What Is Design in the Context of Human-Centered Computing?

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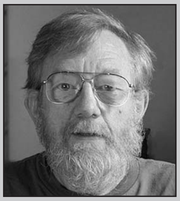
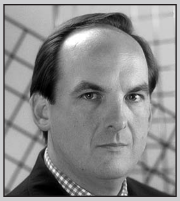
There appears to be no reason to suppose that concepts as yet uninvented and unknown stand between us and the fuller exploration of those problem domains that are most obviously and visibly ill-structured. —Herbert Simon[1]

Problem solving often involves recognizing and fiddling with tacit assumptions. Such realization can often come from seeing things from new perspectives. Appreciating the human-centered perspective may offer some hope for enriching design's scientific foundations and for crafting new and better approaches to it. Essays in this department have introduced such notions as the Sacagawea Principle:[2]

> Human-centered computational tools need to support active organization of information, active search for information, active exploration of information, reflection on the meaning of information, and evaluation and choice among action sequence alternatives.

Certainly this suggests a constraint on or a goal for design, but how do we go from such statements to actual designs that accomplish the stated goals?

We approach this class of question by considering the origins of and historical influences on the notion of design, then by considering the assumptions underlying our modern conception of design in light of the principles of human-centered computing.

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Evolution of the design concept

An investigation of word origins and current usage reveals a number of meanings of "design."

Making meaningful marks on things

The word "design" comes into English from the Latin *de signum* meaning "to mark out," with the root *signum* meaning "mark," "token," or "seal," and also having relations to Latin words meaning "to cut" or "to saw." *Signum* evolved, mostly through French, into words such as signify, assign, designate, signal, and many others. The original meaning of "design" was to physically make marks on something, marks that bear some signification. Current meanings of "design" preserve the notion of drawing representational marks (that is, sketches for artifacts such as machines or buildings).

Working with people

In the eras of the craft guilds, craftsmen gathered the design knowledge behind artifacts such as woodworking tools, farming equipment, and horse-drawn coaches by direct collaboration with the individuals who used their devices. The design knowledge was passed through generations of craft masters and apprentices. The knowledge and skill weren't freely available, at least until Denis Diderot produced *Le Encyclopedie*, which contained essays describing the guildsmen's knowledge and skills.[3] With the emergence of larger-scale designs, especially in the Industrial Revolution, the necessary skills had to be distributed among many specialists. This new task—designing for a class of people with whom the designer did not interact—helped mark the origin of industrial design.

Making machines for machines

Another factor added by the Industrial Age was a new responsibility of designers: To reshape formerly hand-

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crafted processes into ones that machines could do. Mass and assembly-line-based production stimulated, or necessitated, the creation of many designs for artifacts aimed at a broad mass of consumers and for machines designed to help in manufacturing other machines. In this context, design came to have a significant relation to the notion of *plan*.

Design as a plan

A design-as-plan lets the designer develop an entire artifact without having to change the actual things or parts referred to by the design. While making it possible to explore design alternatives, the design-as-plan serves as a design notation, because it defines the artifacts' overall structure as well as the detail required by the many craft disciplines involved in the manufacturing. This idea of design-as-plan was taken to new levels of complexity, or knowledge organization, by the large-scale technology development projects of World War II and the subsequent space program. These demonstrated the power of innovation and initiated directions that necessitated the systematization of design activity, ultimately justifying a scientific discipline of design in the 1960s. The availability of computers for tasks such as design optimization in constraint spaces stimulated an optimistic environment for rationalizing and formalizing design methods.

Design as radicalism

Design has also been used to refer to a *plan of attack* on a problem. This meaning originates from the French *desseigner*, an 18th-century term referring to political plotting or conspiracy. Design in this sense isn't just the mere act of defining and documenting a conceived plan to create artifacts. Rather, it involves imposing (not just suggesting or offering) radical alternatives, innovations that open up new classes of opportunities. This interpretation of design is illustrated in approaches that study the organizational aspects of designed environments in order to explore possibilities for change. Examples include participatory design and certainly any form of use-centered design, with implications that are intended to affect users, communities, or even societies.

Design as intent

Designs often become stand-ins for wishes and desires that are shared by the people involved in the design process or that are interpretations of the designed objects by those who use them. Designed objects can become representations of the mindset behind the design (that is, designer-centered design).[4] Design intent ranges from the attempt to simplify and economize (that is, functional design) to the attempt to provide first aid in order to hide and disguise—an ornamentation activity resulting in decoration.

Beyond the motif of design as a way of showing (or hiding) intent lies the ability of design to highlight or distinguish—that is, design as a deliberate expression of individualism. This ranges from referring to designs as archetypes (for instance, the "styles" of architecture) to expressions of fashion.

> **Debate continues today on the question of whether design is an art or can become a science.**

Design as Gestalt

"Design" is often used to mean disembodied form (or, in German, *Gestalt*). The notion here is that artifacts possess properties that can be abstracted away from them. Hence, we can say, "This has a design," or "I'd like that kind of design for my house," or "I like the feeling of that design for sweaters."

Design as art

The notion of design as art takes the Gestalt notion a step further. Debates about this have raged for centuries. They include, for example, a debate in the 19th century between functionalists ("form follows function") and ornamentalists, who believed that there is no design without ornamentation and flourishes (things whose function is purely aesthetic). Debate continues today on the question of whether design is an art or can become a science. On one hand, some journals on the topic have published empirical studies of design[5]; on the other hand, academic and even industrial design programs are still typically housed in art colleges.

Donald Schön repeatedly encountered this notion of design in his study of architecture:[6]

> Like other practitioners, architects tend to value action over reflection. They tend to take for granted what is most exceptional about their own familiar practice. Perhaps more than other practitioners, they tend to mystify their artistry, treating it defensively as an indescribable something that "either one has or has not." … [T]hey may find it extraordinarily difficult to give explicit, accurate, and useful accounts of the understanding implicit in gradually learned competences that have become "intuitive." (p. 7)
>
> In 1972 [at] a colloquium on professional education … [the participants] disagreed about many things, but they held one sentiment in common: a profound uneasiness about their own professions.… Some were troubled by the existence of an irreducible residue of art in professional practice. The art deemed indispensable even to scientific research and engineering design seemed resistant to codification. As one participant observed, "If it's invariant and known, it can be taught; but it isn't invariant." (pp. 10–11)

Design as a profession

A theme in the history of the notion of design, and most of the notions we have discussed so far, is that design is concerned with change.[7] Designing involves envisioning a future that does not yet exist, but a future that designers predict by suggesting new artifacts for that future, a future that begins in the present. Today this theme has been taken to new levels, in part because the pace of change and the compartmentalization of knowledge have accelerated significantly. Seeds were sown for a fundamental change about the time of World War I. The challenge for the industrial designers in the first formalized academic design programs pioneered by the Bauhaus (1919–1933) was that they had to live in two worlds: the world of the engineer who is concerned with implementation, and the pragmatic world of the user. They had to be able to translate their sponsors' problem statements into innovative design solutions. At the same time, they had to present the implementing manufacturers with just the right degree of skill challenge without being too open to engineering compromise. To bring together the highest potential of innovation with the right justification in terms of technical and economic feasibility became the expertise of these professional designers of the first generation.

Good design is difficult and relies on training and experience. And people can get paid for doing it, so we can say, "She is a designer." Designers are supposed to know how to create novelty even five or more years into the future and are trained in orchestrating the means to bring the envisioned change about. Indeed, some people are very good at it and become famous, or come to be regarded as experts and so come under the psychologist's microscope to reveal their strategies and problem-solving methods. From this perspective, design is both an activity occurring in the medium of thought as well as a set of behaviors (such as keystrokes for a CAD system, making marks on a piece of paper, or scratching lines in the dirt).

Today we have a fragmentation of professions, a range of meanings of design in a number of disciplines. The understanding of design among the engineering disciplines differs from the understanding of industrial and visual communication designers. Consider, for example, the differences in meaning that the word "modeling" might have for an architect versus a software engineer. To the former, it's actually making something (for example, a scale model); to the latter, it's simulating something. As another example, the English use of "design" from an engineering point of view translates to at least three German semiequivalents: *entwerfen* (to envision and define after selection), *entwickeln* (to develop in order to add detail) and *konstruieren* (to commit to a detailed construction in order to implement). Such language-related subtleties surrounding the notion of design led European researchers to distinguish their design methods research from that conducted by the Anglo-American community.[8]

Design as a pervasive activity

Contrasting with the idea of design as a skill residing in select individuals is the notion that design is an element of all professions:[6]

> Among observers of the professions, it has become commonplace that all competent practice involves a kind of design. Indeed, the language of design has entered into the ordinary language of many professions other than those usually called "design professions." In medicine, practitioners speak of the design of a process of diagnosis and intervention; in law, cases and arguments are "designed." One eminent scholar [Simon[9]] of the professions has argued for a science of design as the fundamental knowledge base underlying all professional education.

The computer's impact

The older design credo "form follows function" has become obsolete. Artifacts now might not look like what they do, in part because their inner makings have shifted from a mechanical base to an electronic one. Much of the semantic coding in artifacts gets lost to the human who looks at the artifact, and designing meaningful artifacts for human–machine interaction becomes necessary to channel the vast growth in the belief that intelligent systems would provide means for collaborative technology. At the same time, the computer has entered the design office as a tool that has challenged traditional design expertise and extended the quest in defining what the activity of design entails. (Lore is that most design work is now done using computers.) Designers face challenges in designing new technologies, and they have to design with these new technologies. And they have to do so at an accelerated pace, using designer-centered technologies that require kludges, work-arounds, and make-work.

> **One of the themes in the history of design remains a driving force in current conceptions: the notion that there is a process of design.**

This state of affairs leads to consideration of the notions of human-centered computing. We approach this by focusing on one of the themes in the history of design, one that remains a driving force in current conceptions: the notion that there is a process of design. According to this view, we can look at people and say, "They are designing." This is an important assumption and a focus of our critical analysis.

What designers do and say they do

Psychological studies of how designers conduct design work have used a variety of research methods, including case studies. The most often used methods are interviews and think-aloud problem solving, combined with protocol analysis,[10–12] although observational methods have also been used (for example, teacher critiques of student designs).[6] Studies have looked at a range of design domains such as electronics, software, product design, mechanics, and architecture. Researchers have compared the strategies of domain practitioners with those of students (or apprentices), showing that the primary influence on design strategy is indeed the designer's level of expertise.[13] Such studies have revealed a variety of activities in which designers engage.

Problem finding

The role of problem finding in design work is highlighted in Schön's discussion of architecture education:[6]

> Given an architectural program and the description of a site, the student must first set a design problem and then go on to solve it. Setting the problem means framing the problematic situation presented by site and program in such a way as to create a springboard for design inquiry. The student must impose his preferences onto the situation in the form of choices whose consequences and implications he must subsequently work out—all within an emerging field of constraints.… Professional education emphasized problem-solving, but the most urgent and intractable issues of professional practice were those of problem finding. "Our interest," as one participant put it, "is not only how to pour the concrete for the highway, but what highway to build? When it comes to designing a ship, the question we have to ask is, which ship makes sense in terms of the problems of transportation?" (pp. 6, 11)

Top-down or hierarchical problem work

A widely held view is that designers approach design problems "systematically," by beginning at a functional level (goals, requirements, constraints, and so on) and then progressively working toward specific solutions, worrying about impasses along the way.[14,15] This design strategy fits well with the approach taken in most modern theoretical treatments of design, especially within engineering design, which have approached design problem solving as a matter of search in a problem space.[1] The codicil here is that design isn't always rigidly structured, even when it appears in this form of hierarchy. Linden J. Ball and colleagues have shown that highly experienced software designers deliberately deviate from a breadth-first approach to engage in deepening when they feel uncertain about the feasibility of a high-level solution or when they have encountered an impasse.[13]

Recognition and relaxation of assumptions

Herbert Simon argued that design problem solving involves the recognition of assumptions, that is, redefinition of the design problem.[1] Studies make it clear that this is a critical activity in creative design: As John Chris Jones said, "Changing the problem in order to find the solution is the most challenging and difficult part of designing."[7] Christopher Alexander described this process as involving a "satisficing" solution.[16] The designer decides what constraints to relax in order to respond to the most important ones. The design concept that emerges from this process of sacrificing secondary properties is a satisfying design solution, not necessarily an optimal one, as is generally approached by engineering optimization. The satisficing solution is a necessity when trying to address a complex design problem with so many parameters that optimization approaches would not be feasible.

Cognitive psychologists generally agree with this view or model of design. Linda Wills and Janet Kolodner refer to this as *design problem evolution*, a process in which the designer grapples with contradictions, ambiguities, and specification roadblocks and repeatedly reformulates the problem at hand.[17] Wayne Gray and John Anderson referred to this as *design cycles*:[18]

1. *Planning*—knowledge retrieval and the creation of an abstract solution
2. *Translating*—implementing or concretizing the abstract solution
3. *Revising*—modifying the implementation, the solution, or one's understanding

Recognition and relaxation of assumptions also figured prominently in Jones' discussion of design cycles:[7]

> A designer knows only too well the frustrating cycles of modification and remodification which have to be worked through before the delicate balance of his final design is achieved. The need to recycle continuously obliges a designer to progress towards novelty by modifying one design at a time instead of by comparing several alternative designs simultaneously. (p. 22)

Design by survival

Many designs reflect the survival of previous designs.[19,20] This can be design by reuse (which includes theft), design by adaptation, design by circumstance, or design by fitness. Design by reuse might be especially common in software design. During planning, the software designer's awareness of design goals and constraints brings to mind a known previous design. Along with it comes knowledge about the original context, including the design rationale and source situation. Such contextual knowledge, a "source situation model," is important, although it's rarely included in design documentation because reusable components are often believed to be generic.[11] François Détienne has provided a taxonomy of reuse situations based on the processes that seem to be involved, such as prospection (thinking ahead about how a design solution might be used in the future) and retrospection (realizing that a previous design might be adopted or adapted to a new problem).[11]

> "Changing the problem in order to find the solution is the most challenging and difficult part of designing."

Design by adaptation is when good and sometimes bad designs are adapted, diversified, and improved; an example would be the pencil.[21] Survival can also be a matter of circumstance. The history of the typewriter is a good example: The qwerty keyboard survived not because of its ergonomic soundness but because of mass production, the creation of a cadre of salesman, and the creation of a cohort of secretaries who taught other secretaries.[22]

Finally, design by survival can involve survival of the fit. An example would be the menu interface.

Design by deliberative recognition-priming

Research also shows that designers can recognize patterns, short-circuit any hierarchical or top-down strategy, and go right to a solution path.[13] In other words, they capitalize on their extensive conceptual knowledge of previous designs and design problems. Designers will opportunistically "take immediate advantage of solution opportunities."[13,23] Indeed, one technique that designers apply is that they constantly surround themselves with sketches. Often an entire wall is covered. The designer wants to be prepared for accidental discovery of a design solution that might already be present. In Alexander's pattern-based design technique,[16] complex designs are approached by recombining and orchestrating smaller and manageable modules that have proven appropriate for earlier, similar situations. This strategy is reminiscent of recognition-primed decision making,[24] which characterizes the decision making of experts in diverse fields other than design. It can also be regarded as a form of reasoning by analogy (though the distinction between analogy and case-based reasoning gets a bit fuzzy in the design context).[25]

Design by serendipitous recognition-priming

Recognition can go beyond comparison and refinement of existing designs. New designs can arise by serendipitous recognition stemming from the perception of just about anything—the ability to design "while walking down the street."[26] As Wills and Kolodner observed, "Creative designers often see solutions to pending design problems in the everyday objects surrounding them."[17] As in many arenas of human existence, people keep working on problems even when they aren't working on the problems. The human mind can be ravenously, if not just inherently, opportunistic. Comparisons, analogies, ideas pop up. Something is perceived, and an object gets thought of as serving some function other than the one ordinarily served. If the individual is prepared to recognize possible solutions, the serendipitous discovery may lead somewhere.

Design by collaboration and confrontation

A great many recent empirical studies have looked at design processes conducted by teams.[10] This research showed that patterns and cycles of individual and collective design activity do exist. These include not only collaborative interactions but also confrontations. Collaborative/confrontational design hinges on negotiation of acceptability and negotiation of trade-offs in light of constraints. Furthermore, collaboration can be opportunistic rather than patterned.[27,28]

Design via good, old-fashioned creativity

Each of these strategies hand-waves to creativity, in one way or another. Discussions of these strategies and stages typically acknowledge that they do not necessarily apply to creative design.[1] Creativity (as well as other design heuristics we've mentioned) has been and always will be needed, because design is a matter of coping with conflicting constraints that require trade-offs. Experienced designers concur; for example, Kenneth Grange says,[26]

> The creative mind that turns design toward production and away from the design for one off will have what I regard as true inventiveness. And that instinct—together with inquisitiveness—lies at the core of what produces useful and pleasing product designs.

The importance of the creative process for designing has fostered criticism of systematic design methods.[7,29] We now offer what we hope might be a first step toward a resolution.

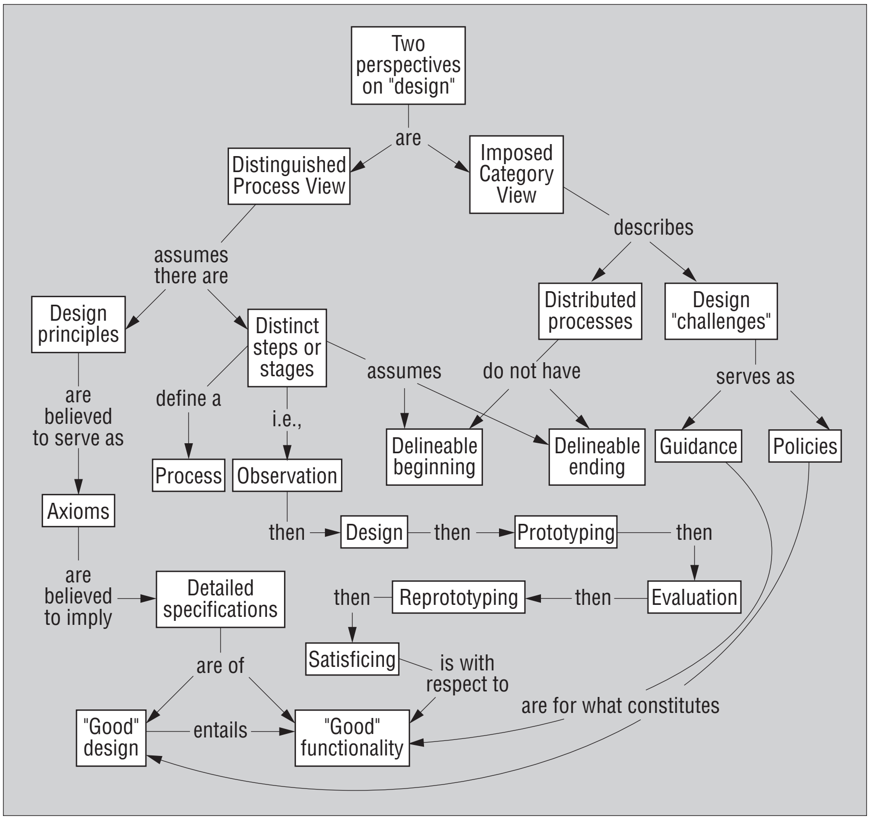

Figure 1. A Concept Map describing two views of design.

A macrocognitive view of design

Design qualifies as a phenomenon of macrocognition.[30] Designing isn't a basic building block of cognition that can be placed in a cause-effect sequence with such mental operations as associative priming, attention shifts, or retrieval of items from memory. But it does piggyback on microcognition. A clear example might be ravenous opportunism, which piggybacks on attentional phenomena and mechanisms.

Design (like essay writing) has been cited as an example of problems that can't be represented entirely in terms of problem spaces and stages of operations.[31] In fact, design work can be highly structured, have clear goals, and involve clear criteria for evaluating proposed solutions. It can involve many constraints (not too few), and these change over the problem-solving process. Design certainly involves great amounts of knowledge, even though we can't specify a priori what knowledge might be pertinent: New resources get induced during the course of problem solving, and "some information only shows up late in the design process after large amounts of search" (p. 188).[1] Hence, the problem spaces, if design were to be conceived in such terms, are indeterminate. Design is multiply structured. Try as we might, we can't shoehorn it into a single set of stages, or a single cycle. We can give key concepts in any given structural view alternative operational definitions from other structural views. Design is dynamically structured and depends on context. English lacks the non-Cartesian term we need here. Consider, for example, Détienne's struggle: "The overall process is cyclical rather than strictly linear.… [Design involves] phases of planning, translation, revision, implementing" (p. 19).[11] To cope with this conceptual/terminological problem, Détienne relies on Jens Rasmussen and Morten Lind's notion of levels of control.[32] Levels of control undergo multiple shifts, between activities that involve high-level knowledge to activities based on rules (for example, the execution of procedures such as trial-and-error).

These considerations suggest two fundamentally different views of design, depicted in the Concept Map in Figure 1.

According to the Distinguishable Process View, design is a process we can distinguish by clear-cut beginning and ending points and that we can unpack into a sequence or series of stages or cycles. This view seeks design axioms or formulas. Ideally, the need for creativity, or at least the need to understand the role of creativity, would be minimized. According to this view, designers rely on heuristics such as recognition priming and ravenous opportunism, and design by survival is still the norm, because our notions of structured design haven't advanced far enough toward mechanization as part of the drive to emulate the human.

The Imposed Category View is that design is a category humans have imposed, not a category of the things-in-themselves. This view regards design as a macrocognitive phenomenon that is distributed, parallel with other macrocognitive phenomena, and highly dependent upon and highly interactive with them. It seeks design guidance, not design formulas. There is not, nor can there be, a yellow brick road to design. In some cases we can see design activity as having relatively clear-cut beginnings or endings, but phenomena such as ravenous opportunism caution us to avoid taking the exception to the rule and elevating it to the prototype. The Imposed Category View highlights Jones' caution about systematic approaches to design: There never was a promise of success guaranteed by systematic processing.[7] Indeed, design lore is that failures are often, if not usually, more useful and insightful than successes. Designers get lost while they explore. After a while, they might get lost in the wrong areas of exploration, areas that might not seem relevant for the design situation at hand. This is when they realize they must focus, and in order to do this, they might refer to design methods.

The human-centered design approach isn't to create microcognitive models that can be implemented as emulations of the human. Rather, it embraces the richness of human cognition so that it might be leveraged and extended by technologies that amplify. Human-centered design involves integrating technological novelty into the world of practice in a way that lets practitioners adapt to innovation. It must provide artifacts that embody innovation and the freedom to modify. In this way, human-centered design can be adjusted to the changing field of work.

With this spirit in mind, must we regard the relaxation of assumptions as an alternative to hierarchical problem work? Must we regard design by survival as an alternative to design by creativity? Are serendipity and confrontation mutually exclusive? Though none of these questions is entirely rhetorical, our answer in all cases is "no."

Design isn't a process. We aren't claiming that there are no interesting empirical phenomena involved in designing, but only rarely does designing have clear-cut beginnings and endings. While stages or cycles might be imposed, designing is never divorced from other ongoing mental activities. Designing involves all the strategies we've listed, and more. And these are typically parallel, highly interactive, and context-sensitive. The principles of human-centered computing discussed in earlier essays in this department aren't cookbook entries; they aren't design axioms. Rather, they are challenges for designers. Project managers or designers may choose to adopt them as policies if their goal is to create good, complex cognitive systems.[33] ■

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NEXT ISSUE

September/October: Dependable Agent Systems

Dependability characterizes the set of properties of a system that lets us trust that the system will behave according to its requirements. Dependable systems are deployed in critical applications such as defense, transportation, energy, process control, and finance. This special issue is devoted to issues in using agent technology as a method to create large-scale, dependable distributed systems. Potential topics include specifying and modeling agent-based systems, complexity and analysis of agent computations, testing and verification of agent-based systems and frameworks, dependability cases for agent-based systems, and the interplay between the need for guarantees and the benefits of flexible, agent-based systems design.