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

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ABSTRACT

We investigate new media to improve how teams of students create and organize artifacts as they perform design. Some design artifacts are *readymade*—e.g., prior work, reference images, code framework repositories—while others are *self-made*—e.g., storyboards, mock ups, prototypes, and user study reports. We studied how computer science students use the medium of free-form web curation to collect, assemble, and report on their team-based design projects. From our mixed qualitative methods analysis, we found that the use of space and scale was central to their engagement in creative processes of communication and contextualization.

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, exhibiting (presenting), and archiving design process. Multiscale design curation instantiates a constructivist approach, elevating the role of design process representation. Student curations are open and unstructured, which helps avoid premature formalism and supported reflection in iterative design processes. Multiscale design curation takes advantage of human spatial cognition, through visual chunking, to support creative processes and collaborative articulation work, in integrated space.

ACM Classification Keywords

H.5.m. Information Interfaces and Presentation (e.g. HCI): Miscellaneous

Author Keywords

Creativity; design; curation; design curation; multiscale; multiscale design curation; ZUI; little-c; iterative design; design education

INTRODUCTION

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,
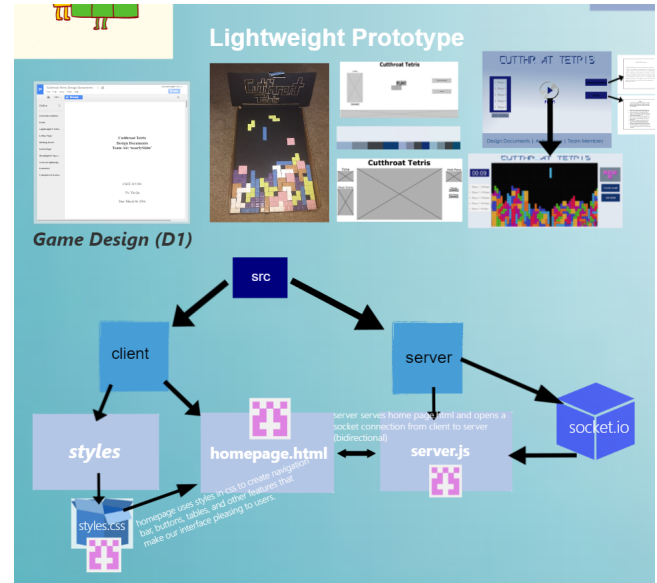
Figure 1. Design curation for an undergraduate team's multiplayer game project. In this view, we see their game design document, as a Google Doc, images of their lightweight prototype, wireframes, and system architecture diagram. Their design curation enabled them to assemble these different types of design elements together in a shared zoomable space. [https://goo.gl/y2wPS5]

diversity, and learning performance [18]. Yet, 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 [14]. When students collaborate on teams, social and organizational challenges compound [52].

To address these challenges, this research focuses on processes of design curation. 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 [49]. 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 [22, 4], mood boards [38], annotated portfolios [9], and pictorials [8].

We investigate the research question, "How does free-form web curation affect student teams' iterative design processes?" We studied teams of computer science students, using 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 [32]. 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 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 effects of new media and methods would be more pronounced with novice designers, as they are more open to trying unfamiliar design methods [14]. We performed two extended computer science and engineering classroom design interventions [3]. 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. Over the course of 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 to present to the instructors for feedback and grading (see example in Figure 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 [19]. In this paper, we present interdisciplinary creativity research to investigate how students use new free-form web curation capabilities, in practice [50].

We argue that the computer science students of our study lie in a spectrum, between professional designers and lay people. This spectrum is defined in the Four C model, in which creativity range from 'mini-c', personally novel to 'little-c' everyday, 'Pro-c' professional, and 'Big-C', domain changing [30]. 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 course of the semester, we interviewed students and gathered their curations. We analyzed this data using grounded theory and qualitative visual methods. From our analysis, we find 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.

CURATION

We present background addressing curation from perspectives of art and design practice. We use these practices to frame our understanding of prior mediums and methods for organizing, presenting, and archiving collections of design artifacts. We situate these methods in context with free-form web curation, the specific medium studied in the present research.

Curation is a means for framing and conceptualizing how people understand creative work and its contexts [49]. Curation emerged in art as a distinct mode of discourse and framework for interaction across disciplines. Web curation subsequently became a popular social media activity, in which people assemble boards and engage in everyday ideation [36], around a variety of topics, including recipes, photography, tutorials, and health and beauty advice [66].

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*: choosing an everyday object, exhibiting it with a new title, in a new context, and so transforming its significance [37]. Where readymade objects are found in the world and recontextualized through the act of curation, in contrast, we call artifacts that people create, with the intention of curating, *self-made*.

Creative curators fasten together readymade and self-made artifacts in processes of *assemblage*. Assemblage visually and conceptually showcases duality and tension between an element's original and resulting contexts [57]. Processes of creating and experiencing assemblages stimulate *visual thinking*: perception, recognition, and reflection become intertwined in creative acts of forming and illustrating new meanings [1].

Design Curation: Medium / Method

Creating and using design artifacts is central in HCI and other design fields [51]. Design artifacts help designers communicate concepts, define approaches, reflect on their ideas, and study their end-users. Design artifacts support communication and reflection in design processes [58].

A body of design research focuses on media and methods in which designers collect, present, and archive artifacts [33, 22, 38, 28, 7, 58, 10, 51, 8, 4]. Our research frames design practices of organizing, presenting, and archiving design artifacts as processes of curation and assemblage. We propose that designers work as collage artists, like Max Ernst, who juxtapose ambiguous materials to stimulate new readings and ideas [62].

We call these pairings of media forms—into which design artifacts are organized—with their complementary processes and methods, *design curation* [39]. McLuhan [45] said, "The medium is the message," meaning that the forms of media determine how one 'speaks' and so what one can express. We turn the phrase for design processes, focusing on how people work and think: *the medium is the method.*

Design curation thus addresses both product and process. Design curation media / methods affect a range of design activities, such as how participants create, collect, organize, edit, and review design artifacts.

Figure 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]

One such design curation medium / method is the 'design workbook', which consists of, "design proposals and other materials drawn together during projects to investigate options for design" [22]. Design workbooks have been used in conceptualization and ideation processes to support designers in expressing, externalizing, and elaborating on design proposals. Workbooks are typically physical books or printed material; content is thus separated into pages and linearly assembled. Another design curation medium / methodology is the 'mood board', which "consist[s] of a collection of visually stimulating images and related materials" [38]. The process of assembling artifacts in a design curation space provokes engagement in design through visual thinking about elements' relationships.

Free-form Web Curation
New media modularize levels of content and interface, while enabling variable assemblage of elements [43]. *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 [32].

Prior studies have investigated the use of free-form web curation in different contexts. One prior study looked at students using free-form curation for classroom presentations [35]. Another developed a pattern language that represents a range of forms in which students use free-form web curation to engage in visual thinking [41]. 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.

A prior study presents supported by the IdeaMâché free-form web curation probe, and develops deep connections between these operations and creative strategies 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* [32]. The present investigation focuses on teams of computer science students performing design curation. It is the first study of free-form web curation to investigate teams collaborating on extended design projects.

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 [54], 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 [21], 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 [11]. We noticed that many students described similar processes for assembling their curations. We performed a visual analysis [2] on the final 27 curations to find the extent of structural similarities in curations across teams.
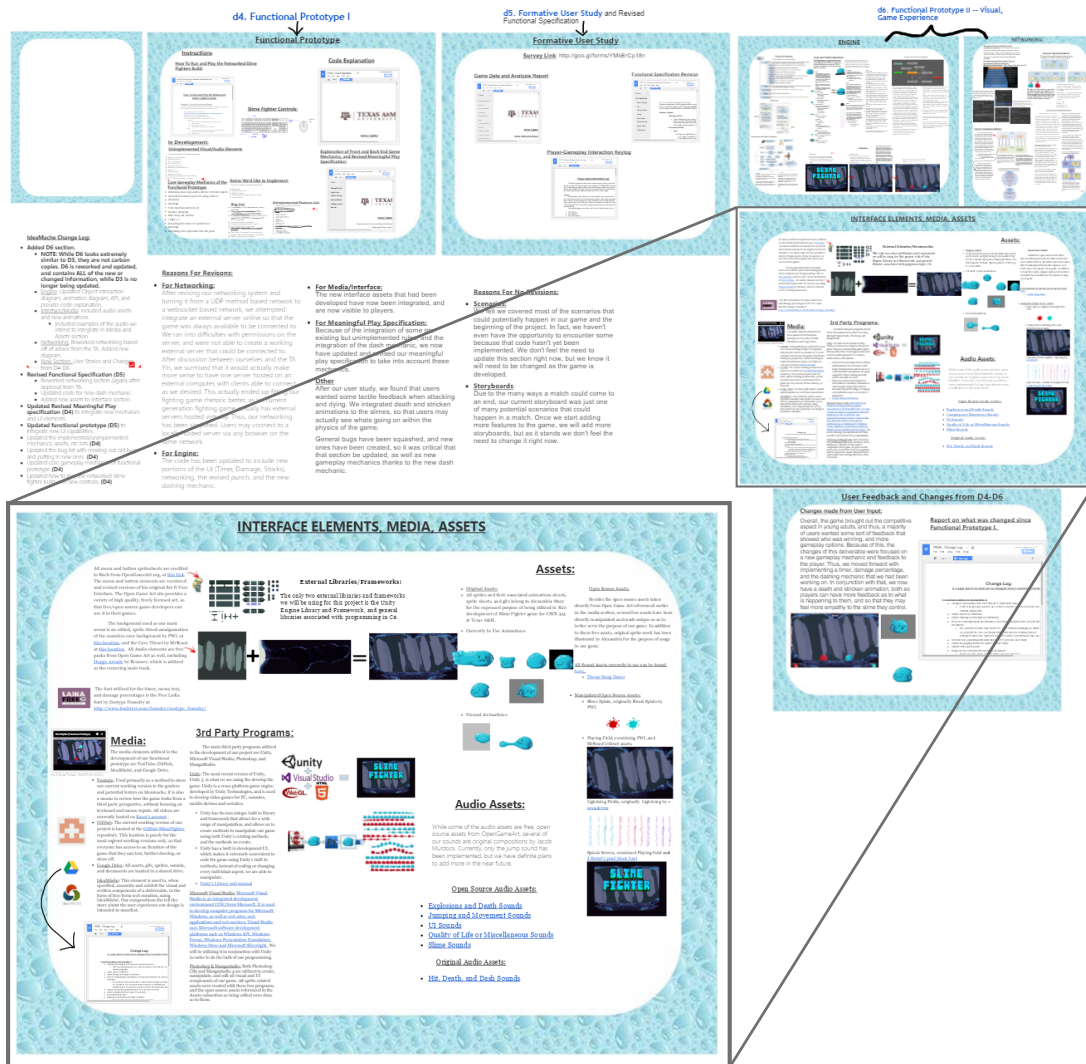
Figure 3. Overview of P8's team curation for their multiplayer arcade game *Slime Fighter*, with zoomed in view of the section labeled 'INTERFACE ELEMENTS, MEDIA, ASSETS' (bottom, left). Each of the blue bordered areas represents a specific weekly deliverable, which they arranged in an L shape, ordered 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].

Using grounded theory methods [11], we coded and categorized student interview data. We identified the use of space and scale as the core theme across the main categories. The importance of space and scale is further supported by visual qualitative analysis [2] of 27 final curations.

Positionality
In qualitative methods, personal bias from researchers' experiences, backgrounds, and motivations should be minimized, but is impossible to remove [13]. Thus, it is imperative for qualitative researchers to be upfront in declaring their position relative to their study [6]. 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" [3]. Design-based intervention research requires evaluations that are no less simple

than the phenomena being investigated, to generate evidence-based claims, which address theory [3].

Some authors of this paper were instructors for courses the paper presents. As instructors 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 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 help students learn and grow.

Courses and Assignments
We performed design interventions [3] in two introductory courses during the Spring 2016 semester: *Programming Studio* and *Human-Centered Computing* (Table 1). Our design

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

Table 1. Studied course contexts, each with the duration of the project in weeks, the number of teams, and the total number of curations created.

interventions take a technology probe approach. Researchers invoke *technology probes* to investigate experimental technologies, in real-life scenarios, to elicit contextualized experiences, for the purpose of understanding potential capabilities [27]. Through the interventions, a total of 102 students, in 36 teams, created 184 curations to organize and report on design projects.

In each course, students used free-form web curation to organize artifacts into a weekly series of 9 project deliverables. Central to the projects was the design of a visual program [46], 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. This was so instructors could easily add in-line comments and track changes. For each deliverable, students were required to assemble 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 panable and zoomable canvas and supports 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. We chose IdeaMâché as the web curation probe, because, at the time of the study, it was the only system we knew of to support embedding editable and scale-able Google Docs—along with image, text, sketch, and video elements—in a zoomable canvas.

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, in which 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 were 9 weekly deliverables—from game experience design to functional prototype, addressing scenarios, storyboards, interaction design, user studies, and system architecture—en route. Ninety students were grouped into 24 teams, each of 3 to 4 students. Figure 2 shows team *Cutthroat Tetris*'s final curation, which assembles all project deliverables. Figure 3 shows team Slime Fighter's curation, halfway through the project.

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

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 9 weekly deliverables, guiding teams through user studies and feedback from instructors. At the end, each team was required to connect all the deliverables together in 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 [53, 34] experiences through 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" [60]. 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.

Protocol
There were 102 students, total, across both courses, 90 undergraduate and 12 graduate. We conducted 15 semi-structured interviews of students (Table 2). The 15 interviews cover 10

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

of the 27 total teams. Interviews lasted an average of 36 minutes. We recruited participants via email. In accordance with our IRB protocol, participants were not compensated. 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 makes use of visual artifacts [21]. The stimulus consisted of the curation that the student and their team had most recently worked on. Each participant was shown their curation, visible both to them and the interviewers. 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.

Analysis

Following a grounded theory approach, as we performed interviews, we transcribed them, performing multiple rounds of open and focused coding [11]. All researchers were involved in the coding process. Once 4 interviews were complete, each researcher independently open coded them. We then met to discuss 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 7 revised codes, we performed another round of focused coding on the last 4 interviews. Next, we collapsed remaining codes into three categories: *structure*, *communication*, and *process*. Subsequently, during theoretical integration [11], we renamed *structure* to *construct context*, shifting our framing from product to process. *Process* was renamed to *reflection*, to more specifically address student experiences. The categories share a theme around the use of space and scale.

FINDINGS: VISUAL ANALYSIS

In conjunction with the interview categories, we found multiple student teams created similar visual structures. This led us to perform a visual analysis [2] 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* [41]. *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 sub pattern 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 which were created earlier as part of an iterative process. We examined each curation, for evidence of these multiscale structure patterns, see Table 3.

For each curation, we also visually approximated the number levels of scale. We use levels of scale as a way to describe how visually stratified the curation elements are along the Z-axis. Elements which exist in 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 this 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 3 shows the results of this analysis. The mean number of levels of scale for the entire data set is 3.15.

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 [40]. 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 [40] contribute to our understandings of the computer science students' design curation processes. Specifically, we discovered student design curations 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 [35, 41, 32],

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.

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.

Constructing Context
Multiscale design curation is based in an unstructured, zoomable space; no templates are provided. Students think constructively [23] 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 [55] 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 quantity of design artifacts increased. And thus, the process of assembling their curations became more vital and challenging. Visual scale was a common technique for students to mitigate the increasing complexity. P11 explains how one of his curations contained too much information, when 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.

Often, students used sketching and spatial positioning to create a visual flow through their curations, showing their process in the order that made 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 [41]. 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.

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 shared visual context [20], 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 [55], 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 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 his 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.

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 [56].

Throughout the project cycles, students were required to submit updated curations at regular intervals. Their curations could be newly created for each deliverable. Or 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, as elements, visually organized, 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 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.

DISCUSSION

We theorize that, in design curation, the medium in which elements are assembled inexorably links to the ways of thinking about, relating, and working 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 the ways in which 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 [16]. We develop contributions involving multiscale design curation, addressing zoomable user interfaces, constructivism, contextualization in CSCW, premature formalism, and reflection.

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" [26]. 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 expressive 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 3, rendering 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 in nature [42]. They can simultaneously show both overview and detail to facilitate spatial thinking and assist in navigating across scales.

Constructivism through Curation
Multiscale design curation instantiates a constructivist approach to team design learning, in which 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 cycles of planning and revising [29]. Students learn through making their own representations and by defining their own organizational structures and flows [17].

We observe that the students' design curations support constructivist activities, such as collecting, organizing, discussing, and evaluating [65]. Over the course of a project, students are required to create different types of deliverables, such as, specification documents, mockups, and functional prototypes. Their design curation acts a central space, in which 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.

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 [25]. 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.

Articulation Work
Through the process of assembling their curations, teams create spaces that instantiate shared visual contexts [20]. A shared visual context acts as common ground for team interactions and communication. Shared contexts support the students in performing articulation work, i.e., the activities of a community that enable and facilitate collaboration, such as scheduling, allocating resources, assigning tasks, and dividing labor [55].

Collaborative Creativity
Students used their multiscale design curations in ways that resemble the creative collaborative practices observed in physical design studio spaces [63]. 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 [24].

Multiscale design curation provides new support for collaborative creative processes. P13 observed that as their team learned to share the curation, they were able to 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 [59], while helping them design for change [44].

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 [12]. Students selected and scaled groups of elements, within their curations, to articulate and differentiate conceptual levels (See Figures 2, 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 [61], 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 difficult.

Having design elements related together, along 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. This 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."

Reflection

Fundamental to multiscale design curation is an underlying methodology of design as a reflective process [56], 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 [15]. Multiscale design curation takes advantage of spatial positioning, which has been shown to support reflection [48], with a zoomable interface. Inspiration gets stimulated when designers organize prior visual material together, alongside their own design solutions [31].

Through this assemblage of heterogeneous elements, multiscale design curation overcomes fragmentation of design artifacts, which hinders reflection [47]. P8, who identifies as a "visual learner", explains how they their team curation provided "all of my assets in one place, instead of having to go through the hurdles in order to get [them in] a Google Drive." This 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 to move its content within the next iteration, placing it to the side or at a smaller scale, manifesting the *multiply strategy* [40] 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 how it was used 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 reported that their multiscale design curations are iteratively developed throughout this process, helping relate and interconnect design elements across all project phases. Extending prior work on supporting reflection with curation, the assembled design elements function as *rich bookmarks*, which integrate a visual representation with semantic information from the element's source context [64]. Prior research shows that rich bookmarks support reflection and creativity in ideation tasks [64]. We find that they have similar benefits when used in collaborative and iterative design processes.

CONCLUSION

In art, *assemblage*—the process of fastening objects together—highlights the duality and tension between the original and resulting contexts [57]. Designers learn to navigate and understand the emerging landscapes of their abstracted design spaces [5]. This provokes them to engage in design synthesis, in which relationships among elements, rather than the elements themselves, become most significant [34]. Gaver states that this a core component of design curation, that assemblage in a design space supports the emergence of new ideas [22].

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, leads 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 [19]. It provides 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.

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REFERENCES

1. Rudolf Arnheim. 1969. *Visual Thinking*. University of California Press.

2. Marcus Banks. 2008. *Using visual data in qualitative research*. Sage.

3. Sasha Barab and Kurt Squire. 2004. Design-based research: Putting a stake in the ground. *The journal of the learning sciences* 13, 1 (2004), 1–14.

4. Jeffrey Bardzell, Shaowen Bardzell, Peter Dalsgaard, Shad Gross, and Kim Halskov. 2016. Documenting the Research Through Design Process. In *Proceedings of the 2016 ACM Conference on Designing Interactive Systems (DIS '16)*. ACM, New York, NY, USA, 96–107. DOI: http://dx.doi.org/10.1145/2901790.2901859

5. Thomas Binder, Giorgio De Michelis, Pelle Ehn, Giulio Jacucci, Per Linde, and Ina Wagner. 2011. *Design things*. MIT press.

6. Melanie Birks and Jane Mills. 2015. *Grounded theory: A practical guide*. Sage.

7. Eli Blevis, Elizabeth Churchill, William Odom, James Pierce, David Roedl, and Ron Wakkary. 2012. Visual Thinking & Digital Imagery. In *CHI '12 Extended Abstracts on Human Factors in Computing Systems (CHI EA '12)*. ACM, New York, NY, USA, 2715–2718. DOI: http://dx.doi.org/10.1145/2212776.2212703

8. Eli Blevis, Sabrina Hauser, and William Odom. 2015. Sharing the Hidden Treasure in Pictorials. *interactions* 22, 3 (April 2015), 32–43. DOI: http://dx.doi.org/10.1145/2755534

9. John Bowers. 2012. The logic of annotated portfolios: communicating the value of'research through design'. In *Proceedings of the Designing Interactive Systems Conference*. ACM, 68–77.

10. David Cameron, Sabrina Hauser, Nadine Jarvis, and William Odom. 2014. Pictorials. In *2014 Conference on Designing Interactive Systems (DIS '14)*. ACM, New York, NY, USA, 121–160 and 473–502.

11. Kathy Charmaz. 2014. *Constructing grounded theory*. Sage.

12. Nelson Cowan. 2001. The magical number 4 in short-term memory: A reconsideration of mental storage capacity. *Behavioral and brain sciences* 24, 1 (2001), 87–114.

13. John W Creswell and Dana L Miller. 2000. Determining validity in qualitative inquiry. *Theory into practice* 39, 3 (2000), 124–130.

14. Nigel Cross and Robin Roy. 1989. *Engineering design methods*. Vol. 4. Wiley New York.

15. Peter Dalsgaard and Kim Halskov. 2012. Reflective design documentation. In *Proceedings of the Designing Interactive Systems Conference*. ACM, 428–437.

16. John Dewey. 2005. *Art as Experience*. Penguin.

17. Thomas M Duffy and David H Jonassen. 2013. *Constructivism and the technology of instruction: A conversation*. Routledge.

18. Clive L Dym, Alice M Agogino, Ozgur Eris, Daniel D Frey, and Larry J Leifer. 2005. Engineering design thinking, teaching, and learning. *Journal of Engineering Education* 94, 1 (2005), 103–120.

19. Ronald A Finke, Thomas B Ward, and Steven M Smith. 1992. Creative Cognition: Theory, Research, and Applications. (1992).

20. Susan R Fussell, Robert E Kraut, and Jane Siegel. 2000. Coordination of communication: Effects of shared visual context on collaborative work. In *Proceedings of the 2000 ACM conference on Computer supported cooperative work*. ACM, 21–30.

21. Susan M Gass and Alison Mackey. 2000. *Stimulated recall methodology in second language research*. Routledge.

22. William Gaver. 2011. Making Spaces: How Design Workbooks Work. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '11)*. ACM, New York, NY, USA, 1551–1560. DOI: http://dx.doi.org/10.1145/1978942.1979169

23. Mark Guzdial. 1997. Information Ecology of Collaborations in Educational Settings: Influence of Tool. In *Proceedings of the 2Nd International Conference on Computer Support for Collaborative Learning (CSCL '97)*. International Society of the Learning Sciences, 86–94. http://dl.acm.org/citation.cfm?id=1599773.1599783

24. William A Hamilton, Nic Lupfer, Nicolas Botello, Tyler Tesch, Alex Stacy, Jeremy Merrill, Blake Williford, Frank R Bentley, and Andruid Kerne. 2018. Collaborative Live Media Curation: Shared Context for Participation in Online Learning. In *Proc ACM CHI*. paper 555: 14 pages.

25. Steve Harrison and Paul Dourish. 1996. Re-place-ing space: the roles of place and space in collaborative systems. In *Proceedings of the 1996 ACM conference on Computer supported cooperative work*. ACM, 67–76.

26. Kasper Hornbaek, Benjamin B. Bederson, and Catherine Plaisant. 2002. Navigation patterns and usability of zoomable user interfaces with and without an overview. *ACM Trans. Computer Human Interaction* 9, 4 (Dec. 2002), 362–389. DOI: http://dx.doi.org/10.1145/586081.586086

27. Hilary Hutchinson, Wendy Mackay, Bo Westerlund, Benjamin B Bederson, Allison Druin, Catherine Plaisant, Michel Beaudouin-Lafon, Stéphane Conversy, Helen Evans, Heiko Hansen, and others. 2003. Technology probes: inspiring design for and with families. In *Proc SIGCHI Conference on Human Factors in Computing Systems*. ACM, 17–24.

28. Nadine Jarvis, David Cameron, and Andy Boucher. 2012. Attention to Detail: Annotations of a Design Process. In *Proceedings of the 7th Nordic Conference on Human-Computer Interaction: Making Sense Through Design (NordiCHI '12)*. ACM, New York, NY, USA, 11–20. DOI:`http://dx.doi.org/10.1145/2399016.2399019`

29. Yasmin B Kafai. 1996. Learning design by making games. *Constructionism in practice: Designing, thinking and learning in a digital world* (1996), 71–96.

30. James C Kaufman and Ronald A Beghetto. 2009. Beyond big and little: The four c model of creativity. *Review of General Psychology* 13, 1 (2009), 1.

31. Adriaan Ianus Keller. 2005. *For Inspiration Only; Designer interaction with informal collections of visual material*. Ph.D. Dissertation. TU Delft, Delft University of Technology.

32. Andruid Kerne, Nic Lupfer, Rhema Linder, Yin Qu, Alyssa Valdez, Ajit Jain, Kade Keith, Matthew Carrasco, Jorge Vanegas, and Andrew Billingsley. 2017. Strategies of Free-Form Web Curation: Processes of Creative Engagement with Prior Work. In *Proceedings of the 2017 ACM SIGCHI Conference on Creativity and Cognition (C&C '17)*. ACM, New York, NY, USA, 380–392. DOI:`http://dx.doi.org/10.1145/3059454.3059471`

33. Jon Kolko. 2007. Information architecture and design strategy: The importance of synthesis during the process of design. In *Industrial Designers Society of America Conference 2007*. 17–20.

34. Jon Kolko. 2010. Abductive thinking and sensemaking: The drivers of design synthesis. *Design Issues* 26, 1 (2010), 15–28.

35. Rhema Linder, Nic Lupfer, Andruid Kerne, Andrew M. Webb, Cameron Hill, Yin Qu, Kade Keith, Matthew Carrasco, and Elizabeth Kellogg. 2015. Beyond Slideware: How a Free-form Presentation Medium Stimulates Free-form Thinking in the Classroom. In *Proceedings of the 2015 ACM SIGCHI Conference on Creativity and Cognition (C&C '15)*. ACM, New York, NY, USA, 285–294. DOI:`http://dx.doi.org/10.1145/2757226.2757251`

36. Rhema Linder, Clair Snodgrass, and Andruid Kerne. 2014. Everyday Ideation: All of My Ideas Are on Pinterest. In *Proceedings of the 32Nd Annual ACM Conference on Human Factors in Computing Systems (CHI '14)*. ACM, New York, NY, USA, 2411–2420. DOI:`http://dx.doi.org/10.1145/2556288.2557273`

37. L.R. Lippard. 1971. *Dadas on Art*. Prentice-Hall.

38. Andrés Lucero. 2012. Framing, Aligning, Paradoxing, Abstracting, and Directing: How Design Mood Boards Work. In *Proceedings of the Designing Interactive Systems Conference (DIS '12)*. ACM, New York, NY, USA, 438–447. DOI:`http://dx.doi.org/10.1145/2317956.2318021`

39. Nic Lupfer. 2018. Multiscale Curation: Supporting Collaborative Design and Ideation. In *Proceedings of the 2018 ACM Conference Companion Publication on Designing Interactive Systems (DIS '18 Companion)*. ACM, New York, NY, USA, 351–354. DOI:`http://dx.doi.org/10.1145/3197391.3205380`

40. Nic Lupfer, Hannah Fowler, Alyssa Valdez, Andrew Webb, Jeremy Merrill, Galen Newman, and Andruid Kerne. 2018. Multiscale Design Strategies in a Landscape Architecture Classroom. In *Proceedings of the 2018 Designing Interactive Systems Conference (DIS '18)*. ACM, New York, NY, USA, 1081–1093. DOI:`http://dx.doi.org/10.1145/3196709.3196812`

41. Nic Lupfer, Andruid Kerne, Andrew M. Webb, and Rhema Linder. 2016. Patterns of Free-form Curation: Visual Thinking with Web Content. In *Proceedings of the 2016 ACM SIGCHI Conference on Multimedia (MM'16)*. ACM, New York, NY, USA, 10. DOI:`http://dx.doi.org/10.1145/2964284.29643031`

42. Benoit B Mandelbrot. 1977. *Fractals*. Wiley Online Library.

43. Lev Manovich. 2001. *The language of new media*. MIT press.

44. Catherine C Marshall and Frank M Shipman III. 1995. Spatial hypertext: designing for change. *Commun. ACM* 38, 8 (1995), 88–97.

45. Marshall McLuhan. 1994. *Understanding media: The extensions of man*. MIT press.

46. Philip B Meggs. 1992. *Type and image: The language of graphic design*. John Wiley & Sons.

47. Philip Mendels, Joep Frens, and Kees Overbeeke. 2011. Freed: A System for Creating Multiple Views of a Digital Collection During the Design Process. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '11)*. ACM, New York, NY, USA, 1481–1490. DOI:`http://dx.doi.org/10.1145/1978942.1979160`

48. Kumiyo Nakakoji, Yasuhiro Yamamoto, Shingo Takada, and Brent N. Reeves. 2000. Two-dimensional Spatial Positioning As a Means for Reflection in Design. In *Proceedings of the 3rd Conference on Designing Interactive Systems: Processes, Practices, Methods, and Techniques (DIS '00)*. ACM, New York, NY, USA, 145–154. DOI:`http://dx.doi.org/10.1145/347642.347697`

49. Paul O'Neill. 2012. *The Culture of Curating and the Curating of Culture (s)*. MIT Press.

50. Jonas Frich Pedersen, Lindsay Macdonald Vermeulen, Christian Remy, Michael Mose Biskjaer, and Peter Dalsgaard. 2019. Mapping the Landscape of Creativity Support Tools in HCI. In *The 2019 ACM CHI Conference on Human Factors in Computing Systems (CHI'19) ACM Conference on Human Factors in Computing Systems*. Association for Computing Machinery (ACM).

51. James Pierce. 2014. On the Presentation and Production of Design Research Artifacts in HCI. In *Proceedings of the 2014 Conference on Designing Interactive Systems (DIS '14)*. ACM, New York, NY, USA, 735–744. `DOI:` `http://dx.doi.org/10.1145/2598510.2598525`

52. Julia Rozovsky. 2015. The five keys to a successful Google team. (2015). `https://rework.withgoogle.com/` `blog/five-keys-to-a-successful-google-team/`

53. Daniel M Russell, Mark J Stefik, Peter Pirolli, and Stuart K Card. 1993. The cost structure of sensemaking. In *Proceedings of the INTERACT'93 and CHI'93 conference on Human factors in computing systems*. ACM, 269–276.

54. Elizabeth B-N Sanders and Pieter Jan Stappers. 2008. Co-creation and the new landscapes of design. *Co-design* 4, 1 (2008), 5–18.

55. Kjeld Schmidt and Liam Bannon. 1992. Taking CSCW seriously: Supporting articulation work. *Computer Supported Cooperative Work (CSCW)* 1, 1-2 (1992), 7–40.

56. Donald A Schön. 1983. *The reflective practitioner: How professionals think in action*. Vol. 5126. Basic books.

57. William Chapin Seitz. 1961. *The Art of Assemblage*. Museum of Modern Art New York.

58. Moushumi Sharmin and Brian P. Bailey. 2013. ReflectionSpace: An Interactive Visualization Tool for Supporting Reflection-on-action in Design. In *Proceedings of the 9th ACM Conference on Creativity & Cognition (C&C '13)*. ACM, New York, NY, USA, 83–92. `DOI:` `http://dx.doi.org/10.1145/2466627.2466645`

59. Frank M Shipman III and Catherine C Marshall. 1999. Formality considered harmful: Experiences, emerging themes, and directions on the use of formal representations in interactive systems. *Computer Supported Cooperative Work (CSCW)* 8, 4 (1999), 333–352.

60. Ben Shneiderman. 1996. The eyes have it: A task by data type taxonomy for information visualizations. In *Visual Languages, 1996. Proceedings., IEEE Symposium on*. IEEE, 336–343.

61. Herbert A Simon. 1974. How big is a chunk. *Science* 183, 4124 (1974), 482–488.

62. W. Spies. 1988. *Max Ernst Collages: The Invention of the Max Ernst Collages: The Invention of the Surrealist Universe*. Harry N. Abrams.

63. Dhaval Vyas, Gerrit van der Veer, and Anton Nijholt. 2013. Creative practices in the design studio culture: collaboration and communication. *Cognition, Technology & Work* 15, 4 (2013), 415–443.

64. Andrew M. Webb, Rhema Linder, Andruid Kerne, Nic Lupfer, Yin Qu, Bryant Poffenberger, and Colton Revia. 2013. Promoting Reflection and Interpretation in Education: Curating Rich Bookmarks As Information Composition. In *Proceedings of the 9th ACM Conference on Creativity & Cognition (C&C '13)*. ACM, New York, NY, USA, 53–62. `DOI:` `http://dx.doi.org/10.1145/2466627.2466636`

65. Robert E Yager. 1991. The constructivist learning model. *The science teacher* 58, 6 (1991), 52.

66. Michael Zarro and Catherine Hall. 2012. Pinterest: Social Collecting for #Linking #Using #Sharing. In *Proceedings of the 12th ACM/IEEE-CS Joint Conference on Digital Libraries (JCDL '12)*. ACM, New York, NY, USA, 417–418. `DOI:` `http://dx.doi.org/10.1145/2232817.2232919`