Communication Functions and the Adaptation of Design Representations in Interdisciplinary Teams

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Abstract
Design representations in user-centered design serve intentions for directing design process and communication functions for enlisting interdisciplinary participation. To disentangle these two factors, a vocabulary for identifying communication functions in design is proposed. This vocabulary, drawn from a selective review of empirical studies of design activity in architecture and engineering, is then applied to three design cases from user-centered design. This analysis shows how representational use is subject to adaptive pressure from the communication demands in interdisciplinary teams. The consequences of this pressure for understanding the nature of design are discussed.

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Keywords: Interdisciplinary design; design representations; design process; design informatics; design information systems; communication.

1. INTRODUCTION

Design is often productively conceptualized as a near individual effort. Schön, for example, characterizes the individual designer as communicating with her materials, sketching provisional solutions and reacting to their 'back talk' [33]. In conversation with her materials, the designer directs the unfolding of the problem through a series of action-reflection cycles. While participants can be enlisted to react to the sketch and prompt the designer to see her work in a new light, here design is a largely individual activity of action and reflection.

Design methods in user-centered design can similarly emphasize the individual designer—or analyst—who rigorously follows technique to fashion personas, task analyses, and other design representations. Once completed, a representation can be seen as a sub-problem solved, at least provisionally, which can then be passed to other members of the team. Under this view, the design methods and accompanying representations are seen as analytic tools for augmenting human intellect [15] and intentionally direct how the process unfolds.

Alternatively, design can be conceptualized as a highly collaborative, social activity where solutions are negotiated [5, 6]. In an ethnographic study of engineering designers, specialists in various sub-disciplines were seen to continually seek understanding for each others' perspectives. Rather than a fully rational process, engineering design has been characterized as a highly social enterprise:

…I do not find it a matter of 'performance specifications', 'concept formation', 'engineering analysis', 'solution specification' and 'production' set apart in well defined boxes. Rather I see continual negotiation, hear banter and stories, sense uncertainty and ambiguity, listen to participants as they voice their hopes, fears and sometimes condemnations. Design is, in process, a social process… [6, p. 185]

User-centered design (UCD) can similarly be conceptualized as a highly social process. In commercial website (re)design, for example, it is common for specialists in such disciplines as visual design, marketing, software engineering, usability engineering, and information architecture to work together in complex arrangements over time and through technology. Communicating across boundaries, these specialists will teach or learn, elicit comments or persuade, and expand or contest shared understandings. Design representations can support this communication process to various degrees. Thus, a representation can be judged by its analytic power to structure a problem within a discipline and by its communicative power to facilitate discourse across disciplines. To improve our understanding for interdisciplinary design it is important to disentangle these two functions.

This paper examines how design representations from UCD can mediate communication across boundaries. Based on a selective review of field studies of design in engineering and architecture, the next section proposes a vocabulary for characterizing the communication functions of design representations. Then, three case studies from UCD are presented which illustrate the explanatory value of this vocabulary for characterizing the use, adaptation, and invention of design representations. Finally, the paper concludes with a discussion of how this vocabulary can be used diagnostically to

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better account for design practices and generatively to structure design process and to teach design competency.

2. COMMUNICATION FUNCTIONS IN DESIGN PROCESS

Star drew attention to the fact that information artifacts can serve the information needs of different stakeholders, coining the term *boundary object*. Boundary objects are: "…objects which are both plastic enough to adapt to local needs of several parties employing them, yet robust enough to maintain a common identity across sites" [40, p. 46]. Star distinguishes four classes of boundary objects: *Repositories* (e.g., a file system for organizing documents), *ideal types* (e.g., a scenario of use), *maps* (e.g., a website blueprint), and *forms and labels* (e.g., a template for submitting bug reports).

Star and Griesemer put this analytic concept to work in a historical analysis of the development of the Museum of Vertebrate Zoology, University of Berkley, CA circa 1910 [41]. At that time, a central aim of the museum was to collect specimens of flora and fauna of California, and a diverse group of stakeholders was involved in this enterprise, including a wealthy patron, scientists, amateur collectors, trappers, and university administrators. The account describes how these stakeholders cooperated, despite radically different interests, through the use of boundary objects, particularly terrain maps of California and standard forms for documenting the collection of specimens from the field. This construct has since been used to evaluate information systems and to envision new systems [2, 4, 7, 21, 24].

Using boundary objects analytically, Henderson described the failure of an integrated computer-aided design (CAD) system in a design engineering setting [19, 20]. The system overly formalized the design process by, for example, introducing dependencies between departments while not making them visible. Thus, "Employees were afraid if they adjusted information in their part of the system and made a small error such as the misplacement of a decimal point—a common error—that monumental consequences could result, such as the ordering of excess inventory" [19, p. 464]. To accommodate to the system, employees were observed to follow a variety of informal practices. Sketching was particularly important for enabling both problem solving and efficient communication. One common activity was working out solutions with paper and pencil and then transcribing solutions back into the CAD system. Henderson introduced the term 'conscription device' to typify the power of sketches to enlist participation and to elicit comments. Indeed, she reported that in engineering, design sketches are so important that it can be hard to communicate without them.

Ten years later, Schmidt and Wagner described similar practices in an architecture office where a centralized CAD system was used to record decisions [35]. Similar to Henderson's observations, architects decoupled from the CAD system, allowing them to work with materials that were more appropriate for exploring problem solutions, including tracing paper, colored pens, and rough 3D models. Once provisional solutions were obtained, the architect might post them outside her office to elicit comments and to inform office staff of progress. Once satisfied, the architect updated the CAD drawings so that other specialists could use her work. This pattern and similar practices are called 'coordinative' because as architects work they create signals about their work priorities and progress that others in the office can react to [35, 42]. These signals are often a happy side-effect of the materials and instruments used to make progress.

In addition, Wagner reported on a variety of informal classes of representation that enabled problem conceptualization, creativity, and coordination [42]. These representations contained various elements, including bullet lists, sketching, photocopied 3D images, metaphors, and so on. These text-graphic compositions were then used by architects to support activities such as prompting conversation and recovering problem solving context. To abstract this function of a design representation, Wagner uses the term 'persuasive artifacts'—a concept similar in spirit to 'conscription device'.

Perry and Sanderson described similar 'coordinative' practices in two engineering design case studies [28]. They characterized the design process in terms of the transformation of representations and the communication that revolves around the representations. They reported, for example, that hand signatures and stamps on paper artifacts and the public display of representations signal progress.

Another discourse function played by documents is 'problem framing' [32, 34] where a document serves as an expression of the values or perspective from which judgments should be made. A clear example comes out of Henry Dreyfuss's office from 1950s industrial design [13, 16]. As a first step in the process, designers would assemble and pin up visual materials of competitive products. These competition boards seemed to enable intuitive cost-benefit analyses and feature comparisons, but they also seemed to bound the design space and gave the team source material for creating a vocabulary in a fashion perhaps similar to design patterns [1, 14].

All of this work touches on the importance of communication. Certainly communication is often problematic in interdisciplinary teams [e.g., 11] and therefore the coordinated searching and sharing of information is an important team phenomenon to examine [29]. In field studies of design projects, Sonnenwald identified 13 communication roles for people who spanned boundaries at the organization, task, and discipline levels to manage and prevent communication breakdowns. People in these 'spanning roles' were found to facilitate the exchange of information across boundaries, help negotiate responsibilities, and resolve conflicts [37]. Sonnenwald introduced the term 'contested collaboration' to refer to cases where designers and other participants in a project "contest, or challenge, each others' contributions" [38, p. 873]. She points out that when specialists seek to work across disciplinary boundaries the likelihood for contention increases because of the difficulty of exchanging discipline-specific knowledge. Rittel has called this the *symmetry of ignorance*, where no one in an interdisciplinary group can guarantee that his or her knowledge is superior to all others [30, p. 320]. When contention occurs, a boundary object that functions in teaching and learning might be deliberately created to resolve the conflict.

These studies suggest that representations are at least dual purpose. First, representations enable analytic and creative problem solving and the specification of solutions that can be judged against requirements. Second, representations enable particular kinds of communication among project stakeholders. From this selective review, I identify five communication functions of representations (see Table 1).

Turning to user-centered design, what design methods are intended to enable such communication functions? An outstanding example, of course, is scenario-based design [8, 31], a deliberate attempt to create boundary objects that represent use. The five specific claims backing the analytic and communicative value of scenarios proposed by Carroll [8] might equally apply to other representations; for example, participatory design techniques aimed at representing and discussing conceptual models of existing or envisioned systems [3]. Finally, the method of cognitive walkthroughs also deliberately creates representations that are to be discussed from multiple points of view [23, 39]. In the next section, I report on three design cases, seeking to show how design representations can be crafted to support these kinds of communication functions to various degrees.

3. DESIGN CASE STUDIES

These case studies come from my own professional practice where I acted at various times as a usability engineer, consultant, and manager. For purposes of confidentiality, certain idealizations have been made and outcomes are not discussed in detail. While participating in these projects, I also found myself viewing the process from a research perspective. At times, I wanted to stop working, become an observer, and rigorously document the action. This, of course, was impossible so I kept informal notes, took digital photographs, and archived selective materials. Thus, these cases are best characterized as the critical reflections of a practitioner.

3.1 Case #1: Left-Side Navigation Design

3.1.1 Project Overview

The aim of this project was to develop a web navigation system. Three constraints were especially important. First, the system had to provide consumers access to a wide range of content areas including popular culture, health, news, shopping, and so on. The structure of these content areas varied significantly from shallow hierarchies to broad and deep hierarchies and to patchy non-uniform hierarchies in between.

Second, the navigation system had to fit within a broader effort to develop a common visual style that would apply globally across numerous content areas. This style was aesthetically motivated and intended to express an online brand in a visually bold fashion.

Table 1. Communication functions of design representations.

Function	Description
Conscripting	Enlist participation and elicit reactions and comments
Coordinating	Express progress and the provisionality of solution states
Framing	Establish or reaffirm a common ground, typology, or constraint field
Persuading	Convince a stakeholder, often a prospective client, that a solution fulfills project requirements
Recording	Record the solution state to be used by others in the future

Third, the navigation system and style guide would be completed by a central group and rolled out to approximately 50 local business units for implementation. The units, ranging in size from 3 to 20 people, were experts in their content areas and were rewarded individually through advertising and e-commerce deals. Like federalism, the central design group stood for elements of unity whereas the local business units stood for elements of independence and innovation in their competitive marketplaces.

3.1.2 Project Participants

This project involved a constellation of participants including product managers, visual designers, specialists in usability and information architecture (IA), and software engineers. The participants, some who worked together locally and others remotely, came together and dispersed in complex arrangements. Project managers held these participants to a timetable and facilitated coordination.

In this account, I simplify these work structures and refer to three stakeholders: The visual designer, *Jude*, the usability specialist, *Tess*, and the IA specialist, *Eric*.

3.1.3 Process

The project began with and was driven by visual design. At the beginning, many decisions about visual style had already been made. These decisions included such elements as: the typography for headings, links, and content units; iconography for wayfinding and signaling services; the page grid for laying out material; and functional zones for placing links and content of various forms. Following the pattern of many sites of this era, the navigation system would be presented as an inverted ell, Γ, with global navigation and breadcrumbs along the top and local navigation on the left-hand side. This much was decided. (See Figure 1 for problem brief and Figure 2 for one possible solution).

Jude's challenge was to draw upon this visual language and create a system for the left-navigation. Jude developed a series of renderings that explored the design space. To illustrate the dynamics of the system, Jude would show the various states of the navigation in sequence. These snapshots illus-

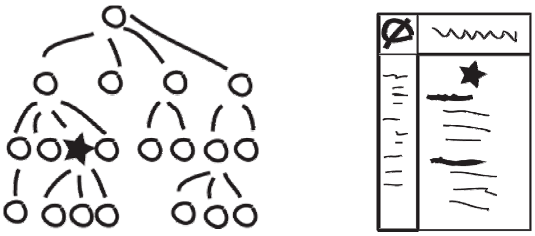

Figure 1. Left-side navigation design problem. *Assume*: a) A wide range of classifications and hierarchical forms (left figure); and b) A location in a hierarchy, denoted by the star (right figure). *Problem*: When located at the star, what information should be shown in the left-navigation? *Comment*: A major question is deciding what state information and what selections—ancestors, siblings, children—should be shown in the left-navigation and what information, should be shown in

trated how a topic's children, siblings, and parent would, or would not, appear as a user drilled into a hierarchical structure. These snapshots singularly focused on the visual language—button appearance and placement, iconography, color changes, and so on—for representing these distinctions. After several weeks of review and theorizing, Jude settled on two alternatives for the left-navigation.

Jude then asked the usability specialist, Tess, to review the two navigation systems. Tess, concerned that the systems had not been examined in light of the units' actual hierarchies and content, declined to give an opinion. Instead, she asked that a small but complete system be mocked up so that it could be studied with users. Jude and his management agreed.

Meanwhile, a specialist in IA, Eric, mocked up the navigation system in HTML. This mockup was a faithful rendition of how Jude's system operated but without Jude's visual language. Rather, it used underlined blue links for buttons, substituted visual icons with text symbols, and omitted color changes. While the mockup represented a hierarchy of only a few nodes, it did employ genuine content and labels. Exploring the mockup raised questions about signaling location, showing links to children and siblings, and integrating the left-navigation and page-content.

Working with Jude, a developer implemented a test-bed for studying the usability of the navigation systems. The topic of the test-bed was a holiday season, and a variety of content was integrated around this theme, including gifts, recipes, and stories. While the site, at about 30 nodes, was small, the pages conformed to the style guide, and the navigation systems appeared and operated exactly as Jude intended.

Tess developed a test plan where participants were instructed to locate, as quickly as possible, six well-defined targets by browsing—search was not allowed. The tasks were of this sort: *Find a recipe for moose milk*. Five participants were studied in each of the two candidate systems. As they completed the tasks, video of the screen and audio of the partici-

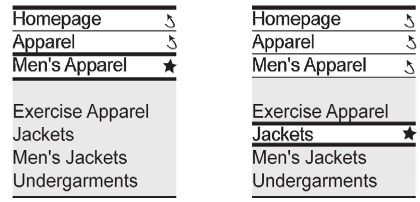

Figure 2. A solution to left-side navigation problem at www.bluelight.com (December, 2003). In the left frame we are located at *Men's Apparel* and we see four children but no siblings. Our location is signaled by the star and other visual features. The right frame shows what happens when we click on *Jackets*. Here we see siblings. Notice that the history of nodes visited is preserved.

pant's think-aloud verbalizations were streamed to a digital editing studio. Eye-tracking was employed for some of the evaluations.

Once the data were collected, Tess went to the video tapes and excerpted a set of clips that illustrated how people used the navigation. The goal of this clip catalog was to prompt discussion and reflection of *actual* use rather than *theorized* use. As Tess expected, a clear winner did not emerge from this evaluation—the two systems differed in subtle ways.

With observations from ten people and lively team discussions, Tess began formulating, and collating, claims about the systems. Some claims were narrowly focused on features of the two systems. It soon became apparent, however, that these issues paled in comparison to a major, common issue: Under certain circumstances, users did not see the left-navigation!

Tess and Eric developed a scanning model (see Figure 3). This model predicted that after a click on the navigation, if useful information was found in the page body, users would look-and-click in the page body and be less likely to notice changes in the navigation. A corollary is that if users do not see useful information in the body of the page they will be more likely to abandon the page without inspecting the left-navigation because it had already been scanned. To mitigate this risk, Tess recommended that, depending on the hierarchy, consideration be given to duplicating the local navigation links in the body of the page.

These findings, of course, were not definitive. The study showed that for a small test-bed with a simple structure and particular semantic relations, some people on some tasks did not see the left navigation. Calibrating these findings against the solution domain—large, messy hierarchies—Tess believed that there was significant risk associated with the navigation system. Alas, with the deadline for the style guide looming, it was not possible to develop a persuasive case.

One navigation system was selected, some elements of its design tweaked, and after a carefully constructed presentation to senior management, the style guide was released. Decentralized business units, with assistance from the central design team, implemented solutions. About a month after deploying the new navigation, a software engineer at one

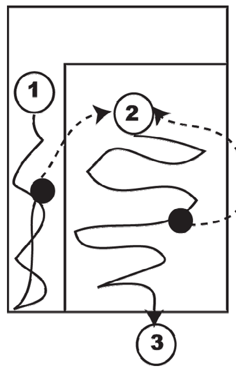

Figure 3. Scanning Model. (1) A user will scan the left-navigation for a link and click at the ●. After waiting for the page to load, users will begin scanning at (2). If useful information is found, they click at ●, wait for the new page to load, and continue scanning (2). If useful information is not found, some users will scan the left-navigation (1); other users will abandon the page (3).

unit changed their system by surfacing a number of child links. Thus, the list of links in the left-navigation became longer. After the change, traffic to the child nodes increased by an order of magnitude while traffic to the other nodes remained constant. Either these surfaced links generated new user wants, which was unlikely, or users were more likely to see them. The central design team fought this move, first contesting the presentation of the data—Tess and Jude created their own charts of the data—and then contesting the data collection process. Defending their mandate for standardization, the unit's solution was rolled back. Nevertheless, the data were consistent with the scanning model: After selecting a link, a significant percentage of users would not see the child links.

3.1.4 Discussion

For this unremarkable design problem, no doubt solved by thousands of teams, I would like to focus on the exchange of representations (see Table 2). To begin, Jude's goal was to extend the visual style guide, and he solved this problem, at least provisionally, by creating visual renderings of the navigation systems. The major constraint was that the solution be compatible with the style guide. When he sought feedback, both Eric and Tess contested the representation and responded with representations that were appropriate to their work but were not immediately helpful to Jude's goal. Here, contention can be seen as a resource for making progress.

And so the process unfolds, with each new representation propelling the team forward. The remarkable feature of this collaboration is that the team did not create a synthetic, shared view. Rather, the team created a variety of special-purpose representations that were then used to communicate specific information to other disciplines.

This use of representations significantly departs from the idealized notion of a boundary object which putatively enables diverse stakeholders to exchange discipline-specific information across boundaries. A better model is contested collaboration [38]. In this project, the only abstraction approximating a boundary object was the schedule, which was managed by the project manager.

Table 2. Design representations exchanged in left-side navigation case study ('→' means leads-to).

DR	Description
1. Style Guide	The Style Guide documents standards and guidelines for the visual presentation of the brand and content.
2. Renderings (1→2)	Informed by the Style Guide, Jude creates visual renderings of the navigation system, showing all expected states. Jude exchanges the renderings with Tess and Eric, requesting a usability evaluation and critical input.
3. HTML mockup (2→3)	Eric contests the renderings on the grounds that they cannot be used to reliably assess navigation flow and completeness of navigation states and selections. In response, he creates an HTML mockup that emphasis the navigation operations and state information but ignores visual style.
4. Working prototype (2,3→4)	Tess contests the suitability of the renderings for usability testing, requesting a working prototype.
5. Video clip catalog (4→5)	Tess summarizes a usability evaluation with selected video clips, annotating clips with observations, claims, and risks.
6. Scanning model (4,5→6)	Tess and Jude propose a scanning model and content development guidelines for minimizing the risks that people will not see the left-side navigation.
7. Navigation Style Guide (4,5,6→7)	Jude and Eric document the standards for the navigation system as a visual style and include guidelines for applying the style.
8. Presentation to Sr. Management (5,7→8)	A carefully crafted PowerPoint presentation is prepared and delivered to senior management. The presentation focuses on the visual style, the generally positive findings from the usability evaluation, and the estimated effort in rolling out the navigation system across the organization.

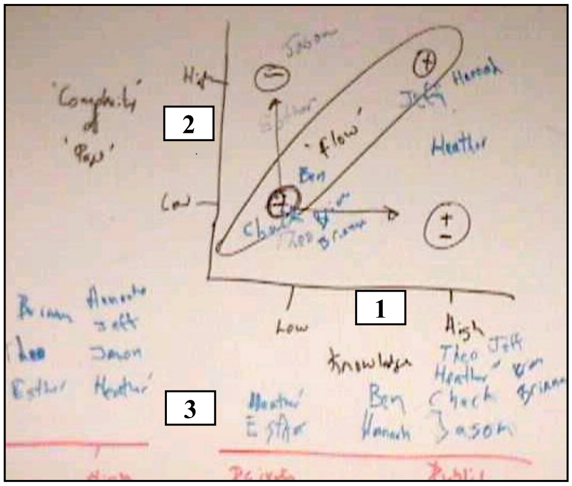

Figure 4. Whiteboard sketch for plotting personas. The horizontal axis (1) represents knowledge for website development (low–high), and the vertical axis (2) represents complexity of site (low–high). This framework draws on the notion of 'flow', which is achieved when skill level is in balance with challenge [10]. At (3), personas are plotted on two additional dimensions.

3.2 Case #2: Prioritizing Work with Personas

3.2.1 Project Overview and Participants

The team was responsible for a homepage hosting site, which offered end-users tools for creating, publishing, and revising websites. The team, consisting of visual designers, dedicated software developers, and project managers, entered a planning phase where they sought to propose and prioritize a list of development objectives. Experience with user-centered design—and, indeed, general research skills—was limited and time was short when the project manager, *Paula*, contacted a usability engineer, *Ted*, for advice.

3.2.2 Process

Ted suggested that Paula and her team employ personas [9], reasoning that by documenting its key users and user goals the team would be able to explicitly bring user needs into its deliberations. Paula was given a brief introduction to personas and it was suggested that she and her team develop three or four personas. When they next met, Paula reported that her team had developed twelve personas.

Ted felt that a set of twelve personas was unworkable. There was significant risk that the wealth of facts contained in the personas would not enable the team to focus on specific user needs. Moreover, many of the facts covered extraneous background information rather than facts that bore directly on homepage building. Yet, Paula and her team were satisfied that they had been able to reduce their collective knowledge of hundreds of users obtained by reading personal home pages, answering helpdesk questions, and categorizing audience feedback. Ted and Paula faced an impasse.

Ted decided that it was important to reduce the number of personas. Working at the whiteboard, Ted proposed that they attempt to locate them on one or more dimensions. He began by drawing the characteristic graph of flow [10], a psychological construct that is achieved when a person's skill level for an activity is in balance with the challenge of the activity. Boredom is experienced when the challenge is low but the skill level is high and anxiety when the challenge is high but skill level is low. Drawing on this idea, Ted proposed that website-complexity be mapped to challenge and knowledge-for-tools be mapped to skill-level (see Figure 4).

It quickly became evident that five of the twelve personas clustered in the bottom-left: Low-site-complexity and low-website-development-skills. Other personas overlapped at other points as well. On further analysis of the clustered personas, it was discovered that they differed in two other important dimensions: Type-of-site (Family Album, Journal, Splash page, Pop Culture, Small Business, School/Education) and Audience (Self, Family, Friends, Organization, Neighborhood). These dimensions enabled the personas to be usefully separated. By seeking a way to frame the personas, a general space for understanding users was produced. The personas and the four dimensions were used by Paula and her team with reported short-term success.

3.2.3 Discussion

Using the vocabulary proposed earlier, we can see that the personas operated effectively as 'conscription devices'. The method enabled the team to create concrete descriptions of its users. And, indeed, the team was able to generate a significant number of descriptions. However, personas alone are an ineffective 'framing device'. Thus, we can see Ted's move to construct a space for organizing the personas. Once the personas are plotted, the resulting plot becomes a 'conscription device' at a higher level of abstraction. From this new representation, one can identify overlapping personas, relationships between personas, and holes in the space.

3.3 Case #3: Task Flows

3.3.1 Project Overview and Participants

A centralized team of user experience specialists sought to create a technique which would enable product teams to conduct user-centered product audits. Approximately twenty product teams, ranging in size from 3 to 20 people, participated in the process. At a minimum the teams consisted of a project manager and one or more, sometimes part-time, visual designers and software engineers. Skills in basic research and in user-centered design were minimal.

Over the previous 18 months, many of these teams had participated in usability evaluations of their products. These evaluations always identified usability issues and sensitized teams to how users interacted with their products. Indeed, teams greatly valued the usability process. Nevertheless, it seemed that many of the problems identified could be uncovered less expensively by an inspection method [27]. The aim of the project, therefore, was to develop an inspection method that would allow teams to compare their site to their competitors' sites in a task-centric fashion.

3.3.2 Process

A template was created that allowed a team to document a user goal and analyze the number of steps required to complete the goal at two or more sites (see Figure 5). At each step, a screenshot was taken and pasted into the template. (A macro was created to facilitate the screen capture and resizing process.) In addition, teams could annotate the screenshots with relevant comments. This technique is easy to explain, relatively fast to perform, and can result in a great deal of concrete information. Branching and error conditions can be handled informally by noting necessary information in the comments area and by linking templates together with a labeling system. By looking at the lengths of the columns a general estimate of the relative efficiency of the two sites is immediately obtained.

3.3.3 Discussion

In this case, the user experience team deliberately sought to create a 'conscription device', a template that would enable teams to readily capture information about task flows. An alternative would have been to introduce task analysis methods or cognitive walkthroughs. For these teams, which had no formal training in user-centered design, it was felt that task analysis would be overly abstract. Nevertheless, teams needed a method for making goals and tasks visible so that they could systematically study differences and identify areas for improvement. This method enabled them to capture the user experience in an extremely concrete fashion.

By inspecting the task flows, information could be abstracted into other forms useful for design:

1. Summary tables showing the number of steps needed to complete tasks;
2. Specific techniques to reduce the number of steps required;
3. Identification of common sequences of steps across goals.

In addition to these relatively straightforward transformations, the task flows can serve as boundary objects, allowing the product team and user experience group to better communicate. The task flows can make task completion issues highly visible, allowing the two groups, for example, to discuss the merits and goals of a usability evaluation.

4. DISCUSSION

These design cases show a close coupling between design representations and communication. While the analytic or empirical appropriateness of a representation is important, so too are the communication demands placed on it by the design team. Inspecting these cases, we can see how particular communication needs become manifest in representational use. Here are five general patterns:

1. *A recording is transformed into a working representation*. Example: A visual designer exchanges renderings of a navigation system with an information architect, requesting feedback. The information architect transformed the renderings into a HTML mockup.
2. *A recording is created or updated from working representations*. Example: A visual designer and information architect update a style guide based on annotated excerpts of use and behavioral model of scanning.
3. *A persuasive representation is created from selective excerpts*. Example: A presentation that explains the style guideline is prepared for senior management.
4. *A conscription device elicits concepts*. Example: A team generates twelve personas for their website.
5. *A framing device is used to establish a common ground*. Example: To teach a team about personas, a consultant organizes twelve personas within a developmental framework.

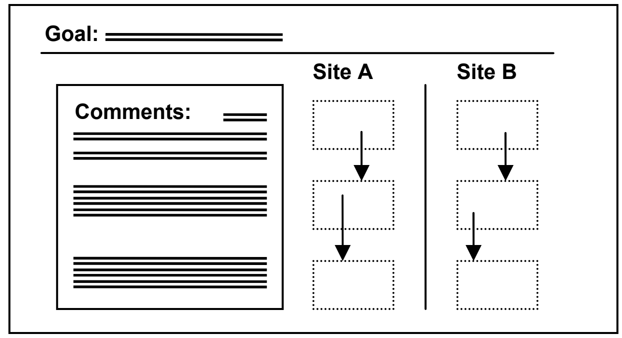

Figure 5. Task-flow template. In this structured template, a goal is identified and the completion of the goal is mapped in a series of screen shots. By mapping different sites, the 'task-flow' is made visible.

Generalizing, the communication demands of the setting apply adaptive pressure on the use of design representations. When specialists contest the expressive value of a representation they may respond by creating a working representation of their own. When teaching or explaining a representation, a specialist may seek a new framing of it. When seeking to enlist participation, a conscription device can be deliberately created to match the talents of the participants. These are productive accommodations that can prevent or repair miscommunication that can otherwise occur if representations are bluntly exchanged across disciplinary boundaries.

Of course, many examples can be found where people are unable to shape a representation to accommodate a communication need. An interesting case is attempting to contribute design ideas (e.g., a proposal for a new dynamic user-interface feature, explained with annotated screen shots) to a bug tracker. While the bug tracker's labeling system may be effective for categorizing, prioritizing, assigning, and tracking software defects, it may be inappropriate for representing interaction design issues and solutions. An interaction problem, for example, may touch upon several code modules but there may be no method to adequately express these dependencies. Moreover, within the open source community, bug trackers typically require the expression of a solution in terms of a particular coded 'fix'. Thus, no mechanism exists for providing a general design solution. Yet, the bug tracker may be the principal mechanism for communicating with developers and building grass roots support for change. For reasons such as this, contributing interaction design in the open source community can be problematic [17] but also essential if significant improvements are to be achieved [18].

In sum, the lesson is that it is often necessary to trade-off the expressive or analytic power of a representation in order to more effectively communicate across boundaries. By better understanding this trade-off, we can advance our understanding for the nature of design, the capacity of interdisciplinary teams, and the role of technology in design. The following sections discuss these topics.

4.1 Communication Functions and the Nature of Design

Design communication appears to have a unique quality that separates it from other forms of communication, such as an inductive scientific argument or workflow commitments in a business setting. Indeed, Nelson and Stolterman present a model called the *allopoietic*[1] *design communication process* [25]. The model proposes that design communication proceeds through the following phases: 1) Conversation for developing trust; 2) Dialogue for developing common understandings; 3) Diathenic graphologue ('to let a thing be seen through its image') for developing new insights.

The communication functions identified in this research—conscripting, coordinating, framing, persuading, and recording—provide a possible vocabulary for describing how common understandings and envisionments are communicated in phases 2 and 3 (see Table 1). This vocabulary captures useful if somewhat fuzzy distinctions.

These communication functions can be identified in user-centered design. For example, in the first case study the renderings of the navigation system, and ultimately the style guide, played a role approximating that of the architectural blueprint. Similar to the observations of Schmidt and Wagner [35], we see specialists re-representing elements of the recording so that specific lines of inquiry can be pursued and then updating the recording. Thus, a contribution of this research is to identify some commonalities between design communication in architecture and user-centered design.

One significant difference is that in Schmidt and Wagner's account [35], the architectural blueprint represents information in a common, neutral fashion such that many different specialists can work with it. In the case of a style guide, however, other forms of representation seem to be required. For example, a software engineer is unlikely to recognize the back-end constraints from the visual design alone. But, this need might be accommodated by including a conceptual model along with the visual renderings of the navigation system. Certainly in scenario-based design [31], the scenario might serve as the scaffolding for assembling other, special-purpose representations. Perhaps, user-centered design has simply not matured sufficiently to develop common representations of sufficient expressiveness.

Finally, it is evident from the above design cases, and other field work [26], that representations have an informal quality. Even more, for website design in general, representations do not seem to always fall into clearly established genres. (See, for example, the design cases collected by DiNucci [12].) One possible account of this is that informality drives out discipline-specific tacit knowledge thereby facilitating better communication across boundaries.

4.2 Capacity of Interdisciplinary Teams

In general, it is claimed that innovation is more likely to occur within interdisciplinary teams because diverse knowledge can be combined and recombined in new ways [7]. If this is so, then we can expect to find differences in documentation practices between mature and immature design cultures. One hypothesis is that experienced design teams adapt representations to accommodate interdisciplinary communication demands. To elaborate, consider this scenario:

A software engineer creates an entity-relationship (ER) diagram for the data storage requirements of an interactive system. While the specification may imply certain constraints on the implementation of an interactive dialog, an interaction designer may not identify the constraints because of his or her unfamiliarity with ER diagrams. Even when inspecting the ER diagram jointly, the constraints may go unrecognized because neither stakeholder fully understands both the inner and outer parts of the system.

Here, the representation is inadequate when used across disciplines during conceptual design and the constraints surface only later during implementation. Over time and as such breakdowns are recognized, what accommodations might take place? Here are three possible answers:

1. The interaction designer might invest in training and learn the tools and techniques of software engineering. This may improve knowledge transfer in this specific case but, in general, is impracticable because of its demands on practitioner time, interest, and aptitude.
2. The software engineer might re-represent the ER diagram, or heavily annotate it, such that it becomes more comprehensible to the interaction designer.
3. The software engineer and the interaction designer might work together to develop a hybrid representation that serves both their needs. With this approach, disciplines within the team, or perhaps the team as a whole, deliberately fashion methods and documentation formats that enable multiple, discipline-specific or interdisciplinary issues to be represented.

In sequence, these approaches suggest a developmental model that might lead to stable design representations that service the needs of multiple stakeholders. Other kinds of adaptations might be appropriate in other situations. A team might employ a meta-format such as a cost-benefit analysis or claims analysis where the important feature of the repre-

[1] 'Allopoietic' is defined as "The making of something outside of one's self, with and on behalf of the other."

sentation is that diverse concerns can be represented in a neutral format for rational decision-making.

This discussion of design capacity leads to questions of design competencies for individual designers. On the one hand, depth of knowledge for technique within a discipline is essential. On the other hand, in interdisciplinary design, a specialist needs to be able to surface his knowledge in productive ways that enlists others. How is this done well and how should this competency be taught? These are open questions. To make progress, we need to seek a deeper understanding for the underlying intentions of design representations and discover how these intentions can be effectively communicated. Through the use of simple vocabulary, this research is an incremental step toward disentangling these two factors. It is critically important to investigate professional practice because it is likely that the most innovative uses of design representations are being pioneered by practitioners in the swamp of interdisciplinary design.

4.3 Technological Implications

The overall picture that emerges from this research is that representations emerge in a relatively opportunistic fashion and are coupled to communication demands. Therefore, technology that imposes ordering constraints, enabling tasks, or other forms of formalization on the capture, organization, or use of representations is at risk of being ineffective. In other words, formality is often harmful [36]. This does not mean, however, that there is no role for technology in design. Embracing opportunism and informality, technology might be applied to these information handling goals:

1. Enable representations to be captured and then moved in and out of the digital and physical worlds;
2. Enable representations to be presented in unstructured piles and visual arrangements;
3. Enable representations to be annotated and linked to discussion spaces;
4. Enable representations to be incrementally structured through, for example, unary and binary predicates; thus allowing representations to be classified and structured.

In short, the technological goal is to approximate many of the contextual factors that we take for granted in the physical world when we arrange information. At present, we simply do not know how to achieve these goals, but they are central to the promises of ubiquitous computing [22].

5. CONCLUSION

This research has reported on some uses of representations in user-centered design, finding that the use of design representations is subject to adaptive pressure originating in the communication demands of an interdisciplinary team. By better understanding these communication demands, we can better understand the nature of interdisciplinary design and how documentation practices enable specialists to work across boundaries. A key direction for further research is to seek regularities in how representations are adapted across a range of design cultures. To better understand design competencies, we must seek general frameworks for understanding how both design intentionality and design communication are enabled through representations. As we move towards design problems that defy easy containment within disciplinary or technological borders, theories of representational use, such as Carroll's theory of scenarios [8], will become ever more important in research, education, and practice.

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