This is how I design: Discussing design principles in small multidisciplinary teams of design professionals

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When addressing complex design problems, multidisciplinary teams are faced with the challenge of successfully communicating their knowledge, skills, and abilities. This study explores an approach to identifying design principles from experienced designers as they engage in design discussion. Two teams of three designers were asked to generate ideas, identify design principles and engage in design discussion to address a hypothetical design challenge in a controlled setting. Four themes emerged from the analysis of the self-reported principles (Problem Understanding, Idea Generation, Idea Refinement, and Solution Implementation), and reflect existing best practices identified in prior design literature. These findings suggest that simulating a design discussion to discuss design knowledge in relation to specific ideas could be a promising approach solicit insights from experienced designers to understand more about design principles and their practical application.

Codifying and sharing design knowledge in multidisciplinary design teams

Multidisciplinary or cross-functional teams are formed in response to the rapid pace of innovation across industries and the increasing complexity of engineering problems [1]. The challenge of solving these complex design problems requires people to leverage their knowledge, skills, and abilities from different domains [2]. As such, effective knowledge sharing processes are increasingly important because each team member brings

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their own experience and domain expertise, and integrating this diverse knowledge base across domains is crucial for team success [3].

Research on expertise typically focuses more on the development and application of expertise than its integration across disciplines. Expertise has been argued as both a bane and a boon to problem solving in design [4,5]. On the one hand, experts are also affected by design fixation [6]. On the other hand, experts have acquired the essential procedural and domain knowledge required to more efficiently organize ill-structured information through their ability to diagnose the relevancy of information and subsequently apply that knowledge [7]. As information relevance is highly dependent upon the context, variations in information diagnosticity may differ greatly between domains.

Over time, expert designers build a wealth of knowledge and experience to draw upon when faced with design problems. One way designers navigate their mental knowledge library is by creating 'rules of thumb' that help them navigate and make sense of information. These design principles, also known as design heuristics, are "a fundamental rule or law, derived inductively from extensive experience and/or empirical evidence, which provides design process guidance to increase the chance of reaching a successful solution" [10, p.3]. Principles and heuristics capture the designers' ability to leverage their existing experience and knowledge to support their solution finding process. Designers also use design principles as a way to codify design knowledge and communicate innovative, archival practices to others in order to more creatively address design problems [9]. These domain specific references serve as a powerful tool for designers to concisely express complex concepts [10], but accurate interpretation is reliant upon the recipients' understanding of the domain [11]. For example, the principles applied to the development of social systems [12] are likely to differ from those used to design secure and usable computer systems [13] or intelligent robotic systems [14].

Further complicating the study of design principles is work that has shown that there is a gap between what people *think* drives their actions and what can be inferred from observing their *actual* actions. Argyris and Schön delineate between these two concepts using two separate, co-existing theories which they respectively call espoused theory and theory-in-use [15]. While people are generally aware of their espoused theory (or can articulate one), they are often unaware of their theories-in-use that are implied by their actions. This disconnect is relevant to team interactions, as designers are likely to articulate their espoused theories while the observing designers are more likely to pick up on the designer's theories-in-use that they display through their behavior.

There is also a temporal component to design principles. As a reflection of the designer's knowledge base, design principles are not static records but dynamically adapt as designers accumulate more knowledge and experiences [16]. Prior work has shown that designers' update these rules of thumb and add new heuristics while retiring obsolete heuristics that are no longer useful [17]. However, it is likely that there is more to this process than mere exposure to new information. People have been shown to respond slowly to corrections that are not in line with their views [18], and misinformation has been shown to affect behavior even when the information was acknowledged to be false [19].

These studies demonstrate the dynamic way that design principles evolve and are applied, and suggest that there is a complex relationship between individual knowledge and context of application during the design process. Due to the highly personal and often unstated nature of design principles in practice, understanding the principles used by designers can be challenging. One way to elicit implicit knowledge held by designers is through collaborative discussions between designers working towards a mutual goal. This forces the designer to reflect upon their design knowledge and, if appropriate, accommodate new insights. Therefore, team discussion about design can provide more insights into the concept of design principles and how they are applied in a team setting. This study aims to contribute to the design literature by identifying the design principles used in practice by exploring the following research questions:

RQ1: What principles do designers use during early phase ideation?

RQ2: What themes emerge across the principles used by the designers?

To address these questions, a qualitative laboratory study was conducted with practicing designers who formed small temporary design teams to address a hypothetical open-ended design problem.

Methodology

Participants

An in-depth qualitative study was conducted with a total of six practicing designers with between 3 to 17 years of experience (see Table 1 for relevant participant characteristics). All participants were identified through the authors' professional networks and through snowball sampling. Only designers who had obtained at least three years of software, graphic, or UI/UX design experience and currently engage in design activities as their primary function in their full-time jobs were recruited for this study.

Table 1 Relevant characteristics of the designers

Team number, Participant number	Design experience	Position title & Time in current position	Organization size and sector
Team 1, D1	3 yrs	CTO, <1 yr	~1-50, custom software dev. & design
Team 1, D2	15 yrs	Graphic design assistant professor, 14yrs	~1,000-5,000, educational institution
Team 1, D3	12 yrs	User experience designer, 8 yrs	~100-500, software dev. & design
Team 2, D4	8 yrs	User experience lead, 3 yrs	~ 51-200, mobile dev. & integration
Team 2, D5	6 yrs	Founder & CEO, 2 yrs	~1-50, custom software dev. & design
Team 2, D6	17 yrs	Graphic design instructor, 7yrs	~1,000-5,000, educational institution

This study employs the method of Intensity Sampling, whereby specific cases (experienced designers) are chosen that intensely manifest the phenomenon of interest (routinely sharing design knowledge in team interactions) [20]. Despite a small sample size of participants, the selection and analysis of information-rich cases for in-depth study has been shown to to uncover valuable insights on complex phenomena and human experience in cognitive science [21] and engineering [22].

Procedures

Two teams of three designers from different domains were formed prior to the start of the study. Each team attended one three-hour session in a private conference room in which they were asked to individually and collectively address a hypothetical, open-ended design challenge through idea and principle generation, reflection, and selection. These design activities allowed for examination of the ways that designers share knowledge, negotiate, and reach understanding. All interactions were video and audio recorded. For the purposes of this paper, only the individual idea generation, principle generation, and idea sharing portions of this study were considered for analysis, resulting in a total of 120 minutes of audio and video data across both study sessions.

After obtaining informed consent about the purpose and procedure of the study, the participants given five minutes to silently read the design prompt ("*Develop concepts for a new, innovative product or system that will reduce the environmental impact of single-use plastic in Omaha, Nebraska*") and a single sheet of background information. A socio-

technical challenge was selected for its ability to be broad enough such that each participant could contribute using their experience without specifically favoring one domain over another. While the issue of single-use plastic is familiar to residents of the city, none of the participants have addressed such a problem in their practice before. Next, the participants were asked to generate as many ideas as possible on provided paper worksheets for ten minutes. The participants then engaged in a brief discussion about design principles, and were informed that, for this study, design principles refer to "*abstract rules or strategies that can be used to guide your design process and decisions. Because they come from experience and understanding built over time, they tend to be more generalizable across contexts, but they can also be specific to certain contexts. For example, "it is important to have a direct conversation with the client before the project starts" could be a principle*". After a working understanding of design principles was reached, the participants were provided with 15 minutes to write the design principles they used to generate each idea next to the idea the principle pertained to. The participants were first asked to generate ideas prior to identifying the design principles they used in those ideas. This was done because pilot testing revealed that the pilot participants could more easily articulate the principles they used *after* performing an initial ideation session. When asked to write down their design principles, the pilot participants used their ideas to reconstruct which principles they had used to generate the ideas. In other words, the pilot participants appeared unaware that their believed rationale behind their behavior (espoused theory) differed from the rationale they actually used to drive behavior (theory-in-use) [15]. For the last 30 minutes, the participants were asked to share their generated ideas and design principles with the group, focusing their explanation on why and how a principle was used for an idea.

Qualitative data analysis

The method to extract design principles was inspired by the approach outlined by Fu et al. in which "design study-based data was collected, from which principles were extracted" [10, p. 7]. In this study, participants were explicitly requested to generate and write down the design principles they used during ideation next to those ideas, and to then discuss these principles with their fellow participants. To analyze the first research question regarding which principles the designers used during early phase ideation, the first author went through a process of data cleaning. The first

step was to digitize the handwritten principles, which resulted in 156 written principles. The audio and video of the team discussions was then analyzed for additional principles, resulting in 8 additional verbal principles, as well as any additional explanations the participants provided for their (written and verbal) principles. This explanation was used to refine each principle into a higher-level abstract principle that, true to the more generic nature of principles, could be decoupled from the specific context of the design problem of this study. The participants did not discuss all of their principles, so 17 principles were removed from further analysis due to lack of interpretability. Lastly, the remaining 147 principles were evaluated and grouped into higher level summative principles that conveyed a similar intent of purpose. For example, the unique principle *Consider the longevity of the solution* was aggregated from *Potentially long-term effects, Fad or long-term, Duration, Longevity option,* and *It gives continuous pleasure*. This data preparation process resulted in 58 unique principles, shown in Table 2.

The audio explanation during this refinement process was critical to the understanding of the design principles. While some written principles would appear to be relatively straight forward, other principles strongly relied on the audio explanation for their interpretation. For example, the written principle *Natural* could have been interpreted as "The solution must feel natural to use", but the designer explained that *Natural* meant that the feeling of the problem (in this case sustainability) should match with the feeling evoked by the solution (in this case earth and nature-inspired). To preserve the participants' conveyed intent of the principles as much as possible, principles that could not reasonably be interpreted were removed from further analysis.

To address the second research question regarding the identification of themes emerging across the designers' principles, the first author analyzed each principle with regards to the purpose it might serve in the design process, and how it might be used to address a design challenge. After developing an initial list of themes, the second author then evaluated the list of themes and identified how the themes related to existing design literature.

Results and discussion

The main goal of this study was to identify which principles experienced designers might use during early phase ideation and what themes emerge from those principles. To this end, qualitative analysis was conducted on

the self-reported principles that participants generated in response to a hypothetical, open-ended team design challenge. The analysis of the role of expertise, team composition and occupational background are beyond the scope of this paper. The results show that the principles that designers generated broadly fell into four main themes. While the designers did not discuss their principles in any particular order, the themes roughly correspond to the design process: Problem Understanding, Idea Generation, Idea Refinement, and Solution Implementation (see Table 2). The following sections discuss each theme, selected principles that exemplify and illustrate the nature of each theme, as well as the connection with design literature.

Table 2 The four broad themes of design principles generated by participants in this study, and the principles belonging to each category (sorted alphabetically).

Problem Understanding	**Idea Generation**
Break down the problem	Build on existing solutions
Conduct a problem audit	Conduct a solution audit
Consider the risks and mitigation	Consider logistics of implementation
Engage with problem before ideation	Find alignments
Explore existing use cases	Generate employment and wealth
Put the user first	Generate solutions that address users' values
Research the problem and solutions	Ideate each problem category
Understand problem context	Increase choices for users
	Move solution up or downstream
	Reduce complexity
	Use analogies
	Use SCAMPER
	Use status symbols
	Use the opposite
Idea Refinement	**Solution Implementation**
Address current undesirable problem	Accessibility of solution
Appropriately scope the problem	Easily understandable for users
Consider the cost of the solution	Enlist help of third parties
Consider the longevity of the solution	Form must follow function
Educate users	Give users ownership over problem
Encourage behavioral change	Guide users to desired behavior
Enlist psychological principles	Hierarchy of design content and form
Ensure the solution does not backfire	Implementing solution across contexts
Extreme solutions are not effective	Intentional familiarity of solution
Make small changes to existing solutions	Intentional uniqueness of solution
	Reduce users' fear
Provide multiple benefits and values	Solution effectiveness

Social aspect Solution context Solution materials	Solutions can have multiple functions Utilize gamification

The first theme that emerged from the design principles is *Problem Understanding*, in which the principles support the designer to gain a better understanding of the problem space. This theme includes principles such as *Explore existing use cases* (by D4) that refers to the best practice of employing use cases to explore the problem and its context. The exploration of a problem space is discussed in literature [23], although the discussion of the problem space is typically more closely tied to the exploration of the solution space than indicated by the principle. Another principle is *Put the user first* (by D4). This principle captures the best practice of user-centered design processes that emphasize understanding user characteristics, abilities, and goals prior to generating solutions to a problem [24].

The second main theme was methods for *Idea Generation*. Principles in this theme centered around philosophies and techniques for generating effective solutions to design problems. This includes principles such as *Build on existing solutions*, as described by D5 who used existing products and technology concepts as a starting point for generating new ideas. This is supported by prior literature that has shown that designers routinely utilize existing examples as inspiration during idea generation [25]. Similarly, D1 drew upon the *Use analogies* principle to create solutions, an approach well recognized in the literature for its potential to foster innovation [26]. Another principle included in this category was the *Generate solutions that address users' values* principle, which D5 used to emphasize designing solutions that speak to users' values in a given context, similar to the Value-Sensitive Design approach developed to generate effective solutions to complex problems [27]. The focus on utilizing frameworks and guidelines for idea generation is in line with the wealth of research that has been conducted on the role of ideation and creativity in engineering design [28].

The third theme of principles discussed by the designers was *Idea Refinement*. These principles centered around strategies for improving solution quality and effectiveness of generated solutions. For example, D2 identified *Appropriately scope the problem* as an important principle that should be considered while refining solutions. This is in line with previous work that has shown that scoping and constraining the problem is a crucial step during the design process [29]. Another principle included in this category is the *Consider the longevity of the solution*, which D2 explained by emphasizing that the solution should not be a cool new gadget but

something that is viable for a longer duration. This is similar to the inclusion of product life cycle considerations during the design process [30].

The fourth and last main theme was the broad category of *Solution implementation*. These principles revolve around factors that increase the successful implementation of the solution. For example, the *Utilize gamification* principle describes participants' focus on making the solution fun and engaging for users. The use of video game elements in non-gaming systems are increasingly applied to improve user experience and user engagement [31]. A frequently mentioned component of this theme was the use of incentive structures to encourage desired behaviors, a concept frequently utilized in the learning sciences to shape human behavior [32]. The *Feasibility* principle was described by D5 as "the ability of the business to execute the solution". This focus on feasibility supports research that has shown that designers frequently focus on the effectiveness, production cost, and robustness of the solution [33]. This theme also included principles that focused on the practical execution of a solution, such as *Form must follow function*, and the reception of the solution with a target audience, such as *Easily understandable for users*. The viability of a solution is an important factor during the design process, and the focus on implementation is dominant in engineering education [34].

Limitations and future work

This study primarily relied on designers' self-reports to extract design principles. This approach assumes that the participating designers have an understanding of what principles are and how to articulate them. To address the former, a discussion of the definition and purpose of design principles was included in the study protocol to create a baseline understanding of principles. Despite the designers' various interpretations of what principles are or could be, the findings suggest that they were able to develop a working understanding to meaningfully discuss their design principles.

The designers were grouped in small teams to gain additional insight into the principles they provided. Although efforts were made to evenly distribute the members according to occupational background, the participants in this study did not possess equal amounts of expertise across the domains being studied. Although more experienced designers are known to more deeply reflect on their knowledge than their less experienced counterparts [5], no such differences were found between the designers with regards to the depth of their generated principles.

The literature on design principles tends to depict principles as imperative statements that support the design process by providing prescriptive guidelines [8]. However, the designers in this study were found to frame their principles more as keywords or short phrases. This may be a result of the study format as the designers were asked to provide their principles within a time limit and (deliberately) without a template of what design principles could or should look like. Interestingly, the designers framed some of the principles as questions that they would like to address in further stages of the design process. Again, this may be a construct of the study set-up as the designers were only provided with a design brief without a specific client or further information beyond the provided one-pager. Therefore, one could argue that not all of the provided principles should be considered principles according to the definitions provided by Fu et al. [8]. The data provided by the designers during this study did not make such further distinctions possible, and further research is needed to examine the various forms in which principles may be expressed in practice.

Conclusion

The main purpose of this study was to investigate what principles designers would bring forth during an actual design activity and what patterns might emerge from these principles. Due to the highly personal and often implicit nature of design principles in practice, understanding the principles used by designers was facilitated by the collaboration of experienced designers engaging in real time discussion of design principles that were applied to a specific design activity. Thus, a major contribution of this work is advancing an approach for eliciting implicit design principles in a controlled setting. The results of this study indicate that leveraging the group dynamics of a small team of experienced designers as they worked on a hypothetical design problem in a laboratory setting may be a promising avenue to identify design principles that are employed in practice.

Individually, the designers provided a fair number of principles after generating ideas to a hypothetical design challenge. These principles were then verbally expanded upon throughout the team discussion as the designers communicated and reflected on their own and each other's design knowledge and application. This increased the detail provided for each design principle in a way that did not require the researcher to continuously prompt each participant for more depth. While the generated principles are likely to change depending on the designer, the results suggest that there are underlying themes behind the principles that

designers employ. In this study, those themes were labeled as *Problem Understanding, Idea Generation, Idea Refinement, and Idea Implementation*. While not directly named as such by the designers, these themes and many of the principles within these themes reflect existing best practices identified by prior design literature. Thus, this study adds to understanding of how experienced designers from different backgrounds approach ill-structured design problems, and to knowledge of design expertise in practice. Overall, this study suggests that soliciting insights from experienced designers could be a viable strategy to understanding more about design principles and their practical application.

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