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A DESCRIPTIVE STUDY OF DESIGNERS' TOOLS FOR CAPTURING, REFLECTING ON, AND SHARING USER NEEDS AND CONCEPTUAL DESIGNS

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ABSTRACT

Designers employ a range of tools to gather, create, explore, sort, and act on user needs and conceptual design information. However, designers work both individually and collaboratively. This research is a descriptive study of technologies employed by designers to individually capture and collaboratively share user needs and conceptual designs. In this paper we examine the range and affordances of tools used by designers, and how they use these tools to share design information. We do this by looking at data gathered in interviews with practicing designers and design researchers, as well as documents produced in undergraduate and graduate-level new product development courses. We gather a wide range of tools from our informants, and analyze them based on sharing semantics and formality. We then introduce a model of sharing as a cycle of capture, reflect and share. Finally, we provide design recommendations for future information tools that support both personal and collaborative user needs and conceptual design information.

INTRODUCTION

During the user needs research and conceptual design stages of the design process, engineers and designers gather, create, explore, sort, and act on design information. This information is kept in a variety of design information tools, for both personal and shared use. It is important to understand how designers use these tools in both personal and collaborative settings, as integration of individual and shared work is key to shared success.

In this paper, we examine the spectrum of tools available for use during user needs research and conceptual design phases of the design process. We focus on user needs research and conceptual design phases as these early-stage phases both require massive amounts of information handling. Our research questions include:

- *What are the range of information tools in use by today's engineers and designers for user needs and conceptual designs?*
- *How do the affordances of these tools affect their adoption and use in collaborative settings?*
- *How do designers manage and share information as they transition between individual and collaborative work in user needs research and conceptual design?*

We surveyed and interviewed a range of engineering designers and design researchers, both students and practitioners, to get a better sense of the range of information technology currently in use by engineering designers. We looked at specific features of each technology, and the roles they played in their use. We looked at the formality of the information being captured, archived, and presented using a given tool.

RELATED WORK

Several design researchers have looked in-depth at the use and content of specific design tools (e.g., logbooks [1], email [2], electronic files [3]). Others have looked into how specific design activities are supported by tools, such as sketching and the use of design journals [4][5]. Building upon this research, we will look at all tools used to capture and share information in early stages of the design, rather than focusing on the specific content captured within these tools.

Because of our interest in both individual and collaborative use of tools, it is important to consider how information is shared in teams. In a discussion of face-to-face collaboration that occurs around tables, Shen et al. define a gradient of sharing semantics of *private, personal, public* [6] (see Table 1). Their proposed UbiTable executed this vision by differentiating visibility and accessibility from each other to create the "personal" shade of sharing semantics.

	Sharing Semantics
Private	not visible or accessible to others
Personal	'on-my-side-of-the table' data, semi-private (it is visible but not accessible by others).
Public	allows shared visibility and access.

Table 1: Sharing Semantics, according to [6]

	Information Formality
Informal Design Information	"Informal design information is unstructured text, captured as it is generated. Unstructured, fragmentary documents, such as those captured in design logbooks."
Semi-Formal Design Information	"In the middle is semiformal information, which is essentially informal information with a limited amount of structure imposed, such as design rationale systems or case studies."
Formal Design Information	"At the formal end are highly structured, detailed documents, such as final reports, patents, and CAD drawings"

Table 2: Information Formality, according to [7]

In their discussion of design information for possible reuse, Yang et al. [7] propose a "spectrum of formality" to differentiate different types of information created throughout a project. Their spectrum is outlined in Table 2. As we consider different tools, it will be important for us to also consider what formality is supported by these tools, and how information evolves from one level of formality from the next.

Researchers in human-computer interaction and computer-supported collaborative work have also looked at tools that support both individual and collaborative work. Greenberg et al. developed SharedNotes, a tool to support the transition from personal to public information and back, in the context of group meetings [8]. While this tool facilitated the transition between individual and collaborative work, it was primarily focused on meeting notes, task lists, and calendar management. Beginning from an interface for collaborating field biologists [9], Lee et. al. [10] proposed iDeas, an ecosystem of digital and tangible tools for designers that facilitates sharing of ideas. The deployment of the iDeas logbooks, using Anoto technology, helped researchers better understand and explore the dynamics of design in teams [11]. These proposed technologies

METHODOLOGY & TEST BEDS

This research draws from a variety of data sources, including interviews and surveys with practicing and student designers.

- *Survey of Practicing Designers & Design Researchers*. We surveyed 11 practicing user researchers and designers about their design practice. In the survey, we asked each practicing designer or design researcher "What types of information tools do you use as part of your job? For example: paper notebook, mobile phone, software, whiteboards, web applications."
- *Interviews with Practicing Designers & Design Researchers*. We interviewed 15 practicing user researchers and designers. Our interviewees were from the San Francisco Bay Area, Chicago, New York, and London. We spoke with 3 mechanical engineers (3), industrial designers (2), user experience (software) designers (2), designer researchers (7), and a project manager. Six of these interviewees were recruited from the survey. In these interviews we asked about what tools they use, what information they choose to share (and choose not to share) with their collaborators, as well as how they select tools or methods to use in their design process. For those that had filled out the survey, we followed-up on specific tools the interviewee had mentioned in the survey to learn more about when and why they choose to use that particular tool. We also analyzed notes from interviews with two practicing designers, conducted by an undergraduate student team.
- *Interviews with Student Designers*. We interviewed four students from the Fall 2009 semester of ME290P, a graduate-level multidisciplinary course on new product development. Two of the students we interviewed were MBA students, while the other two were trained in software engineering and interaction design. We also analyzed notes taken from interviews of 13 student designers recorded by a design team conducting user research on design capture. These students were from various disciplines, including engineering, architecture, and interaction design.

Table 3 includes a summary of the testbeds, including the number of student and practicing designer participants in each.

Testbed	Number of Practicing Designers	Number of Design Students
Interviews with Practicing Designers & Design Researchers	17*	0
Survey of Practicing Designers & Design Researchers	11	0
Interviews with Design Students	0	17
Total	**22**	**17**
**6 interview participants recruited from survey respondents*		

Table 3: Summary of testbeds and participants.

Methodology

To understand the range of information tools in use by today's engineers and designers for user needs and conceptual designs, we first read through all our survey results and interview transcripts and coded each mention of a different design information tool. We then categorized this list of tools based on their media:

- **Tangible Tools**: Physical, often paper-based tools.
- **Digital Hardware**: Electronic hardware running software and web services, or are embedded systems.
- **Software**: software installed and running on personal digital hardware.

- **Web Services**: software that is hosted via a web server.

Next, we went through the data again, this time counting the number of unique individuals reporting the use of each particular information tool.

For each tool, we then coded of the stage in the process when it was being used, as well as whether or not it was being used in an individual or collaborative setting. We also focused on where the tool fell on the gradient of formality (based on Yang et al. [7], see Table 2) and sharing semantics (based on Shen et al. [6], see Table 1). Finally, we collected and analyzed qualitative quotes and anecdotes to understand which features and tools were adopted, in what contexts, and why.

RESULTS: RANGE OF TOOLS

We gathered a list of 53 design tools in use by all testbed participants. Table 4 provides a summary of all tools mentioned by our sources, with a count of the number of unique individuals who mentioned using a particular tool aggregated for each subcategory. Additional detailed data is in Appendix A.

Tangible Tools

Small-scale tangible tools, including post-it notes, index cards, and paper scraps, that are lightweight and mobile. This affords the ability to easily reconfigure and combine these pieces of information.

Medium-scale tangible tools include various formats paper notebook (e.g., Moleskine, spiral-bound), which are used as design journals or engineering logbooks [1]. These formats afford implicit chronological use, as consecutive sheets are often filled out in chronological order. *Loose-leaf paper*, as well as tools that organize loose-leaf sheets of paper such as folders and binders, are also medium-scale and allow individual interaction. However, loose sheets of paper afford later reconfiguration or reorganization. *Magazines and books* are also medium-scale, but are not generated by the designer and are used as an informational reference.

Large-scale tangible tools, including whiteboards and large-format paper, are used for collaborative tasks that require a shareable, viewable representation that is easily malleable by a team of designers.

Physical prototypes may exist at a small, medium, or large scale, depending on the concept. As prototypes are embodied concepts, they often afford a richer, more visceral representation than a sketch on paper.

Digital Hardware

Digital Hardware includes both hardware platforms for software or web applications, and standalone capture devices.

Mobile Computing Devices include smartphones and digital pens and paper. These tools are mobile and afford interaction while standing or walking; as a result, they are often taken into the field for user research.

Portable Computing Devices are platforms that, while portable, necessitate a workspace in order to operate. While laptops can be taken into the field, they were more often shuttled between desks and other meeting spaces within a design studio. Unlike mobile computing devices, portable computing devices have larger displays and can run most software – as a result they are the hardware platform of choice for most software and web services.

Digital Capture Devices include audio recorders, video recorders, or digital photography, and are primarily used to capture user research data, but may also be used in creating prototypes.

Software

Where digital hardware is able to multitask, software generally has more specialized functionalities that allow its users to accomplish particular tasks

Prototyping software helps the designer actualize a digital representation of their concept. Depending on their design domain, this may include solid or surface modeling CAD tools for product designers, wireframing tools for interaction designers, or desktop publishing for graphic designers.

Designers used the full range of office suite software throughout the design process. *Word processing software* was often used to for transcripts of user needs interviews. *Spreadsheet software*, however, stood out as a non-specialized tool used by designers to manage and analyze user research data. These spreadsheets afford quick tagging and sorting of data. *Presentation software* is used to present ideas internally within a design team, or to external audiences like managers or clients. It also affords a linear and hierarchical structure to information.

	Tool	Number of Practicing Designers	Number of Student Designers
Tangible Tools	Small Scale	15	12
	Medium Scale	10	9
	Loose-leaf Paper	7	6
	Large Scale	12	3
	Physical Prototypes	5	0
	Magazines & Books	5	0
Digital Hardware	Mobile Computing Devices	13	2
	Portable Computing Devices	3	5
	Digital Capture Devices *(e.g., Audio, Video, Photo)*	29	1
Software	Prototyping Software *(e.g., CAD, Wireframing, Graphic Design Software)*	13	9
	Spreadsheets *(e.g., Excel)*	13	0
	Presentations *(e.g., PowerPoint)*	14	2
	Word Processing *(e.g., Word)*	11	3
	User Research Capture and Editing	15	0
	Notetaking Software	2	2
Web Services	Online User Needs Tools *(e.g., Surveys, Card Sorting, Recruiting)*	11	0
	Online File Management Tools (*e.g. Google Docs, Dropbox)*	7	6
	Online Communication Tools *(e.g., Email, Chat, Webconference)*	21	4

	Online Notetaking/ Journaling *(e.g., Blogging, Evernote)*	1	4

User Research Capture and Editing software is used in the capture and manipulation of user research data (e.g., screen capture, video editing, custom-built qualitative analysis software). This includes screen recording and qualitative coding tools. Some design firms will use custom software

Notetaking software applications are text editors used to take notes during a meeting, or during a user interview. While most afford text input, some augmented systems can synchronize audio recordings with the text input.

Web Services

Web services are either web-hosted services or web-dependent applications that require Internet access for full functionality. As much of the data for web services exist "in the cloud", it affords the peace of mind that files are safe on an external server.

Online User Research Tools are used to communicate or capture interactions with users. User research participants are recruited from public-facing online tools like Twitter, Mechanical Turk, Mailing Lists, and User Forums.

Online File Management tools are used to coordinate files or tasks across collaborators. Web-hosted applications like Google Docs will be used to collaboratively co-create documents or artifacts.

Online Communication Tools are used to communicate with collaborators, either asynchronously (e.g., Email) or synchronously (e.g., Instant Messaging, Webconferencing). Webconferencing tools afford the widest range of features, including audio, video, and text chatting, and shared desktops.

Online Notetaking/Journaling tools are similar to note taking software, but afford access on any web-accessible device and extra peace-of-mind. Individuals use many of these tools, but some afford multiple accounts to contribute to a single archive, and therefore allow collaboration between teammates.

We found that practicing designers mentioned using a broader range of tools than students. This could be because practicing designers in industry have resources that make using any given tool a more accessible, viable option. For example, professionals have consistent access to studio space where large-scale tangible tools can be posted on the walls. Professionals also have larger budgets that can be spent on Digital capture devices, specific prototyping software, or online user research services.

However, students exceed designers in their use of online notetaking tools. This may be due to increase comfort with new technologies, or evidence of exploration as new habits are being formed. One of the interaction design students we interviewed experimented with using a Tumblr blog for his design journal. He found that many of the features not only benefitted himself (for example, using his iPhone to take pictures of sketches so that he could never lose his ideas), but also his collaborators (for example, posting links to relevant technologies and competing products that could be viewed by his collaborators online).

Table 4: Range of tools used by (17) student and (22) professional designers.

RESULTS: SHARING SEMANTICS

As teams progress through the design process, they continually share design information amongst team-members, and then to people outside the team, such as managers or clients. As such, we asked our respondents to discuss when and how they shared different design information. We then assessed their responses using Shen et al.'s three-level framework for sharing semantics [6]. In our analysis, we found examples of each category:

Private information is not visible or accessible to other people. For our respondents, most private information was kept in design journals – a designer's personal archive of information relevant to a design project. As noted earlier, this was often a medium-sized tangible information tool such as a paper notebook, or collection of loose-leaf paper. We also found instances of digital design journals which made use of information tools that afford single-user access such as software tools connected to a specific digital hardware device, or password-protected online notetaking tools.

Personal information is visible but inaccessible to others. Among our respondents, this was most often information stored in design journals that they reviewed during meetings. These personal design tools are brought to face-to-face meetings where collocated collaborators may observe these tools in use. While visible, collaborators needed to ask permission in order to access that information. Similarly, digital tools may be considered personal if software is seen in use on personal digital hardware.

Public information must be visible and accessible to all collaborators. In tangible tools, large-scale tools like whiteboards or butcher paper allow everyone to see the design information and have access to manipulating it. In digital tools, online software can afford collaborators access to a shared information space. One interesting example of public information we came across were students who kept their design journals using web services such as a Tumblr blog. In this case, public information is not only accessible to collaborators, but also to the general internet audience. These types of web services afford an ambient awareness by a public audience, making what is generally a "private archive" public as it is created.

Transitioning between Sharing States

Though Shen et al. [6] focus on the status of information in different situations, we also looked at transitions from one state to another.

Private to Personal. Information becomes personal as designers begin to collaborate and previously private information is now visible from across the table. Some of the

designers we talked to attempt to keep information private in order to protect their collaborators from irrelevant or unnecessary detail. However, one of the interaction design students preferred paper to laptops, because of their visibility to his peers:

> *"Like, the notes I'm taking in the meeting. I can be, like, 'Okay so now we have three things. Which ones do we agree with?' So, everybody can see it because, you know, if you have a laptop I don't really know what you're doing."*

Personal to Public. Public information often comes from personal sources. Personal information is made public when individuals make contributions to the material anchor of the team's conceptual blend (e.g., everyone contributes post-its with ideas towards a larger representation of the prioritized ideas of the entire team) [12]. Personal information may also be made public as a reference to inform the team's direction as they focus on another task.

Some designers keep two parallel tracks of information: the main storyline they are developing as a deliverable, and the additional detail that may or may not be relevant to the primary message. In an effort to include the full extent of detail available, extraneous information will be pushed to less-direct methods of communication. One practicing design researcher at a consultancy commented on how he decides what goes into the report (primary message) versus the appendix (additional detail) presented to the design team:

> *"Putting together PowerPoint, there's stuff that doesn't fit. Though it seems interesting or important, it's not a part of the story because it doesn't fit in the story. It goes in an appendix, but not in the final report."*

The risk of not sharing information directly in a face-to-face manner is that, despite being public, it will remain unread or misinterpreted through a mere skimming. One of our participants noted that if she did not present her designs to her manager in-person, there was no guarantee that her manager had actually seen anything that was sent to her.

However, much like design journals and notebooks act as extended memory for an individual [13], information shared indirectly is available to the group despite the fact that it may not be immediately relevant to the current thinking on the design problem.

Public to Private. Information that has been made public to the team may be transformed into private design information by being recorded into individuals' private archives. This recording may be notes from meetings, reflections on the team's ideas, or new concepts based off the public information. For example, some of the students we interviewed reported using smartphones to take pictures of collaborative whiteboards.

Personal to Private. At the end of a meeting, a designer withdraws their personal information from view. Though collaborators are aware of an individual's personal information, its lack of visibility returns it to the private realm.

Sharing across stages

When looking at different stages of design, sharing semantics is fundamentally different between user research and conceptual design due to information ownership. In the user research phase, an individual designer collects information about the user on behalf of the team, conveying the user's story back to his or her collaborators. On the other hand, initial concepts and ideas implicitly belong to the designer who generated those ideas. One practicing designer described this implicit ownership of concepts, and learning to let go of that attachment:

> *"Though we're really attached to this idea, because you have some sort of, I don't know where that emotional attachment comes from, maybe it's your idea, maybe it's just pretty, literally. You just have to remind yourself, 'No, no, no. I have this information here that we've worked really hard to get and we know what the consumer wants or we need to have X. so don't go in this direction, go here'. So it happens every iteration, essentially. It happens when you're reviewing with the group, it happens when you're sitting down with the designer, and you're talking about things like where can this go, where can that go."*

Thus, while teams share user research data to reach the same frame as their users, teams share conceptual design information in order to reach a shared frame with each other on what the solution should be pursued [14].

RESULTS: SPECTRUM OF FORMALITY

Two primary aspects of Shen et al.'s framework are visibility and accessibility [6]. However, implied in visibility and accessibility is the increased formality required to guide the audience through the information presented. The act of sharing forces the designer to prepare a more formal embodiment of information, or verbally contextualize the information to highlight what they believe is most interesting and relevant to their audience.

While we initially coded our data using Yang et. al.'s formality spectrum [7], we quickly encountered information or

	Description	Example
Informal	Captured in the moment	Notes, Jottings
Semi-Informal	Sorting of informal, adding some structure.	Clustering of concepts, features, needs, etc.
Semi-Formal	The beginnings of a formalized structure	First drafts, working documents
Formal	Major components, but not fully fleshed out and finalized	Presentation slide deck requiring presenter for additional context
Archival	Stands Alone, detailed	"Slideument" (presentation that stands on its own without a presenter), final reports, patents

Table 5: Revised spectrum of formality

documents that were less formal than semi-formal, yet not informal. We also identified a distinct difference between formal documents to be used in the immediate context of the design task (such as formal presentations) and even more formal documents used to archive and document a design for future reference. As a result, we propose the addition of two categories of formality; this modified formality spectrum is summarized above in Table 5.

Informal information remains defined as "without structure", and requires fluent documentation of observation or thinking on to some medium. This takes the form of hand-sketched or handwritten notes on tangible tools, or captured audio, digital, or video data from digital capture tools. It is particularly important to highlight that the audio, video, and photograph data collected by digital capture tools is still highly informal, despite being high fidelity. Though it includes a great amount of detail, the lack of structure to that detail puts it on the informal end of the formality spectrum. *Semi-informal* includes documents that capture the beginning of a formalized structure. This may be annotated field notes and concept sketches, or the butcher paper resulting from a team meeting placing up post-it notes – often the results of the reflection phase of the sharing cycle.

We redefine *semiformal* as including semi-structured documents as they are being further refined – first drafts, fleshed out frameworks, or concepts that still require further detail. These semi-formal tools allow for some fundamental structuring, and often afford iterative refinement into a formal form. As a result, software tools for prototyping or presentations are used for semi-formal and formal documents. *Formal* documents refer to fully fleshed-out information, but may still require someone present to contextualize within the immediate design context, such as formal presentation documents. Formal information will be the most refined version of semi-formal documents.

Archival documents are meant for future consumption beyond the immediate design process, such as CAD documents and final reports. Particularly for archival information, designers prefer digital tools (e.g., CAD, desktop publishing, presentation software, etc.) that can not only be easily polished and refined, but also distributed across a wider audience and digitally archived for future reference.

Given these definitions, formality is constantly shifting throughout the design process; as captured information is formalized and shared, the next stage is often to restart with informal representations again. For example, the formalized, synthesized results of user research shared within a group will lead to informal concept sketches in the conceptual design phase. These sketches will once again be gradually formalized into CAD drawings, or even an archival form such as a patent application.

This parallels the converging-diverging model of the design process – just as the team must converge, informal information must be synthesized into a cohesive vision for the team's design priorities, which in turn leads to identifying divergent paths forward and capturing these potential paths in an informal format. It is therefore unsurprising that software and web service tools – particularly those that afford formalized representations or shared work – are commonly used in converging phases of the design process.

The anticipated audience makes a big difference on the required formality of the shared information – if a designer is discussing with collaborators, less formality is required than if talking to someone who is a spectator to the design process, such as a client or manager.

DISCUSSION: SHARING CYCLE

We identified a common sharing cycle across the situations recounted to us in our interviews with students and practicing designers. We propose the model of *Capture*, *Reflect*, and *Share* to better describe and understand how information is transferred between individuals and collaborators across both user research and conceptual design stages of the design process. An illustration of this model is provided in Figure 1.

- **Capture:** Designers individually or collaboratively gather information that may be of use in the design process. During user research, this consists of capturing raw data such as photos, videotapes, audio recordings, and transcripts; in conceptual design, this includes capturing concept sketches and possible design directions.
- **Reflect:** Reflection involves evaluating captured data and prioritizing, adding additional structure, and making decisions as to which data should be pursued further in the design. These reflections may or may not be recorded in a design tool.
- **Share:** The designer elects to share his or her prioritized information with their collaborators, or the design team elects to share their progress with people outside of their design team, either upper management or an outside client.

This cycle is conducted *individually* as team members prepare to share their findings and ideas with each other, and *collaboratively* as the team prepares to share with outside audiences. The cycle also repeats as each stage of the design process progresses, and as the team iterates through their design process and integrates new information. After user research information is captured, reflected, and shared both individually and collectively multiple times, conceptual design information is then captured, reflected, and shared individually and collectively, again through multiple cycles.

Capture: User Research. Information must be captured before it can be sorted or shared. One of the most basic ways to capture is to experience through the human senses, and refer back to the memory of that experience. In an effort to better record these experiences, information can also be captured through tools that allow for better recall and more objective validity. In addition to personal notes, designers will also employ capture tools (e.g., audio, photo, and video recording devices). One of our participants, a practicing design

researcher at a consultancy, described his efforts at doing user research alone:

> *"Videocamera on tripod, and then a plastic folder and paper for taking notes, and field guide. And I'm holding the camera, put the camera down, do this octopus thing, take still pictures, have a video camera, take notes, have a conversation."*

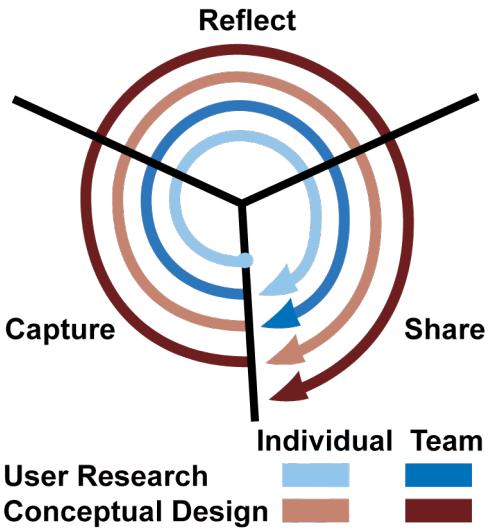

Figure 1: Sharing Cycle, across User Research and Conceptual Design Phases. The sharing cycle alternates between capturing reflecting and sharing as individual designers, and capturing, reflecting, and sharing as a team.

While these tools can be individually-operated, most of our respondents conducted field research as a team.

Few tangible tools are used besides private notetaking. The owners of these personal archives have a fear of their loss [15], however they are more often used as a memory aid [16] that allow the designer to offload some of their cognition on to this artifact and allow their thoughts to stay focused on the task at hand [13].

Web services are sometimes used to capture user behavior (e.g., card sorting, surveys, design games, Mechanical Turk), as web accessibility allows for remote observation and research, capturing user behavior in a manageable and accessible format for the rest of the design team. Newer digital tools, including Pear Note and Anoto-based digital notebooks and pens, are being used to integrate different media into the same representation (e.g., audio with text or handwritten notes).

Capture: Conceptual Design. During conceptual design, individuals capture their ideas in small-scale personal, and often-tangible tools that allow for hand sketching. The digital exceptions include tablet laptops, which afford the direct capture of hand sketching, or CAD tools that are used in later stages of design. Designers will also capture ideas, both nascent and developed, through the building of tangible or digital prototypes. One designer told about capturing ideas as rough prototypes she called "Frankensteins" while interviewing a potential user:

> *"When we go into a session, sometimes with Frankensteins, I can think of a couple times where one person will be like, 'Oh, you're using it that way, let's do it like this' and they'll take one part off and screw another part on."*

Reflect: User Research. During user research, field notes generally begin as private to each individual. Once data has been collected, individual designers or researchers must reflect on what is pertinent to their research goals. These reflections may be recorded in notes as annotations or reflections, or simply tagged in their minds as important to consider and perhaps shared with peers.

After the pertinent information has been identified, it is themed, clustered, and sorted in order to make sense of the data. This may occur on an individual level or as a group. Tools to support reflection and organization activities included spreadsheet software (e.g., Excel), or large-scale tangible tools (e.g., butcher paper). These tools can accommodate individual contributions by breaking down into smaller units, either cells within a shared spreadsheet, or the accumulation of smaller tangible tools (e.g., post-it notes). In either case, the outcome is a record of the reflections, discussions, and decisions in the form of a digital or tangible representation.

As these representations are being created, designers reference the raw data (e.g., user research transcripts, video, audio, photographs, or conceptual designs). The choice of representation media may affect how the designer or group of designers is able to structure or synthesize their captured data. For example, one user researcher described her use of informal, tangible tools to synthesize results:

> *"What we do is read them, make notes, and talk about them. It's pretty low-fi, there's post-it notes everywhere; we're clustering, debating, identifying patterns. If you've been doing this for years, themes emerge in the field and you get instincts and know where you're heading. Analysis is checking that, giving things weight and priority, figuring out how they relate to each other. Then it's piles of post-it notes, putting stuff together."*

Her coworker, however, preferred the linear structure offered by presentation software:

> *"PowerPoint for me is a good thinking tool because it's linear in a certain way, bit by bit by bit."*

Reflect: Conceptual Design. During conceptual design, additional documents are often referenced to help structure or filter ideas. These documents are often more formal than the rough concepts (e.g., product specifications, results from usability testing, etc.). Introducing these external sources may also open the designer to previously unconsidered options or constraints, and inspire further creative idea generation.

Either as an individual or as a team, design directions and concepts must be evaluated and decided upon. Individuals decide what concepts to share or to combine, while teams

discuss possibilities, building off each other's ideas, and draw in new ideas during the reflective discussion.

Share: Conceptual Design. Once designers have reflected on what is pertinent, interesting or valuable, they may share the results of those reflections in the form of synthesized user research findings, concepts, mock-ups, or prototypes. As these artifacts are shared, they are refined to include increasing amounts of detail. To accommodate this detail while maintaining their comprehensibility to an outside audience, these shared documents require increased structure and formality, eventually becoming the formalized documents as identified by Yang et al. [7].

Due to their ability to iterate on high-fidelity, polished concepts, digital tools such as CAD, publishing software, and presentation software are often used to create and share many types of refined representations. The amount of embedded detail increases significantly when the designer or designers are anticipating sharing with a future audience, or archiving information for future reference.

Share: User Research. To create sharable, formalized representations, designers will curate the raw user research data or conceptual designs into a representation that supports a particular point of view. For example, one of the practicing designer researchers we talked with created a set of video "trailers" or short "edu-mercials" to inform different members of his consultancy's client company about user insights and design imperatives arrived at through the user research. From hours of interview and observation footage, they carefully selected and edited together clips that supported their conclusions in an engaging and memorable way, both to facilitate buy-in and stimulate curiosity about what else was learned.

Not all sharing is done solely for the sake of information transfer – some of the user researchers we interviewed chose to engage designers in activities or workshops where conceptual design stems directly from the communicated synthesized research results. They saw these workshops as increasing the likelihood that the information was immediately useful in the next stage of design, concept generation. We heard this both from design researchers at consultancies:

> *"Presentations are when we're telling you what we learned, it's our download to them. The mode of the workshop or ideation session is very different -- we're now facilitating, we've a specific process we want them to go through, we're taking these opportunity areas that are trailheads."*

We also encountered in-house design researchers finding value in hands-on workshops with their designer coworkers:

> *"Anyone who's really interested will come to the meeting later to review and talk about the next activity, which might be to create a persona to personify the voice if we're looking for a human voice in the software."*

As designers take this formalized information from the user research phase, they return to an individual, informal capture mindset as they create new ideas, and the sharing cycle continues.

One insight from the interviews, surveys and document analyses was the changing interplay between levels of formality and sharing semantics in the early stages of the design process. As information is captured, reflected upon, and shared, its formality gradually increases as structure is imposed through synthesis and decision-making.

CONCLUSIONS & FUTURE RESEARCH

With the intent of creating innovative new tools for capturing, reflecting, and sharing user needs, the goal of this descriptive study is to understand current usage trends in early-stage design tools. Based on our study we propose the following design principles as well as areas for future research.

Design Principles For Future Tools

After examining the range of tools offered to today's designers and how they are used to support design practices, we ask: *What features should future information tools have to best support the intersection of personal and collaborative design practices in the early stages of the design process?*

Allow for translations between tangible and digital media. Just as design journals are increasingly taking a hybrid form between tangible and digital media [5], design teams use an ecosystem of design tools to support their individual and collaborative information needs [10]. Designers use rich ecosystems of tools to ease the process of capturing, reflecting upon, and sharing diverse media with their team. Future tools need to be able to translate between tangible and digital forms to accommodate for different medium preferences at various stages of the design process.

Allow smooth transitions between private, personal and public design information. The same principles from general-purpose applications such as UbiTable [6] and SharedNotes [8] can and should apply to tools for design teams: separating privacy and visibility, providing a gradient of sharing semantics, enabling control of what is made personal and public, and leveraging the existing roles and affordances of mobile devices and shared displays. However, it is important to acknowledge how these transitions need to be tailored based on the particular nature of early-stage user needs research and conceptual design work. What needs to be made public or kept personal may vary depending on the stage in the design process, and how this is negotiated given the massive amounts of user research or conceptual designs captured throughout the design process.

Allow for varying degrees of formality. Throughout the design process, everything from informal to archival documentation is produced; it is important that future tools are able to accommodate for these shifts in formality. It is also important that these tools allow for various formalities to exist side-by-side. For example, a tool should allow designers to simultaneously reference formal information (e.g., synthesized

user research results) while creating informal information (e.g., initial concept sketches).

Future Research

Given this understanding of the range of tools and the context of their individual and collaborative use in user research and conceptual design, our next goal is to apply the proposed design principles to a set of future conceptual design tools for development and testing. Criteria for evaluation will include:

- *Effectiveness in sharing information from individuals to collaborative teams and establishing shared understanding*
- *Effectiveness in transitioning from the collaborative team's sharing of user needs research to individuals' generation of conceptual designs.*

For the latter criteria, we are particularly interested in the case of separate teams for design research and engineering design.

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APPENDIX A
RANGE OF TOOLS USED BY STUDY PARTICIPANTS

	Subcategory	Tool Name	Design Phase	Affordances	Practicing	Student
Tangible Tools	*Small Scale*	Post-It Notes	All	User Needs Analysis, Conceptual Design Capture & Analysis	8	6
		Paper "Scraps"	All	Communication	0	4
		Index Cards	User Needs	Analysis	7	2
	Medium Scale	Paper Notebook	All	Design Journal	10	1
		Bound Notebook (*e.g., Moleskine*)	All	Design Journal	0	4
		Spiral Notebook	All	Design Journal	0	3
	Loose-leaf Paper	Loose-leaf Paper	All	Conceptual Design	6	4
		Folder with Loose-leaf Paper	All	Design Journal	1	2
		Binder with Papers	All	Design Journal	0	1
	Large Scale	Whiteboard	All	Collaborative Work	9	3
		Large-format Paper *(e.g., Butcher Paper)*	User Needs	Collaborative Analysis	3	0
	Other	Magazines & Design Books	All	References	5	0
		Physical Prototype	All	Prototyping	5	0
Digital Hardware	*Mobile*	Smartphone *(e.g., iPhone, Android)*	User Needs	Data Capture	11	2
		Digital Pens & Notebook *(e.g., Livescribe)*	User Needs	Data Capture	2	0
	Portable	Tablet *(e.g., iPad)*	Conceptual Design	Capture	0	1
		Laptop (non-Tablet)	All	User Needs Analysis, Prototyping	3	4
	Digital Capture Devices	Photo Camera	User Needs	Data Capture	7	1
		Video Camera/Recorder	User Needs	Data Capture	13	0
		Audio Recorder	User Needs	Data Capture	4	0
		Tablet Input *(e.g., Wacom Tablet)*	Conceptual Design	Conceptual Design, Prototyping	1	0
Software	*Prototyping*	Solid Modeling CAD *(e.g., Inventor, SolidWorks)*	Conceptual Design	Prototyping	3	2
		Surface Modeling CAD *(e.g., Rhino, SketchUp)*	Conceptual Design	Prototyping	0	3
		Wireframing Software *(e.g., Omnigraffle)*	Conceptual Design	Prototyping	3	0
		Image Editor *(e.g., Photoshop)*	Conceptual Design	Prototyping	3	3
		Desktop Publishing Software *(e.g., InDesign)*	All	Data Sharing	4	1
	Notetaking	Notetaking Software *(e.g., One Note)*	User Needs	Data Capture	1	1
		Augmented Notetaking Software *(e.g., Pear Note)*	User Needs	Data Capture	1	0
		Digital Post-It Notes	Conceptual Design	Capture	0	1
	User Needs Capture & Editing	Video Editing Software *(e.g., QuickTime, iMovie)*	User Needs	Analysis	3	0
		Custom-built Software	User Needs	Analysis	3	0
		Audio Recording Software	User Needs	Data Capture	5	0
		Usability Testing Software *(e.g., Morae)*	User Needs	Data Capture	2	0
		Screen Capture Software	User Needs	Data Capture	2	0
	Other	Word Processing *(e.g., Word)*	User Needs	Data Capture	11	3
		Spreadsheet Software *(e.g., Excel)*	User Needs	Analysis	13	0
		Presentation Software *(e.g., Powerpoint, Keynote)*	All	Data Sharing	14	2
Web Services	*Online User Needs Tools*	Online Surveys	User Needs	Data Capture	2	0
		Online Card Sorting Tool	User Needs	Data Capture	3	0
		Online Design Games	User Needs	Data Capture	1	0
		Twitter	All	Communication	2	0
		Mailing Lists/User Forums	User Needs	Communication	2	0
		Mechanical Turk	User Needs	Data Capture	1	0
	Online File Management	Online Whiteboard *(e.g., Dabbleboard)*	Conceptual Design	Collaborative Capture	1	0
		Online Applications *(e.g., Google Docs)*	User Needs	Data Capture, Analysis	6	3
		Online File Sharing & Project Management *(e.g., Dropbox, Basecamp)*	All	Collaborative Development	0	3
	Communication	Email *(e.g., Gmail)*	All	Communication	10	3
		Instant Messaging	All	Communication	1	0
		Web Conferencing *(e.g., Skype, GoTo Meeting)*	All	Communication; Collaborative Work	6	1
	Notetaking	Blogging *(e.g., Tumblr)*	All	Design Journal	1	1
		Online Notetaking *(e.g., Evernote)*	All	Design Journal	0	2
		Wiki	All	Design Journal	0	2