DESIGN ANALYTICS DASHBOARDS TO SUPPORT STUDENTS AND INSTRUCTORS

An Undergraduate Research Scholars Thesis

by

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TABLE OF CONTENTS

ABSTRACT

Design Analytics Dashboards to Support Students and Instructors

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Design coursework is iterative and continuously-evolving. Separation of digital tools used in design courses disaffects instructors' and students' iterative process experiences.

As technology becomes increasingly integrated into design education, new opportunities arise for supporting the iterative, living process of design. These opportunities include providing on-demand, automatically computed insights to instructors, and facilitating instructor and student communication of feedback. I present a system that integrates support for design ideation with a learning analytics dashboard. The system enables instructors gain insights into a student's work across multiple dimensions. Instructors can view design work in the same environment in which students create it, which allows them to provide assessment and feedback in-context. I conducted semi-structured interviews, and recorded interaction logs over the course of an academic year to understand users' experiences.

My research contributes to our understanding of how to present interactive, on-demand insights to instructors, as well as how to facilitate communication in an iterative process between instructors and students. Findings indicate benefits when systems enable instructors to contextualize creative work with assessment by integrating support for ideation with a learning analytics dashboard. Instructors are better able to track students and their work. Students are supported in reflecting on the relationship between assignments, and contextualizing instructor feedback with

their work. We derive implications for contextualizing design with feedback to support creativity, learning, and teaching.

CONTRIBUTORS

The LiveMâché system presented in Chapter IV was developed through the leadership of graduate researchers Nic Lupfer and Bill Hamilton, working with PI Andruid Kerne. The course dashboard and underlying schemas were developed by undergraduate researcher Aaron Perrine, working with Lupfer, Kerne, Ajit Jain, and undergraduate Hannah Fowler. Design Creativity Analytics were defined by graduate researcher Ajit Jain, working with PI Kerne. I worked alongside Jain to construct the web interface for integrated submission and versioning, while developing mechanisms for in-context assessment and bi-directional feedback between instructors and students.

CHAPTER I

INTRODUCTION

Design has been identified as an iterative process: it commonly begins with identifying a problem, constructing prototypes to solve it, analyzing the efficacy of those prototypes, and determining how to improve them [1]. Design can thus be described as a "living" process, with feedback and reflection at the core of the work. In design courses, feedback from instructors guides students from one iteration to the next [2], and helps students understand how others perceive their work [3].

The increasing integration of technology into design and design education has prompted instructors to consider novel approaches in augmenting traditional methods to provide timely, extensive feedback to students [4, 5]. In this direction, this research investigates how the living nature of design can be supported through different forms of computation. Specifically, I develop and evaluate in-context submission, assessment, and feedback mechanisms by integrating them into an existing design curation software, LiveMâché [6] (Figure 1).

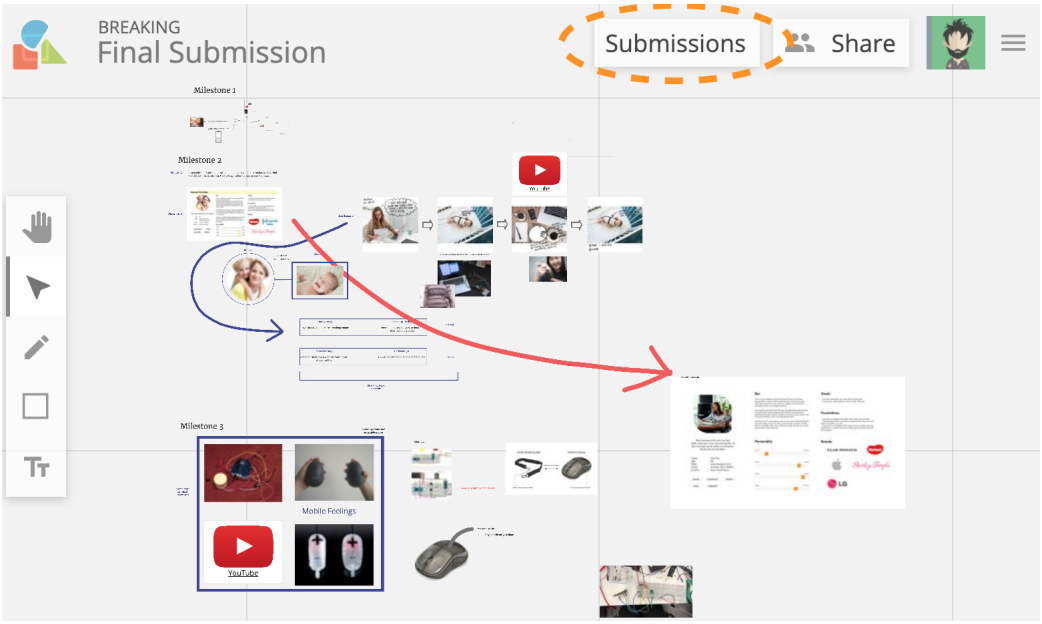

Figure 1: Students used LiveMâché, a collaborative, multi-scale, and free-form system for performing design curation. We integrated submission mechanisms into LiveMâché. Once students join a course, the 'Submissions' affordance becomes available on any of their design works (top right: highlighted with dashed orange oval). When a student presses the "Submissions" button, they see a dialog where they can select new deliverables to submit to and see previous submissions (See Figure 2 and Figure 4).

Digital submission systems are often external to the environments in which students perform design. These systems fall short in accounting for the living nature of design, as they only assess narrow, static windows of the broader process. By integrating the submission process into the same environment where students are ideating, further mechanisms can be constructed to support the iterative design process, specifically reflection and feedback. To reflect on prior work, students can visit their previous submissions and reuse concepts and materials to generate new ideas. To view work in context and provide feedback, instructors can access the student work from a course dashboard. The instructor can leave feedback on the work, and notify the students of available feedback, all within the ideation environment.

Integrating an in-context submission system into a design software creates opportunities to provide instructors with computationally-derived analytics on student design work. Specifically,

I use analytics that extend the information-based ideation (IBI) metrics for "investigating open-ended tasks and activities in which users develop new ideas" [7]. Examples of IBI metrics include the number of ideas (fluency), the number of categories of ideas (flexibility), visual presentation, and the emergence of new features from component concepts. Instructors can view the metrics computed on the current versions of their students' work.

Through the development of this system and its use within design course contexts, I aim to answer the following research questions:

- How does integrating ideation and assessment affect students' iterative design processes?
- How does integrating ideation and assessment affect instructors' insights into students' creative design processes?

From the quantitative and qualitative data I collected, I explore how automatically-computed analytics as well as in-context feedback and assessment can impact design education.

CHAPTER II

RELATED WORK

I discuss related work on how computational modeling can be used to automatically assess aspects of open-ended work. I then discuss digital submission, versioning, and feedback systems.

Computational Modeling of Open-Ended Tasks

As technology becomes increasingly integrated into creative work, more data becomes available for modeling open-ended, creative tasks. Modeling creative tasks computationally can allow for gaining insights into how individuals generate creative work, in addition to new methods of supporting them in their creative processes.

Kerne et al define two kinds of metrics for assessing the creative products of information-based ideation tasks [7]. The first kind are *elemental ideation metrics of curation*, for assessing the creativity of digital artifacts collected to fulfill an ideation task. The second kind are *holistic ideation metrics of curation*, for assessing the creativity of how those digital artifacts are put together. Examples of elemental ideation metrics include *fluency* (the total number of ideas in a work), and *flexibility* (the diversity of each idea within the work). Examples of holistic ideation metrics include *emergence* (the measurement of phenomena in which combinations of components exhibit characteristics not present in individual elements). Their elemental conceptual metrics, however, are derived from metadata such as URLs. Further, holistic conceptual and visual metrics are based on human ratings, which are expensive and time-consuming to attain.

Artificial intelligence and machine learning techniques present new opportunities for holisitic analysis of creative design [8]. Reinecke et al use algorithmic approaches to assess visual aesthetics of a work using a variety of different metrics [9]. Siangliulue use document metadata as well as a machine learning model trained on crowd-sourced data to create a system capable of identifying and presenting similar ideas to users during their ideation process [10]. However, hey did not investigate the usefulness of these models in design course contexts. Using these approaches, we

derive new elemental and holistic analytics by building a computation model based on conceptual and visual analysis of ideas within creative design. We present these to design instructors through a learning analytics dashboard.

Automated Assessment of Student Work

As we pointed above, while computational models have proven useful, there has been limited investigation of their usefulness in the classroom. We now present prior work in the direction of using automated assessment in the classroom.

As demand for design courses increases, instructors have begun exploring methods of augmenting their feedback process. One such method is employing computers to automatically assess student work and provide feedback instantaneously. The BOSS submission system developed by Joy et al was capable of providing students with feedback on the correctness of their work by subjecting student-submitted programs to predefined test cases [11]. While primarily focused on assessing correctness and efficiency of student programming assignments, the BOSS submission system was also capable of presenting instructors with limited basic insights into open-ended aspects of student programs. Oh et al investigated how user-provided drawings could be automatically assessed for compliance with text-based, manually-entered rules [12]. Dixon et al employed sketch recognition algorithms to give feedback to users learning how to draw. By automatically identifying misplaced or misshapen features of a user's sketch, users could improve their freehand sketching ability through the use of technology [13]. However, both Oh et al.'s and Dixon et al.'s automatic methods rely on manual entry of baselines, either through providing sketches or through fragile rules to evaluate on.

Digital Submission, Feedback, and Versioning Systems

Digital submission systems have been employed in various course contexts for collecting student assignments. These systems have demonstrated their ability to make the learning process more flexible for students by removing the implicit geographic and temporal restrictions of in-person submission [14]. Brusasco et al employed the use of a digital submission system to collect design students' coursework [15]. When students felt as though their work was ready for instruc-

tor feedback, they could create a version of their work that the instructor could review. Instructors could then provide feedback directly on student work, leaving comments and emphasizing different parts of the work. Brusasco et al's work demonstrates that providing instructor feedback on students' submissions in-context—in the same environment in which they created it— is valuable to students.

As iterative design oscillates rapidly between creation and feedback, providing rapid feedback to students is important in creating the next iteration [2], and is highly valued by both instructors and students [16]. Integrating digital submission systems into education creates new opportunities for providing fast, effective feedback [17]. Brusasco et al demonstrated how collecting assignments and providing instructor feedback on students' design work in-context through redlining and commenting is valuable to students [15]. However, their work solely relies on expert human feedback, and does not incorporate automatically-computed insights on students' designs. Others have used a mix of human and computational intelligence to provide feedback for open-ended tasks. Machine learning techniques have been used to provide interactive guidance to users leaving peer feedback [18, 19]. Our work investigates automated assessment, using a computational model as the source of feedback. In addition, we develop new features to support instructors in providing feedback in-context.

Learning Analytics Dashboards

As an ever-increasing amount of data is generated by students, analyzing that data can offer opportunities to provide insights to students on their own performance. In addition, the analysis of data can give an instructor insight into their course's performance, and how it changes over time. For both students and instructors, it can be helpful to present this information through a learning analytics dashboard.

Blikstein employed learning analytics to understand student behavior in open-ended programming tasks by recording code compilations and character transformations [20]. While insights can be derived from presented numerical analytics, presenting visualizations of those analytics and how they change over time can enable users to reflect on their own behavior when completing

open-ended tasks [21].

Learning analytics dashboards have been demonstrated to increase student retention [22], as well as prompt students to reflect upon and improve their own performance [22, 23]. Students who use learning analytics dashboards in a course report higher rates of satisfaction, as measured by their enjoyment, self-esteem, and recommending the course to their peers [24]. Despite established usefulness, prior dashboards have not focused on design learning.

CHAPTER III

METHODOLOGY

We provided the integrated submission, versioning, and feedback system to six design courses taught by four instructors at three universities over the course of an academic year (Table 1).

University	Course	Semester	Instructor	No. of Students
KAIST	Design Studio	Fall 2019	D_1	8
ISU	Design Studio	Fall 2019	D_2	14
ISU	Digital Media Design	Spring 2020	D_2	15
ISU	Selected Topics in Art Technology	Spring 2020	D_2	19
TAMU	Visualization Studio	Spring 2020	D_1	7
TAMU	Programming Studio	Spring 2020	D_3	146
TAMU	Programming Studio	Spring 2020	D_4	40

Table 1: The courses that used LiveMâché over the course of the academic year. One course was taught at the Korean Advanced Institute of Science and Technology, two were taught at Illinois State University, and four were taught at Texas A&M University.

We took a participatory approach [25, 26] in developing our prototype: two of the instructors were involved as co-designers of the software that they interacted with. Their feedback was incorporated in the design, prioritization, and development of new features.

To construct a holistic understanding of user's experiences and how our prototype affected them, we employ a mixed-method approach to collect and analyze data. Firstly, we utilize quantitative data generated by users as they interact with the prototype. Students generate data as they develop their design curations, as well as when they interact with submission links found in emails or with the courses dashboard. Instructors generate data when managing their course, using dashboard functionality, or providing feedback to student work. Their actions create interaction logs, from which we derived usage metrics and activity patterns. We also utilized database records cre-

ated while users interacted with the system to analyze student-created content and how instructors managed their course.

In addition to the quantitative data yielded from our user interaction logs, we also collected qualitative data, which can provide detailed, rich understandings of users' experiences interacting with software. We conducted semi-structured interviews with two students and two instructors in order to understand their perceptions of the systems they were using, as well as how it affected students' iterative design processes and instructors' feedback processes. Each interview was conducted remotely through video conferencing, using the questions listed in the Appendix. Afterwards, each interview was recorded and transcribed. Then, using grounded theory methods [27], we analyzed each interview. First, a graduate researcher in my lab and I initially coded the interviews. We met to ensure that our codes were aligned. Then, we engaged in focused coding of the remaining data, organizing the codes into categories. We interpreted the codes and categories using the prior work and guided by research questions to derive a theory grounded in data.

CHAPTER IV

USER EXPERIENCE FLOWS

The submission, versioning, and feedback systems were constructed as part of LiveMâché, an art-inspired web app that provides live, collaborative capabilities for collecting and organizing content, along with writing, sketching, and chat [6]. LiveMâché helps users in discovering and interpreting relationships through visual thinking [28]. LiveMâché features a built-in role-based access control (RBAC) system [29] that enables different users to have different roles related to a specific design work. This system is utilized significantly within the integrated submission, versioning, and feedback system to designate certain users as instructors, and certain users as students.

When an instructor creates a course within the system, an invitation link is created that, when accessed, will enroll the user in the course. By default, newly-enrolled users are designated as students, but instructors can easily grant instructor privileges to any user enrolled in their course. Once the course is created, the instructor is able to add assignments to it, view previously-created assignments, and view student work submitted to each assignment. Assignments can be "open" or "closed", indicating whether new student submissions will be accepted or not.

Once a student joins a specific course by invitation from their instructor, they can submit any of their design works to any open assignment within that course. In addition, if a student is collaborating on a curation with other students enrolled in the same course, those students can submit a curation on behalf of the team as well. Submission is performed from within the student's ideation environment (Figure 2).

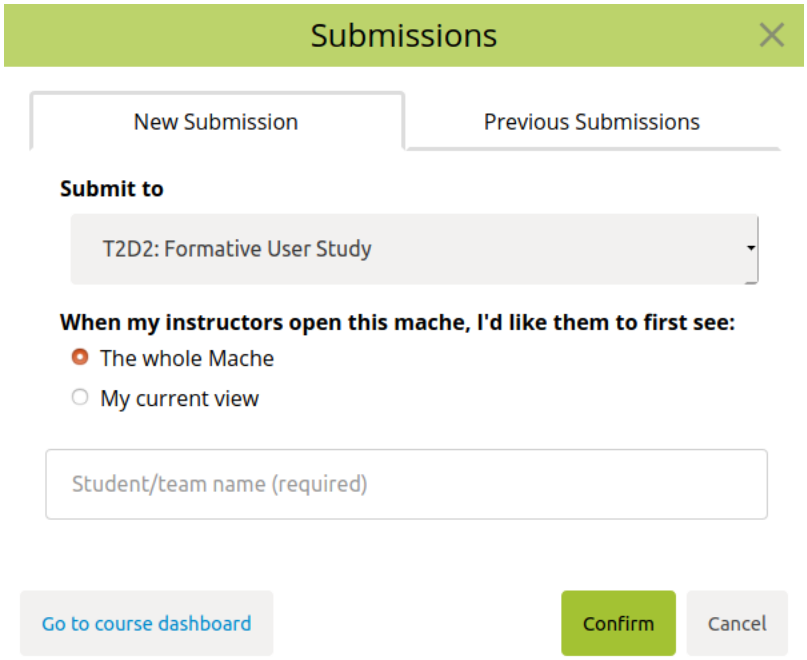

Figure 2: Submissions dialog: the student selects a deliverable to submit their curation to. They choose whether the instructor will initially see a subarea of their work—i.e., the current view—or the whole work when the instructor opens it from the dashboard.

If a student thinks as though a specific area of their work should be emphasized, they can choose to initially present their instructor with that area when they access it. Upon successful submission, the students' work is then automatically associated with that assignment, and all users with permission to edit the work are notified via email that they can view the work from their submission dashboard (Figure 3).

Assignment	Submission Open?	Submitted By	Student/Team Name	Latest Snapshot	Submission Link (Live)
Milestone 1	🔓	Username 1 (Anonymized)	Student 1 (Anonymized)	Nov 7 11:57	Milestone 1
Milestone 2	🔓	Username 1 (Anonymized)	Student 1 (Anonymized)	Nov 17 23:20	Milestone 1

Figure 3: Student Dashboard: viewing submitted works across deliverables. Students access all their submissions, for a course, through this view. They can also see the deliverable name, whether the deliverable is open or closed for submission, the latest submission (snapshot) and when it was submitted, the username of the student that submitted it, the student or team name input by the submitter, and the original curation from which the latest snapshot was created.

Our investigation indicated that while some instructors prefer to assess students' live work where students can still be designing, others prefer to assess what students accomplished by the deadline. Thus, when a student submits their work to an assignment, an additional read-only *snapshot* is created that reflects the state of the student's work at that time. While students can continue to edit the original work, creating snapshots at each iteration creates documentation of how the work changes over time. The history of snapshots can be accessed by students from within their ideation environment and dashboard (Figures 3 and 4), allowing them to re-use materials and ideas during their iterative design processes.

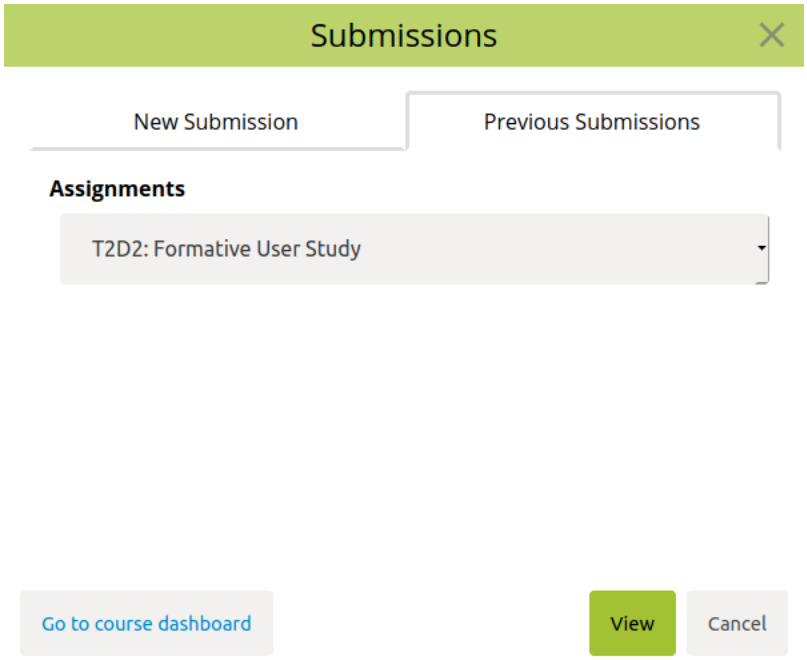

Figure 4: Submission Dialog: previous versions. The student can visit all of the previous versions of their work, across deliverables, ordered by submission date.

Once a student's work is submitted to an assignment, instructors are granted access to both the student's living work as well as the latest snapshot. When viewing an individual assignment, instructors can access the live submission, the latest snapshot, as well as design analytics automatically computed upon both (Figures 5 and 6).

Student/Team Name	Submitted By	Mache	Elements	Words	Images	Zoom Levels	Element Groups	Latest Snapshot (Copy)	Submission Link (Live)
Student Name 1	Username 1	Mache Name 1	158	1015	43	5	12	Jan 20 21:50	Apr 02 12:27
Student Name 2	Username 2	Mache Name 2	32	232	6	2	2	Jan 22 20:58	Jan 22 20:58
Student Name 3	Username 3	Mache Name 3	41	425	6	2	3	Jan 23 01:05	Jan 23 01:05

Figure 5: Instructor Dashboard: view of one deliverable across students. Instructors are presented with fluency analytics—the number of elements, words,and images—derived from the latest submission, holistic metrics—such as the number of zoom levels or groups of elements—and links for the instructor to view the latest submission and live work.

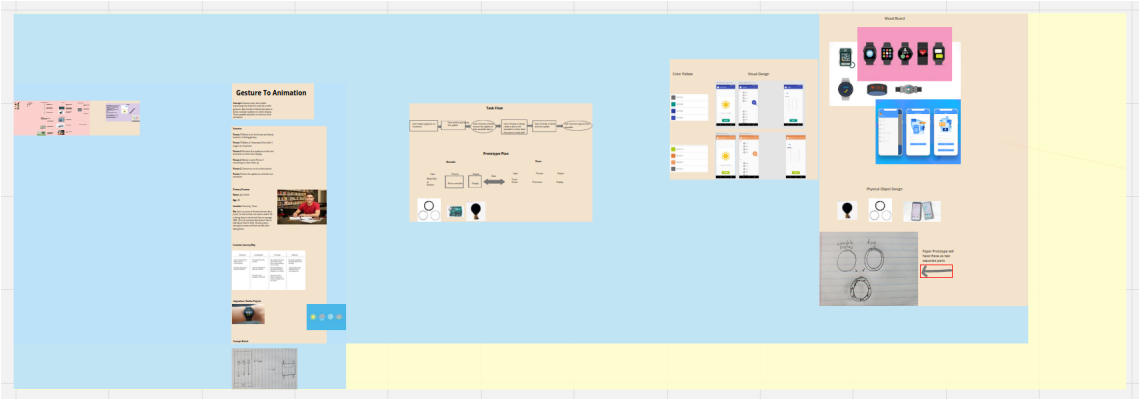

Figure 6: A visualization of the different zoom levels present within a student's work that an instructor can view.

We present instructors with three fluency analytics: word count, image count, and element count, in addition to links to the live design and the latest submission snapshot. In addition, we provide two holistic analytics of curation, including the number of different spatial zoom levels the student used in their work, as well as the number of visual groups that exist within the work. Data regarding the utility of the holistic analytics has yet to be collected.

When instructors access student work, they are opened in LiveMâché ideation environment, and instructors can interact with the work in the same way as the student. Instructors are also able

to leave feedback on the work within the ideation environment. From our investigation, we found a need for instructors to notify students that their work has been reviewed and feedback has been left. Thus, we created a system by which instructors can send all of the students an email, informing them that their work has been reviewed (Figure 7). To emphasize a certain part of the work, the instructor can choose to initially display that part to students when they view the feedback (Figure 8).

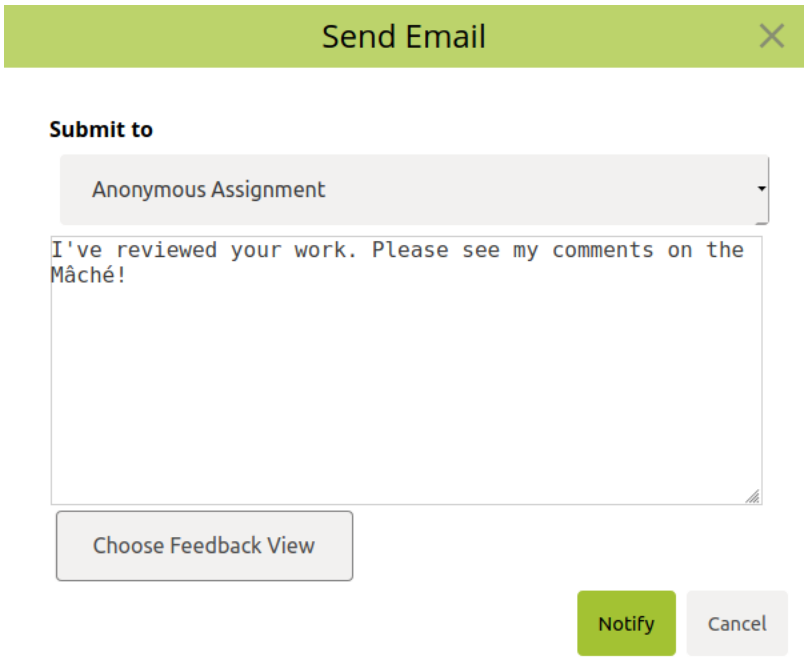

Figure 7: Notification dialog: instructors can send a notification to all of the contributors to a work from within the ideation environment. If the instructor wishes to leave personalized feedback to the contributors, they can alter the default email body in the text box. In addition, they can choose a section of the work to emphasize to the student (see Figure 8).

Figure 8: Preview mode: Instructors can freely move about the student's work without disturbing it, searching for an area of the work that they wish to emphasize. When ready to capture that part of the work, the instructor can imply click the camera button at the top of the view, which will capture those coordinates in the work for the student to see.

I have provided visual representations of both student and instructor workflows (Figures 9 and 10).

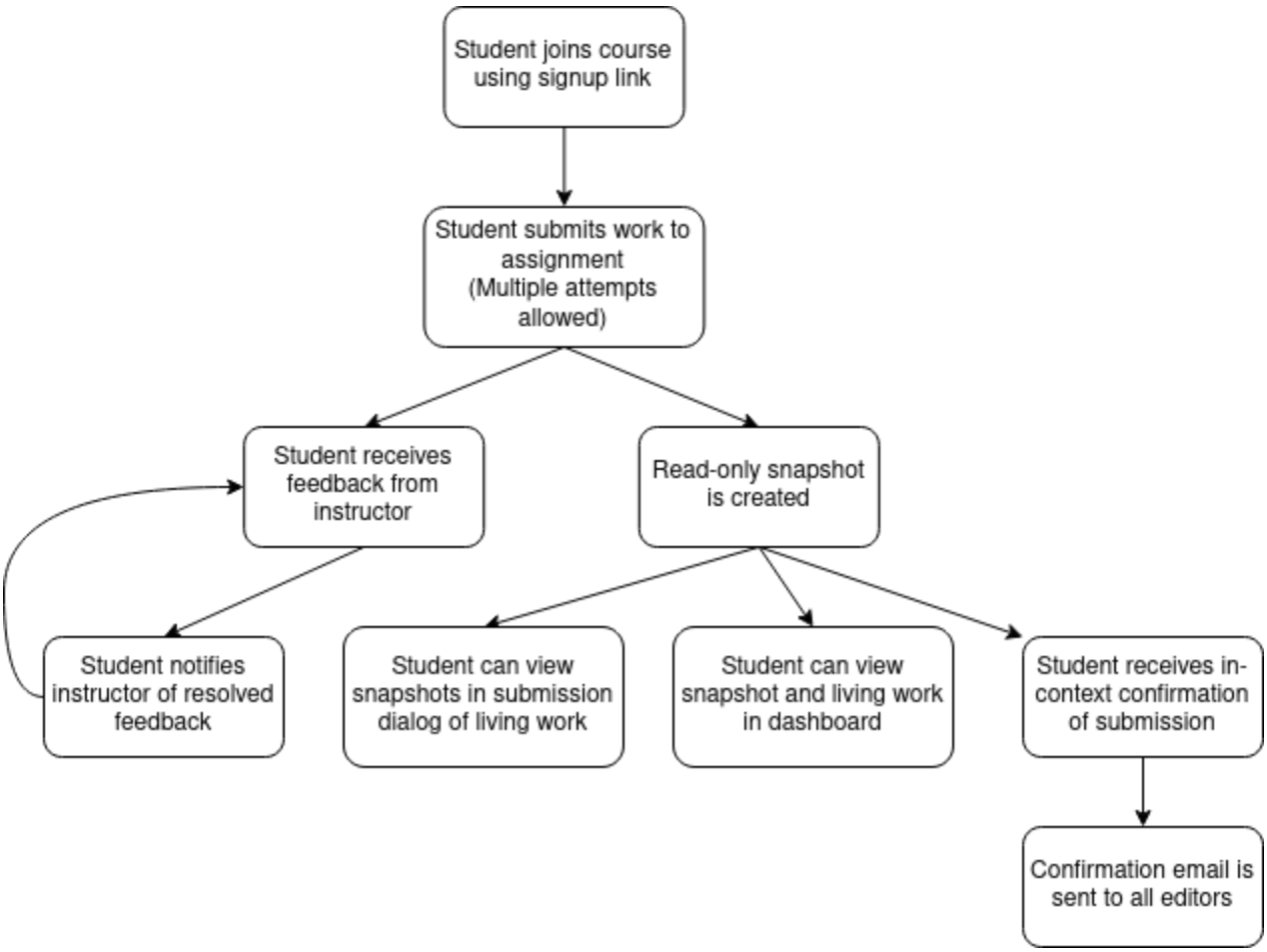

Figure 9: A visual representation of students' interactions with the prototype

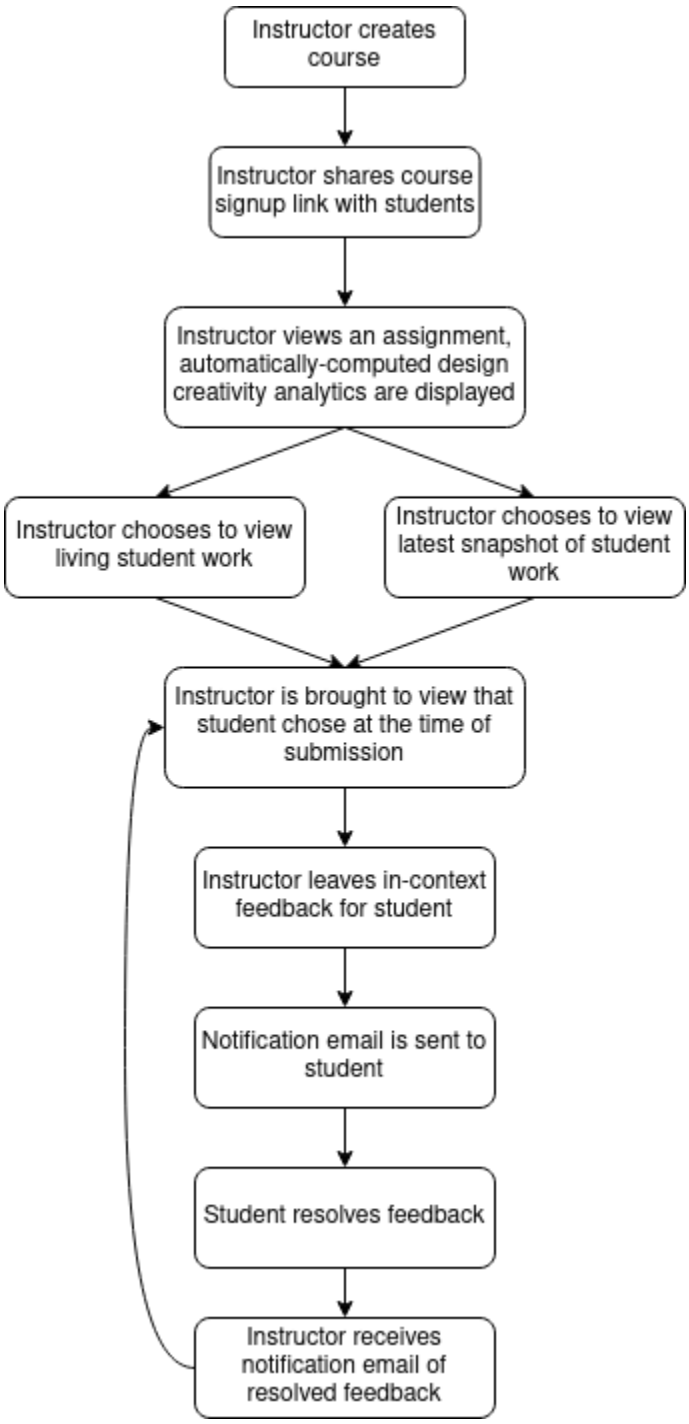

Figure 10: A visual representation of instructors' interactions with the prototype

CHAPTER V

FINDINGS

Quantitative Analysis

As users interacted with the system over the course of two semesters, their interactions were logged. We derived usage metrics from both logs and database records to assess how users interacted with the features I deployed. I improved LiveMâché's logging functionality, which made it more robust during the spring semester as compared to the fall semester. Hence, visualizations of data are from the over 1,700 events logged in the second semester between 5 classes (see Figure 11).

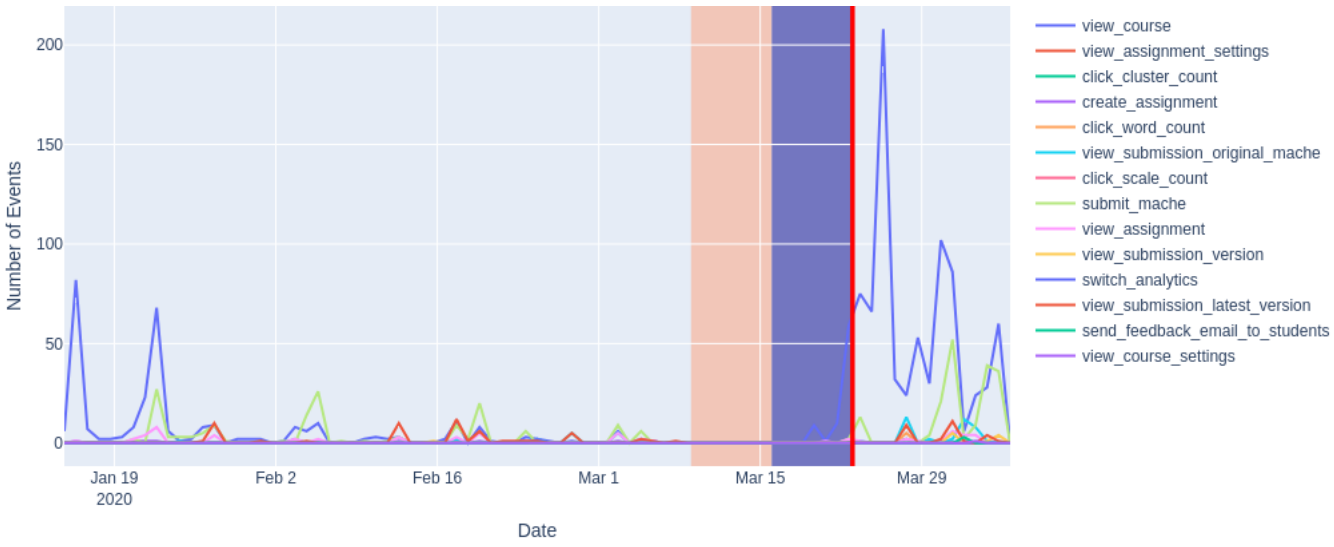

Figure 11: All LiveMâché course activity for the spring semester of 2020. The orange and blue shaded regions are Texas A&M University and Illinois State's spring breaks, respectively. The solid vertical red line is the date that both universities turned to online classes during COVID-19.

In total, 172 design curations were created by students using LiveMâché: 29 in Fall 2019, and 143 thus far in Spring 2020. As students' design processes are iterative in nature, drawing

from ideas and materials present in earlier versions of student work contributes in generating new ideas in new iterations. Of the 172 design curations created by students using LiveMâché, 37 were submitted to at least two assignments: 5 in Fall 2019, and 32 in Spring 2020 (approximately 21.5%), indicating that students continued to operate within the same ideation environment and highlighting the living nature of design. These 37 curations generated 19% of all submissions (Figure 12).

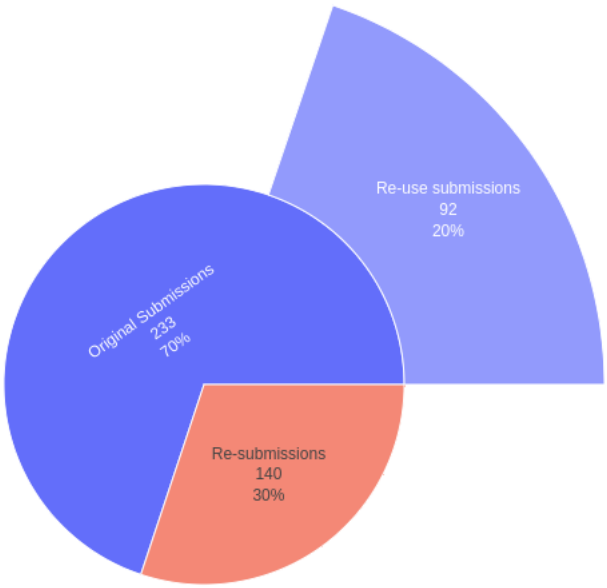

Figure 12: The number of submissions over the course of the study. Students submitted their work 373 times (43 times during Fall 2019, and 330 times during Spring 2020). Re-use submissions are submissions generated by design curations that were submitted to multiple assignments.

Mache access was primarily dashboard-driven (Figure 13). Students accessed their design work a total of 133 times from the dashboard. Some users chose to access an original design work (55 times), while others preferred to access the latest version of a work (78 times). While more

data must be collected, one explanation for the higher number of accesses to the latest version is students verifying that their work was submitted successfully to an assignment.

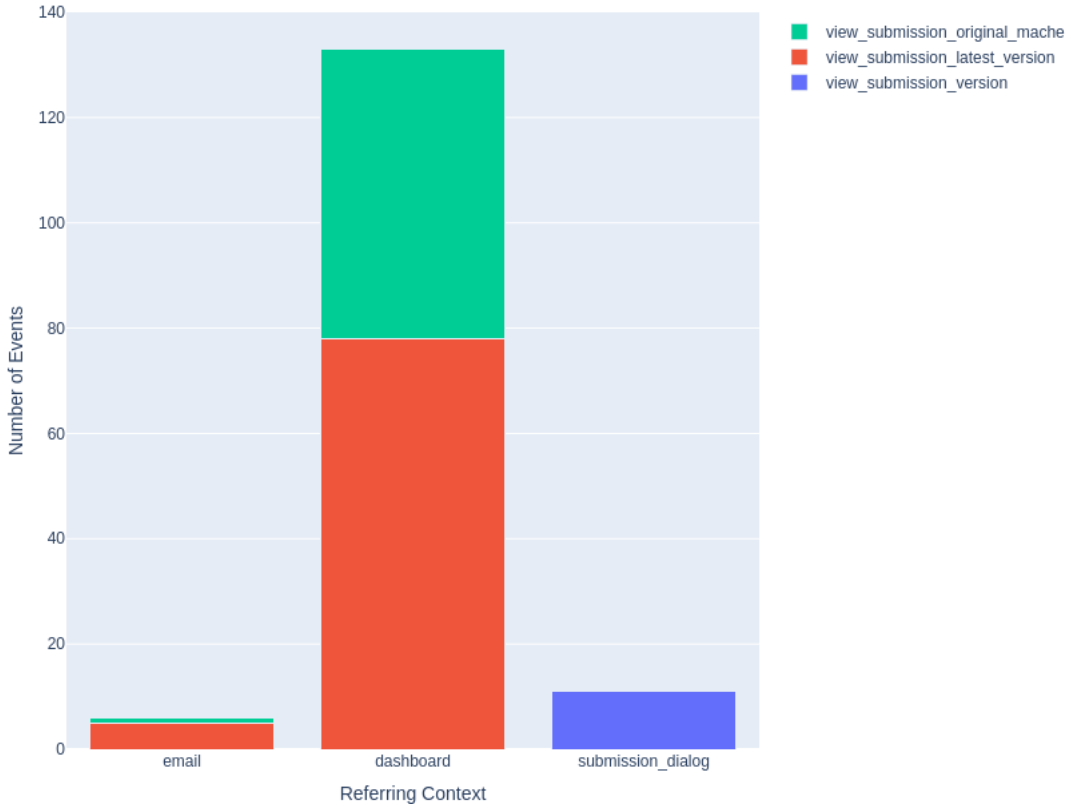

Figure 13: The number of times a user accessed their design work, and their originating location. Most users viewed the latest version of their work, and accessed it from the course dashboard. This can be attributed to students verifying that their work was successfully submitted to an assignment from their course dashboard.

Users also made use of the versioning feature, accessing a version of their work from the submission dialog a total of 11 times. A small set of users accessed their work from the emails sent upon submission. The access patterns remain the same across instructors and students (Figure 14).

Feedback notification functionality was released to students midway through the spring semester, close to the time where students were going on spring break, after which the COVID-19 outbreak escalated in the United States. While usage of feedback notification features was low,

with only 3 events recorded since their release, instructors expressed a strong interest in these features and the opportunities they provide. The features are expected to facilitate transition to remote work.

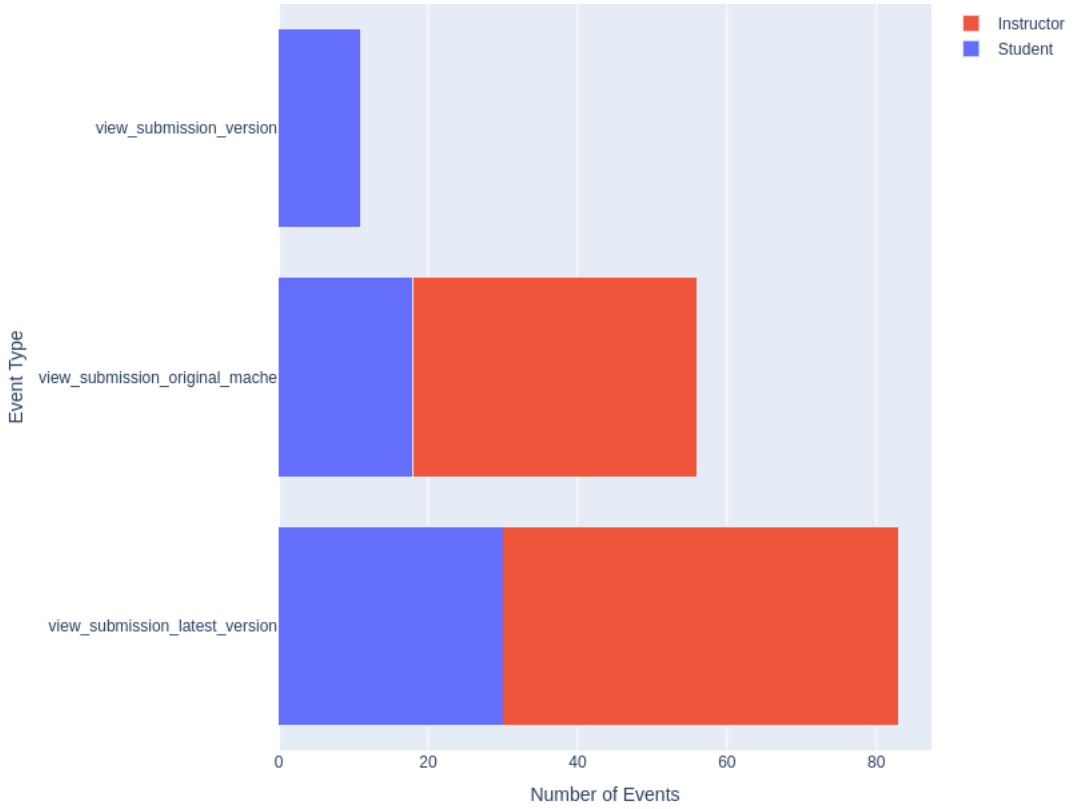

Figure 14: The number of times students and instructors viewed the latest version of a design work and the living version of a design work. Both instructors and students viewed the latest version of a work more frequently than the living version of a work.

Qualitative Analysis

To understand how the system affected design instruction and learning, we conducted four semi-structured interviews at the end of the first semester: two interviews with instructors (D_1 and D_2), and two interviews with students (S_1 and S_2) from D_1's course. A graduate researcher and I analyzed the qualitative data derived from these interviews, using a grounded-theory approach [27], which resulted in the following categories.

Integrating Design with Dashboard Supports Iterative Processes

Both instructors reported that the integrated submission system supported them in viewing, managing, and grading the submitted assignments. Compared to their experiences with prior learning management systems, both instructors and students found that an integrated system enables them to assess the current deliverable in the context of ongoing work, rather than in isolation. D_1 felt as though they were part of the students' ideation process and progress, *"kind of like building ideas together"*.

> D_1: As the name of the program tells, you're live...it's not a fixed and frozen document, it's still a living thing.
>
> D_1: I felt more engaged with the students' whole process rather than checking certain points. As classes are becoming larger and larger, it becomes difficult to know every student's work from beginning to end.
>
> S_1: [Previous LMS was] only for uploading the files I made in...other software. LiveMâché is literally live, I could [perform creative work] and submit it.

Students reported that the system supported their iterative design processes by enabling them to easily reuse material across deliverables, and reflect on their previous work.

> S_1: Firstly, I cannot memorize every statement or special terms...so I visited my [previous submissions] to check it. Secondly, for uniformity of my [design].
>
> S_2: [LiveMâché]...refreshes my memory on how I design: why I designed this, and how I designed this, and what my deliverables were, all in one image...I guess [LiveMâché] is [useful] for a designer to reflect upon what worked, what didn't work, what was hard, and what their process was.

As I described in the System Design section, multiple channels of accessing a design work were constructed. We learned about different purposes served by different channels.

S_1: I don't really read [the submission confirmation email]. People don't care about the confirmation email, they care that [there] is a confirmation email, but they don't really read it.

Both instructors and students felt that traditional LMSs offered more features for managing administrative functions of the class. For example, D_2 suggested that *"it would help [if the system] supports keeping track of deadlines."* Indeed, in order to cope with the lack of "deadline" functionality in the system, instructors resorted to including the due date in the assignment name. Students echoed the need.

Instructors' Assessment and Feedback to Students

Instructors report that being granted automatic access to student work on submission streamlines their assessment and feedback processes. Previously, students often forgot to grant instructors access rights to submissions—despite instructions—which delayed instructors' delivery of feedback. Instructors want students to submit work early, well in advance of deadlines, and then continue to iterate, allowing for instructors to provide feedback early. Submitting creative work early for contextual feedback represents a new user model for design.

D_2: Being able to see how their processes evolve has been helpful for me...in seeing how much they actually learned.

D_1: I expected them to submit sooner, so that I could provide feedback before the class. I couldn't provide a lot of feedback in advance.

Instructors viewed the snapshot feature differently. While D_1 preferred to leave feedback on the live design curation, in which the students are iterating, D_2 preferred to use snapshots.

D_2: *Verbal feedback [is often] not taken into account. Feedback documented in a snapshot would be better taken into account.*

Computational Derivation of Analytics from Design Work

Instructors report that while the numerical values of the analytics presented on the dashboard do not indicate the quality of a design, they provide insight into students' effort across certain dimensions. According to D_1, while the numbers do not indicate the quality of a design, they are insightful into the students' effort. D_2 likewise noted that analytics helps in comparing efforts in certain dimensions across students or teams.

> D_1: I think it showed me this student worked hard, they did a lot of research...[but] it's challenging to see numbers and somehow assess the quality of work.

Both instructors desired the ability to see advanced analysis of student design work, in particular, presenting conceptual ideas present in students' design.

> D_1: Numbers are nice, but things like a word cloud would be helpful.
>
> D_2: If students were to use [text, image, video] elements online, would I be able to see the sources that they use?
>
> D_2: I would like to see how we can analyze the images... Though whatever the computer reads is different from the designer's aspect.

Their feedback inspired the development of features for visualizing different conceptual aspects of a students work like the one shown in Figure 6).

CHAPTER VI

IMPLICATIONS FOR DESIGN

Systems that integrate ideation and assessment by contextualizing deliverables mutually support instructors and students in design education. Their understanding of design processes and progress becomes enhanced. As S_1 articulated, *"what worked, what didn't work, what was hard, and what their process was."*

We developed multiple interfaces to access student work, which served different purposes. As S1 said, users only *"care that there is confirmation email, but they don't really read it."* Dashboards were found to be preferred means of accessing work (Figure 13). Dashboards provide a centralized place to present information to a user all at once, and allow them to interact with that information—and its sources—as needed.

Design is alive: as a process. The dashboard keeps a link to the live submission available to instructors, facilitating ongoing feedback. In addition, it keeps links to snapshots that allows instructors and students to view how work evolved through deliverables. It supports students in viewing and reusing ideas from previous submissions. In support of design's living nature, students and instructors benefit from integrated systems that contextualize creative design work with assessment.

As part of this, build systems that enable instructors to leave feedback on designs and notify students. Close the loop by notifying instructors when students address the feedback. This need emerged in our study; consistent with in-context assessment support by Brusasco et al. [15]. Different kinds of instructors have different preferences for how they assess their students' work. While some prefer to assess the latest, static copy of a student's work, others prefer to assess the work as the student last left it.

Design education will benefit from extending AI-based content recognition techniques [30, 31] to perform computational analysis of design work [8]. Instructors said design analytics provide

insights into student work, across dimensions.

Future research needs to investigate, in-depth, how instructors evaluate student work, to guide computational modeling of their approaches. As D_2 expressed, *"whatever the computer reads is different from the designer's aspect."* These include marking feedback as incorporated when a student thinks they have sufficiently resolved it, in addition to notifying students when feedback on their work is ready for resolution.

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APPENDIX

Student Interview Questions

- How have you engaged in documentation of design processes in the past? How does using design curation as a design documentation practice compare?
- Have you used electronic homework submission systems in the past? How does LiveMâché's submission system compare to similar courses?
- How do you determine that your work is submitted successfully to an assignment?
  - Have you used the course dashboard to confirm what you submitted for an assignment via the dashboard?
  - Have you used the submission confirmation email to check your submission? Did you navigate to the submission mache and dashboard links in the email?
  - Did you use the course dashboard or confirmation email link to visit the mache version that gets automatically created on submission?
  - Do you think anything could be improved? Confirmation popup, dashboard, email, etc.
  - Have you encountered any issues or difficulties when submitting a mache to an assignment? Viewing the course dashboard? Navigating to the submission?
- How does the integration of submissions and the courses dashboard compare with making things in an external design tool (like Photoshop, Illustrator, InDesign, . . .)?
  - Do you keep track of versions of design work? How?
  - Do you generally have issues keeping track of versions of a design and the course deliverables that you turn them in for?
  - How does keeping track using LiveMache's integrated submission system compare with using external tools such as Photoshop, Illustrator, etc.?

- What did you learn about iterative design processes? Did your understanding of design processes change by using LiveMache? How?
  - Have you chosen to send your current view to your instructor, rather than the whole Mache? Why or why not?
  - Have you used the course dashboard to revisit what you submitted for an assignment via the dashboard? If so, why?
  - How did you use your previous submissions, if at all? Did you use the versions that get automatically created? How?
- What kind of other information would you want to see on the dashboard, if any?
- What are your suggestions on improving the submission and dashboard interfaces?
- Any suggestions on making them more suited for design learning?

Instructor Interview Questions

- Please briefly describe your experiences with the LiveMâché courses dashboard.
  - Do you think the class / students / etc. would be different with / without the dashboard? How?
- How does using the LiveMâché courses dashboard compare with other dashboards or learning management systems? What is similar? Is anything different?
- Has using the LiveMâché dashboard to follow and track student design processes changed how you teach or interact with the students? What has changed?
  - Do you use mache versions that get automatically created on submission? How?
  - Does versioning support in tracking iterations, in your evaluation and feedback processes? How?

- Has using the dashboard shown you anything new or unexpected about your students or class or learning?
  - Did you see the numbers presented on the dashboard with submissions?
  - How do you understand and utilize them?
  - Do they support in monitoring and intervening? Evaluation and feedback? How?
- Will you do anything differently next time you teach the class?
  - Has your understanding of design learning changed? How so?
- What are your suggestions for making the dashboard more suited for your instruction practices? Or for design education in general?