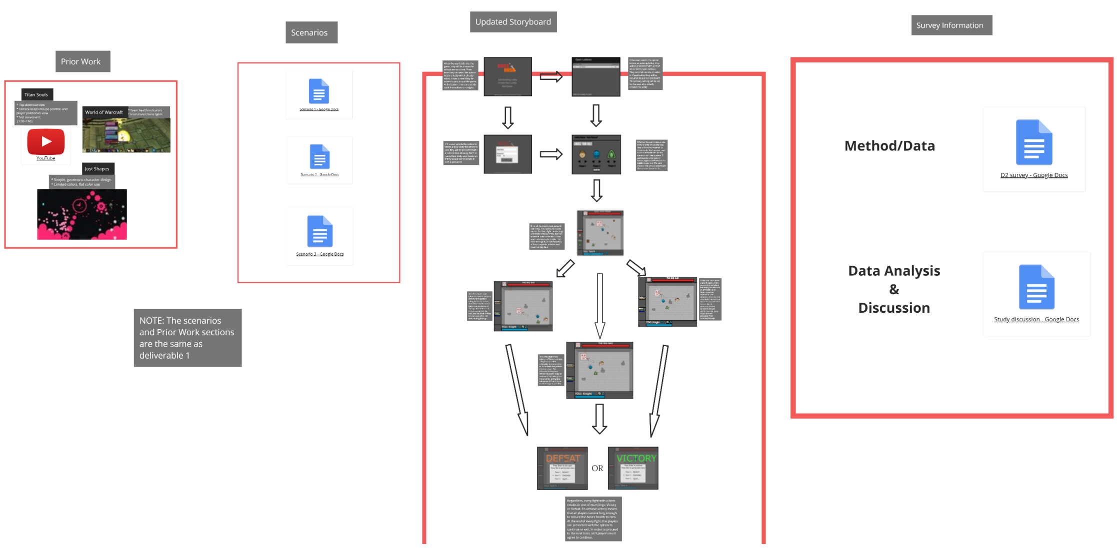

Figure 5.5: A partial view of a student team's design project curation showing their project assignments of Prior Work, User Scenarios, Storyboards, and User Survey. This course requires students to write project reports as Google Docs, which are embedded as elements in their project curation. Course: $CpSc - 1$. Fluency: 211. Visual Patterns: $group \mid spatial$ and $path \mid non - linear$.

5.4.2 Data Types: Process and Product

Studying the complex and interconnected activities involved in creativity and learning requires data methods that are likewise complicated and interconnected. Our specific data methods are essential in investigating creativity and learning. A panoply of data methods is needed to get a complete picture of the complex phenomena.

As part of the sustained prototype methodology, we develop an ever-growing bricolage of data collection and analysis methods, including our prior evaluation methodologies of visual grounded theory [8] and ideation metrics of curation [71]. We take a mixed-methods approach involving qualitative and quantitative methods. Different data collection methods are useful for understanding different phenomena. We collect both process and product data. Product data captures what is created, and process data captures how. The distinction between process and product data is essential. Instructors may choose to focus on how students are engaging in creative processes throughout the project, rather than the outcome [148].

5.4.2.1 Process Data: Operation Logs

We capture process data through automated operation logging. Every editing or interface interaction performed by the participants within the LiveMâché editor generates an operation log event. Each operation event consists of a timestamp, the user identifier, the curation identifier, and the operation type such as "element_move" and "camera_zoom". Additional operation-specific data is appended, which contains relevant information for that event such as: "start_position" and "end_position". Operation logs are batched together and uploaded to the Logging Service every 12 seconds.

While the operation logs are one of the least rich forms of data we utilize, log data is quickest to collect and analyze. The operation logs can provide a general overview of the specific features that are being used. Operation counts also provide corresponding measures of participant engagement in particular curation strategies. Because of their comprehensiveness, the logs are useful for identifying potentially interesting phenomena across use contexts. Phenomena, in this case, refer to interesting ways in which curation activities support forms of creativity and/or learning. Operation logs are a vital tool we use to discover curations and participants for more targeted data methods such as interviews. We use the process data to compute the curation working time in terms of activity sessions. We define an activity session as a period of interacting with the curation with less than 15 minutes between logged operations.

5.4.2.2 Process Data: Cooperation Index

Our cooperation index extends prior research on measures such as the Cooperation Activity Composite Indexes, which capture magnitudes of cooperative work in relation to the overall activity [172]. We calculate each student's contribution to a curation as the proportion of their editing operations compared to the total. From this, we derive the *cooperation index*, a weighted value from 0 to 1, which captures the collaborative-ness of a curation. To compute the index, we first identify the student with the most editing operations. We then find the mean editing operations performed by the remaining students and divide that by the maximum student's operations to get a number from 0 to 1. For example, if each student performed an equal number of editing operations, the cooperation index would be 1. If one student performed all the edit operations, the index would be 0. This index is limited in its scope, as it does not assess the quality or magnitude of the edit operations, only the number.

5.4.2.3 Product Data: Curations

As a form of product data, we use the curations themselves. We use the curations as data in two ways. One, we use the semantic representation to compute curation metrics. Two, we use the curations as visual data to perform qualitative analysis.

5.4.2.4 Curations: Semantic Form

Curations are represented in the system database according to set schema. Each curation stores general information such as the title, visibility, and authors, and a set of curated elements. Each element stores its transformation data, such as position and scale, semantic data, such as the source context, and visual data, which is different for each element type. For example, image elements contain the images remote and local locations and its native size.

We use the curation as data in this form to derive a range of curation metrics [45]. Our understanding of curation metrics is an extension of general ideation metrics [173]. The curation metrics we utilize most frequently are Element Fluency, Element Type Fluency, and Site Variety. Element Fluency is the number of elements that have been curated. The general ideation metric of fluency which is the number of ideas generated during a task. Element Type Fluency is the count of each element type: image, writing, sketch, shape, video, and embedded Doc. Site Variety is the number of unique sites from which authors have collected elements. We use Element Fluency as a rough measure of how much effort a participant has invested in a particular creative product.

5.4.2.5 Curations: Visual Data

We treat the created curations as visual data. We use visual qualitative methods [78], following other researchers who use visual evidence as a primary form of data [79]. Studies investigated how visual objects, as material, are seen, watched, touched, and carried [80]. We perform visual qualitative analysis by looking at the curation and open coding its visual features. Features include the layout of elements, groupings, the use of scale, and overlapping elements, creating recognizable shapes or forms. The curation metrics or operation logs do not capture these more nuanced visual features.

5.4.2.6 Curations: Visual Patterns

Lupfer et al. defined a pattern language of free-form curation [8]. Qualitative visual analysis was previously used to identify these visual patterns in creative product data [8]. We use these patterns to label the visual properties of the curations. There are four main patterns, $morphology$, $overlap$, $group$, and $path$, each with additional sub-patterns. The $morphology$ pattern is the arrangement of elements in recognizable form. The form can either be $morphology \mid concrete$, corresponding to a specific object or being, or $morphology \mid abstract$, corresponding to a map, shape, or plot. The $overlap$ pattern is the use of spatial arrangement and transparency to such that elements coincide in the X-Y plane and are stacked in the Z-plane. $Overlap$ has three sub-patterns:

$overlap \mid compose$, in which the multiple elements partially or completely overlap; $overlap \mid composite$, in which the use of alpha blending visually synthesizes elements; and $overlap \mid map$, where the elements are overlaid on an element that relates to a physical space or geographic area. The $group$ pattern is the arrangement of elements into distinct subsets. $Group \mid spatial$ creates subsets by arranging elements to create white space, which separates one or more sets of elements. $Group \mid nested$ is the use of scale and arrangement to create subsets by placing some elements within the bounds of another. The $path$ pattern is the arrangement of elements into one or more visual sequences. Sequences can be $path \mid linear$, a single, ordered sequence, or $path \mid non-linear$, branching sequences with multiple connected components.

5.4.2.7 Process Data: Interviews

We interview participant to understand their personal experiences using LiveMâché. We use an interview structure similar to the stimulated recall method [117], that we call curation elicitation. In stimulated recall interviews, the interviewee is shown an image or document to help them remember their experiences. We show the interviewee one of their curations and ask them to describe its contents and structure. We will also ask specific follow up questions about exciting or unique aspects of their curation. Having the curation visible to both interviewee and interviewer makes it easier to communicate about the visual and spatial aspects.

5.4.3 Data Set

We organize our data into Course Instances. A *Course Instance* refers to a set of students and instructors, who use LiveMâché for a specific course during a set period, typically a semester. To separate the Instances, we use access codes that are used by students when they initially register for a LiveMâché account. We choose to separate these contexts as Instances on a per-semester, per-course basis for two reasons. First, the pedagogy around using LiveMâché often changes and evolves each time a course is taught. Even in the same course or with the same instructor, how it is being used may change as the instructors develop their pedagogy around using curation. Second, the prototype is continuously updated and improved over time, with major releases scheduled for the break time between semesters.

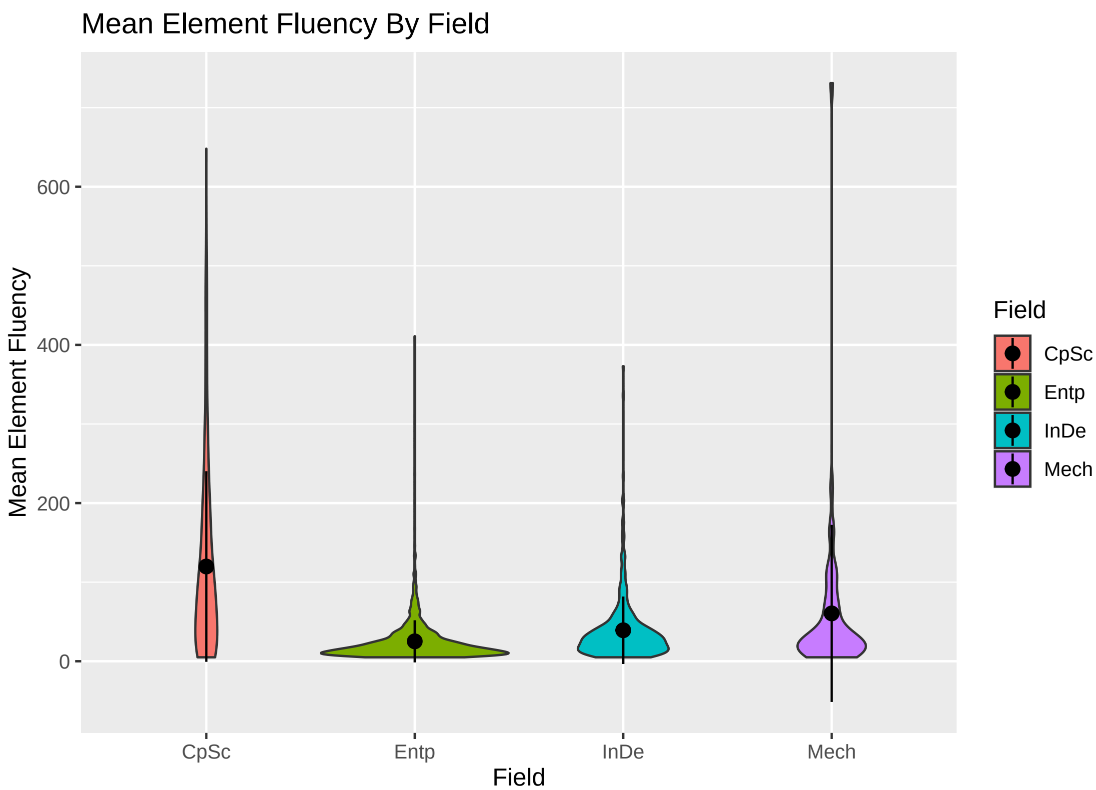

Figure 5.6: Violin plot of mean Element Fluency for each of the four design fields represented in the data set: $CpSc$ computer science, $Entp$ entrepreneurship, $InDe$ interaction design, and $Mech$ mechanical engineering. For each shape, the width is the distribution frequency and the black dot is the mean.

To gather the curation data for a course instance, we first aggregate all students that registered their LiveMâché account with the context-specific access code. Once we have all the students, we aggregate all curations that they permission to access. This set includes all curations that they created and ones that they have editing or viewing permissions.

From this set of curations, we filter out curations based on two criteria. First, we remove curations that have Private visibility. Because we do not limit how students use LiveMâché, some will create personal curations that do not correspond to a specific course instance. We encourage this form of use and support it through the inclusion of the 'Private' visibility setting, which only

Semester	Instance	Instructor	Course	Students	Curations
Fall '17	$Entp-1$	I1	Creativity & Entrepreneurship	216	970
	$Mech-1$	I2	Advanced Product Design	35	13
Spring '18	$Entp-2$	I1	Creativity & Entrepreneurship	347	1600
Fall '18	$Entp-3$	I3	Creativity & Entrepreneurship	117	67
	$CpSc-1$	I4	Programming Studio	58	61
Spring '19	$Entp-4$	I3	Creativity & Entrepreneurship	308	241
	$CpSc-2$	I4	Human-Centered Computing	20	38
	$InDe-1$	I5	Interaction Design Studio	40	139
	$Mech-2$	I6	Designing Engineering Systems	35	16
Fall '19	$InDe-2$	I5	Body Interfaces	10	78
	$InDe-3$	I7	Interaction Design Studio	15	9
Spring '20	$InDe-4$	I5	Interactive Environments	9	44
	$InDe-5$	I7	Interaction Design Studio	32	58
	$Mech-3$	I6	Designing Engineering Systems	21	17
	$CpSc-3$	I8	Programming Studio	187	111
Total	15	8	8	1450	3462

Table 5.2: Courses which have used LiveMâché the past 6 semesters. For each course, we label the specific Course Instance based on the course discipline, the 4 fields represented: $Entp$ Entrepreneurship, $Mech$ Mechanical Engineering, $CpSc$ Computer Science, and $InDe$ Interaction Design. Green highlighted cells indicate Instances which have a high of curations per student. Red highlighted cells show an Instance with a low amount of curations per student.

grants viewing and editing permissions to authorized users. As a point of ethics, we exclude Private curations from all curation analysis.

Second, we remove curations that have an Element Fluency less than five. We do this to remove curations, which are most likely not real engagements with curation activities. For example, users will often create one or more curations as part of their process of exploring and learning to use LiveMâché.

5.5 Findings

To show how LiveMâché is working as a sustained prototype, we present data from 3 years of course interventions. In Table 5.2, we list 15 Course Instances from 6 semesters of our investigation to date. For each Course Instance, we list the instructor, course title, the number of student participants, and the total number of curations. In total, LiveMâché has been used in 15 course instances, by 8 instructors, across 8 unique courses. Some courses and instructors used LiveMâché in multiple semesters.

To show an overview of how LiveMâché is being used in project-based education, we present Table 5.3 which lists the mean Element Fluency and percentage breakdown of elements by type per course instance. This data shows that different courses have used LiveMâché to support a variety of project based learning activities.

We graph the mean Element Fluency by course field in Figure 5.6. From this violin plot, we can see that curations in $Entp$ have the lowest mean Element Fluency. We attribute this to that course being an introductory course available to all majors. $CpSc$, and to a lesser extent, $InDe$ and $Mech$ have a more spread distribution of Element Fluencies. $CpSc$ has the highest mean, which we attribute to the fact that those courses have the most specific and developed pedagogy regarding how the curations are to be used through the project cycle. $InDe$ and $Mech$ have similar distributions because there is a similar level of fit and expertise in how those courses incorporate curation into the project work. Regardless, in each field, there are some outliers of very large curations created by students who went above and beyond.

Because our data can not be directly compared across conditions like controlled laboratory experiments, we present a series of data vignettes. Each vignette focuses on a view of the data that shows evidence for either the sustained prototype methodology or the use of LiveMâché to support project-based education. We focus on how the system is used in different disciplines, how the functionality has evolved over time, and how the pedagogy affects curation. We are not encyclopedic in describing the courses and assignments but will focus on a few interesting findings. We also present and describe a selection of example curations as visual data. We chose our examples to show a range of uses of design curation and a variety of expressions that emerged through use in different contexts.

5.5.0.1 Curation: Mac & Squeeze

Figure 5.4 shows a curation from Course Instance $Mech-2$ titled "Mac&Squeeze - Concept Generation". The curation was created for an ideation assignment in a graduate-level mechanical engineering courses about designing tools and systems. In the curation, the student collected a variety of images and videos to help them ideate about new designs for a nut-cracking / sorting device. They have arranged the elements into rectangle shaped groups using scale, alignment, and proximity. They use writing elements to label each group and for some of the groups, they used rectangle shape elements to create a distinct border. In the top left group is a set of YouTube videos of nut-crackers in action. In the top right and left half of the curation are groups of patent images including: "Classification: Machines for hulling, husking, or cracking nuts" and "Sifting/sorting Objects". In the bottom right quadrant, there are 9 groups of existing products categorized based on a specific function such as: "Hair and String Management", "Personal Cutting Devices", and "Personal Pressure Methods". This curation shows how students use spatial arrangements to organize and group elements to support the processes chunking and restructuring.

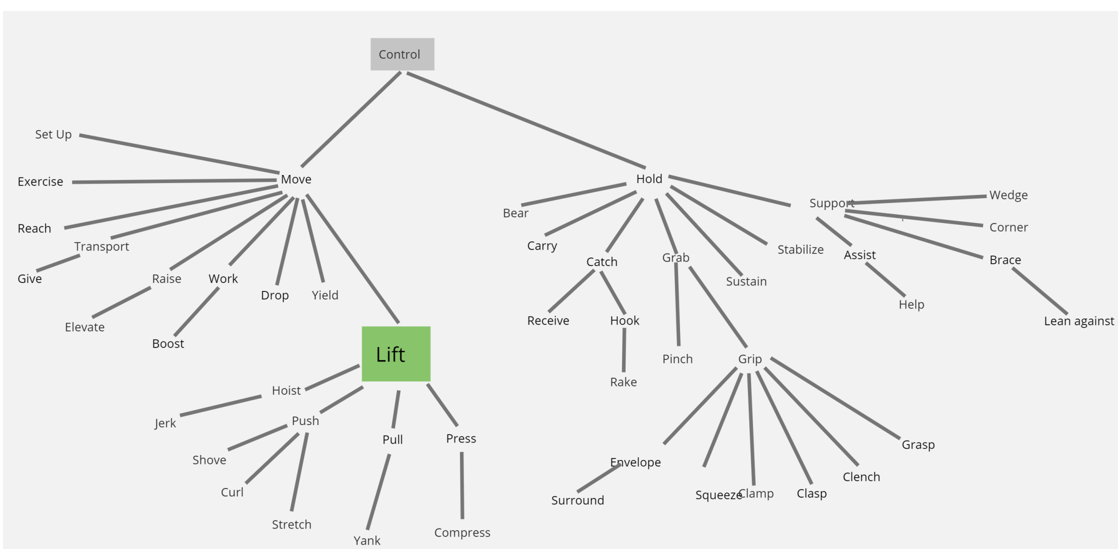

Figure 5.7: An example mind map curation from a graduate engineering course. The curation consists of purely text and shape elements. Course: $Mech-3$ Fluency: 105 Visual Patterns: $path \mid non-linear$

Course Instance	Element Fluency	Images	Writings	Sketches	Shapes	Videos	Google Docs	Other
$Entp-1$	27.2	40.7%	35.3%	7.8%	14.7%	1.1%	0.0%	0.4%
$Mech-1$	19.8	31.9%	34.5%	7.6%	24.4%	0.8%	0.0%	0.8%
$Entp-2$	25.0	41.7%	37.8%	6.1%	12.0%	1.9%	0.1%	0.4%
$Entp-3$	17.8	43.8%	30.1%	4.4%	18.5%	1.8%	0.8%	0.7%
$CpSc-1$	198.2	26.0%	45.3%	7.2%	15.3%	0.7%	4.8%	0.7%
$Entp-4$	20.6	55.3%	26.1%	3.9%	11.9%	1.5%	0.4%	0.8%
$CpSc-2$	123.4	22.3%	51.3%	9.0%	14.8%	0.2%	2.5%	0.0%
$InDe-1$	47.9	18.6%	50.8%	5.9%	21.1%	3.3%	0.2%	0.2%
$Mech-2$	49.4	27.1%	54.2%	10.2%	7.7%	0.5%	0.0%	0.3%
$InDe-2$	40.8	26.2%	48.0%	8.2%	15.7%	1.9%	0.0%	0.0%
$InDe-3$	15.6	48.6%	41.4%	8.6%	1.4%	0.0%	0.0%	0.0%
$InDe-4$	40.1	19.3%	47.3%	9.5%	23.2%	0.7%	0.0%	0.0%
$InDe-5$	21.0	55.9%	26.8%	5.0%	11.1%	1.2%	0.0%	0.0%
$Mech-3$	82.4	9.2%	44.6%	7.8%	38.3%	0.1%	0.0%	0.0%
$CpSc-3$	84.5	15.1%	45.1%	7.3%	19.7%	0.5%	8.8%	3.4%
Mean	33.4	38.1%	34.9%	7.8%	14.8%	1.5%	1.4%	1.5%

Table 5.3: Mean Element Fluency and mean element type make up for each course instance. This data shows how different courses emphasized certain types of elements such as how $Mech-3$ used more shape elements than others. The last rows shows the means for all the curations in the combined data set.

5.5.1 Sustainable Prototypes: Inspiring Use Among Courses

For our first vignette, we show how LiveMâché, as a sustained prototype, has been useful in maintaining participation across courses and instructors. Because of the stability of LiveMâché as a prototype, we are able to offer continued use in course across semesters. For example the course, Creativity & Entrepreneurship, an introductory undergraduate course, consistently used LiveMâché for four semesters in a row. Instructor I1 taught instances $Entp-1$ and $Entp-2$ and was one of the first instructors to integrate LiveMâché into their course. I1 had students use LiveMâché for multiple individual assignments, which explains why instances $Entp-1$ and $Entp-2$ have over 4 curations per student. Starting in Fall 2018, I4 began teaching the course. Sometimes when a course changes instructors, the new instructor will see the benefit of LiveMâché and wish to continue using it in the course (sometimes not). They reduced the role of LiveMâché. It was only used in a single assignment. This explains the lower number of curations per student in instances $Entp - 3$ and $Entp - 4$.

Another way LiveMâché functions as a sustained prototype is by engaging instructors in the benefits and possibilities of curation. Instructors will often start using LiveMâché in one of their courses and then later will want to use it in a different course they are teaching. This happened in the cases of I4 and I5.

However, LiveMâché is not always a good fit for an instructor or course. For example, students in course instance $Mech - 1$, a graduate mechanical engineering course, had a difficult time using LiveMâché, partially due to bugs and missing features around the use of shape elements. The 35 students in that course only created 6 curations and the instructor I3 decided that LiveMâché was not appropriate for the kind of design work their students were doing, namely creating functionality mind maps. These bugs and features were later addressed and updated in the prototype.

5.5.1.1 Curation: Control - Mind Map

Courses $Mech - 2$ and $Mech - 3$, which are also a graduate mechanical engineering course, were able to use LiveMâché to successfully create mind maps as seen in the example Figure 5.7. This curation, titled "Safety Squat Rack" is a mind map of different functions associated with the root function: "Control", placed in the top center. In this curation, the student didn't collect any elements from the web, but rather, they used LiveMâché to write associated functions and connect them with shape elements into a tree structure. So far, we have only seen this kind of mind map curation in the mechanical engineering courses. While these may not be web curation or make use of heterogeneous element types, they show how LiveMâché supports lightweight, thinking exercises.

5.5.2 Actively Structure: Embedding Live Documents

The Course Instances $CpSc - 1$ and $CpSc - 3$ are the undergraduate computer science course, Programming Studio. In this course, student teams used curation to document and present their iterative design project work. One notable feature of this course is the use of embedded Google Doc elements. In these courses, the assignments had significant written components that the instructors required to be submitted as Google Docs. The role of Google Docs in these design curations is to support extended textual explanations with change tracking.

After the heavy use of Google Doc elements in instances $CpSc-1$ and $CpSc-2$, we received several reports from students and the instructor of software lag in curations with multiple embedded Docs. We addressed this issue by implementing a form of semantic zooming on both embedded YouTube and Google Doc elements to improve performance. When the curation view is zoomed out, the embedded elements are rendered as a icon. This can be seen in the example curation from $CpSc-1$, Figure 5.5, which has multiple embedded Google Docs. As you zoom in closer to the embedded elements, they will dynamically load in as they reach the minimum size on screen. We attribute the increase in the use of Google Doc elements in the later course instance $CpSc-3$, to this performance increase.

5.5.2.1 Curation: Game Development Project

Figure 5.5 shows a subsection of a team's curation for their multiplayer game project for Instance $CpSc-1$. The curation was created over a 9 week period with different components of the project due each week. In this view, there are 4 groups of elements, each represents a different week's deliverable. Starting on the left is "Prior Work" shows images and videos of existing games similar to team's idea. Then "Scenarios" which are a collection of three embedded Google Docs. In the central column is the "Updated Storyboard" which contains screenshots from the team's game prototype and written explanations of each screen. The students connect these screens in a branching path using arrows to show how the player progresses through their game. The far right group, is labeled "Survey Information" and contains two Google Docs. Other research has more thoroughly investigated how computer science students have used curation in this way to create visual repositories of design work [165].

Discipline	Element Fluency	Images	Writings	Sketches	Shapes	Videos	Google Docs
Entrepreneurship	22.6	44.9%	32.9%	5.8%	14.1%	1.5%	0.2%
Mechanical Eng.	50.5	18.0%	46.4%	8.6%	26.5%	0.4%	0.0%
Computer Science	135.4	22.6%	47.1%	7.8%	16.1%	0.5%	4.9%
Interaction Design	33.1	28.2%	45.4%	7.5%	17.1%	1.7%	0.1%

Table 5.4: Mean Element Fluency and Element Type Percentage by course fields.

5.5.3 Manage Complexity: Curation as Process

Course Instances from $CpSc$ and $InDe$ had students use LiveMâché to document their team design project work as they engaged in iterative design processes across multiple weeks. However, the different instructors encouraged their students to use curation differently. Instructor I6 encourages the student teams to create a new copy of their curations for each week to preserve the previous stages of the project cycle. This can be seen in the instances $InDe-1$, $InDe-2$, and $InDe-3$, which has a high number of curations per student.

In contrast, instructors I5 and I9 in $CpSc$ courses encouraged their student teams to use a single curation over the course of the project. Students would add onto the curation week by week as they developed their project. This explains why these instances have a much lower amount of curations per student.

5.5.3.1 Curation: Wearable Sensor

Figure 5.2 shows a project documentation curation from $InDe-2$, titled “Sketch 2”. The elements are arranged in columns similar to the curation Figure 5.5. This particular curation is from the 3rd stage of the project. Each column holds a different stage of the project. In the first column, the elements are readymade images and videos of different wearable devices that inspire the student’s concept. In the other two columns, the elements are self-made photographs and videos of the student’s prototype.

5.5.4 Access Information: Heterogeneous Elements

Project-based learning involves students creating artifacts to address a range of purposes: visual, diagrammatic, functional, and explanatory. To support use in the wild, LiveMâché strives to accommodate all possible content types that students may need to curate. This is one of the strengths of LiveMâché as a curation system, the support for different types of elements existing side-by-side, in a single space. Combining multiple media types has benefits to human perception and thinking [174]. Cognitive science has shown how human working memory can simultaneously process images and text [175].

Table 5.4 compares how the different fields of courses emphasize different types of elements. We plot these percentages in Figure 5.8 to help illustrate the differences between fields. The mechanical engineering courses use more shapes and written elements, as we see in their mind map curations (Figure 5.7). The three more technical disciplines: mechanical engineering, computer science, and interaction design seem to use more writings and sketches compared to the other two. But, across all courses, as shown in both Tables 5.3 and 5.4, all types of students are using a diverse set of element types.

5.5.5 Work Together: Process Data Reveals Engagement

To reveal the extent of how students engage with LiveMâché, we use the operation logs to compute the number of active work sessions and unique calendar days of activity, shown in Table 5.5. We can see that $CpSc$ and $InDe$ student engage with their curations for longer time spans which corresponds to the longer and more involved projects in those courses as compared to the introductory $Entp$ courses.

We also show the mean number of curation contributors and cooperation indexes for each instance and field. Overall, the cooperation numbers are low, meaning that most curation work is being done single student on the team. On average, the number of contributing students per curation is also lower than expected. One possible explanation for the low amount of measured cooperation is that these are being calculated as a mean across all curations created from students

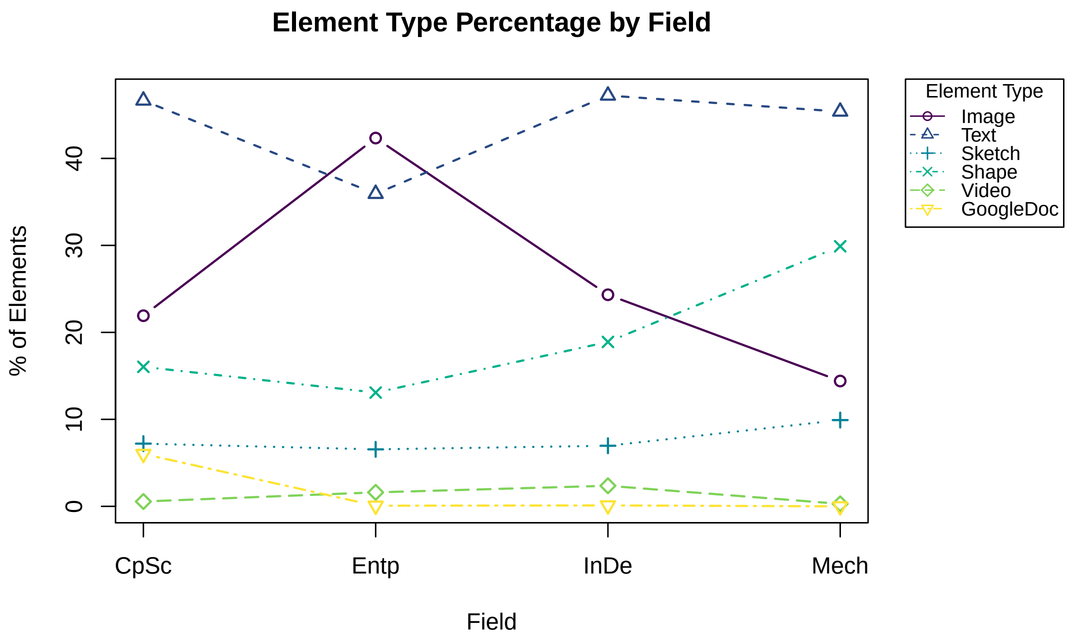

Figure 5.8: Element Type Percentage shown as the mean percentage of each different element type across the four design fields involved in the study. From this plot, we can see how Images are most used in the $Entp$ courses and how Shapes are more heavily used in $Mech$.

in each course instance. That is to say, not just the specific curation which is created to fulfill specific project assignments.

These numbers do not reveal the extent of actual as collaboration. Teams may be communicating and working together in ways which are not being captured by the operation logs. We question how this pattern, that is having a single student act as curator for the team, compares to existing team design practices. Perhaps more cooperation could be beneficial for the future of work. If so, technology and pedagogy should be more geared towards teaching cooperation as an integral part of project-based learning.

5.6 Implications for Design

Sustained prototypes are a response to the throw-away model for research. Sustained prototypes require a considerable investment in terms of technical development and cyber-human infrastructure. The infrastructure itself becomes the method, while the method dictates the infras-

Instance	Days	Sessions	Contributors	Cooperation Index
$CpSc - 1$	12.1	53.5	4.4	10.1 %
$CpSc - 2$	8.8	51.8	3.5	4.0 %
$CpSc - 3$	10.5	50.4	3.6	9.2 %
$CpSc - All$	10.8	51.5	3.8	8.7 %
$Entp - 1$	2.8	6.1	1.8	0.1 %
$Entp - 2$	2.8	5.7	1.8	0.2 %
$Entp - 3$	2.4	12.3	1.1	0.3 %
$Entp - 4$	3.8	16.9	2.0	0.4 %
$Entp - All$	3.0	8.2	1.8	0.2 %
$InDe - 1$	8.8	36.6	2.7	2.1 %
$InDe - 2$	11.1	44.1	1.5	3.2 %
$InDe - 3$	5	13.7	1.2	4.8 %
$InDe - 4$	6.5	44.8	2.2	3.8 %
$InDe - 5$	5.6	19.4	1.4	4.4 %
$InDe - All$	8.0	34.5	2.2	3.0 %
$Mech - 1$	5.2	14.8	3.1	23.9 %
$Mech - 2$	7.9	33.6	2.5	5.2 %
$Mech - 3$	4.8	17.1	1.8	2.3 %
$Mech - All$	6.0	22.2	2.4	9.4 %
Total	4.6	17.3	2.1	1.8 %

Table 5.5: For each course instance and field, we list the mean number of work days, activity sessions, contributing students, and cooperation indexes. We list the cooperation index as a percentage, with 100% meaning that there is a completely equal distribution of editing operations between students and 0% meaning that all the editing operations were from a single student.

tructure.

Sustained prototypes strive to be artifacts that are both transformative and innovative. Transformative, in that, they address the specific needs of a context, and innovative, in that they uncover and inspire new understandings [176]. While these goals can conflict and lead to friction in research, we argue for the value of doing sustained, contextualized research.

5.6.1 Infrastructure Helps Sustains Research

To do relevant, transformative research, we need to sustain work in situated contexts. Understanding and meeting user needs takes time. Slow technology is an example of how new uses and needs can emerge over time [177]. Contexts of use are always evolving and changing. Prototypes must change as well. Prototypes and their infrastructure shape and are shaped by their communities of practice [160].

However, merely continuing research is not sufficient. Sustained prototypes encourage researchers to be sensitive to the evolving co-adaptive practices. They support researchers in consistently monitoring user feedback, interaction logs, and what users create with the prototype. They are iterated upon, improved, and extended.

Creativity and learning need to be studied from multiple angles, using multiple forms of data. Different types of data can reveal different understandings. Prior research with a previous sustained prototype, IdeaMâché, supported a range of research investigation methods. A study on how free-form curation can supports new forms of presentation used interview data to understand student experiences [50]. A study used the curations themselves as qualitative visual data to identify visual patterns of how students arrange their curations [8]. Another study used interaction logs and curation metrics[45] to understand the students' different strategies during curation activities [16]. Collecting and analyzing all these different forms of data would not be possible without sustained field research.

5.6.2 Context is Necessary for Investigating Cyberlearning

Sustained prototypes are important for creativity and learning because these are highly contextualized situated activities [152]. In project-based learning, students need access to information to develop and evolve their ideas [9]. New technology can help students collect and think about information. Systems must be flexible and open-ended to understand creative and learning activities, which similarly, are open-ended and divergent. The open-ended nature of project-based learning is well suited to the sustained prototype method because open-ended activities are more likely to lead to emergent practices of use with the prototype.

The National Science Foundation's program *Cyberlearning for Work at the Human-Technology Frontier* seeks projects that investigate learning processes and introduce emerging technologies within the learning environment [178]. Cyberlearning courses are ideal contexts for sustained prototypes because of their cyclical nature. Courses are offered multiple times, often with the same instructors. The students will be different each time, but they will be similar in terms of education level and experience.

Studies can compare data across course offerings. These will not be controlled studies, as the pedagogy and prototype should continue to evolve. Such studies should, instead, focus on identifying and understanding changes across course offerings. How has the prototype and pedagogy changed between offerings? How has student behavior changed? Correlating these changes can help reveal new phenomena that can then be studied more specifically.

5.7 Conclusion

LiveMâché has impacted project-based learning in a variety of design courses. It has introduced instructors and students to new forms of design and ideation activities and pedagogy, which capitalize on human visual and spatial thinking. Future research may investigate the specifics of how students and instructors in different courses or disciplines utilize and co-adapt the LiveMâché prototype to fit their practices and pedagogy. This work highlights how these and future real-world classroom investigations are made possible through LiveMâché and its role as a sustained prototype.

Sustained prototypes are a valuable design research method for studying complex, interconnected phenomena. They help develop long-term, co-adaptive relationships with contexts of use. While sustained prototypes can constitute a significant investment in technical development and cyber-human infrastructure, engaging in long-term, contextualized research is vital to understanding practice and creating real-world impact with new technologies.

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