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Design as an interactive boundary object

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Abstract

What is it about the term 'design' that facilitates the emergence of interdisciplinary interactions even though the term may hold different meanings for those involved? To address this question, we analyzed the vocabularies, practices and orders of worth proposed by the members of an interdisciplinary *Center for Design*. Our analysis revealed similarities and differences in the meanings accorded by these individuals to the term design. The analysis also revealed an awareness on their part that their notions of design were incomplete, and that they had to rely on the inputs of others. Such reflexivity was an important factor in fostering meaningful interactions between these individuals. Based on these findings, we argue that design is an *interactive boundary object*, which enables different meaning structures to co-exist and co-inform actors from multiple disciplines and domains. Within such a view, the emergence of interactions occurs not despite but because of the diversity of views about the notion of design itself.

Keywords: Design, Vocabularies, Practices, Orders of worth, Design games, Reflexivity, Interactive boundary object

The term 'design' is of considerable interest to academics and practitioners alike. For instance, well-known organizations such as Apple, Samsung and PepsiCo have been implementing design thinking and practices (Ignatius 2015; Kolko 2015; Yoo and Kim 2015). In management, a robust body of literature has now emerged around design practices (e.g., Boland and Collopy 2004; Burton et al. 2006; Liedtka and Ogilvie 2011; Martin 2009). A review of these developments highlights how design thinking and practices are key to the emergence of organizational cultures enabling innovations (Elsbach and Stigliani 2018; Garud et al. 2006).

Riding on this wave of promise around design, we investigate how design and emergence are interrelated. Of particular interest is the ability of actors from different disciplines to continue interacting with one another even when individuals might accord different meanings to the notion of design including technical interoperability, efficiency, aesthetics, customer satisfaction, and societal sustainability. Indeed, understanding how and why such interactions occur is all the more intriguing given that some of these meanings may be at odds with one another.

What is it about design that makes it possible for interdisciplinary interactions to emerge given that the term itself has multiple meanings? To address this question, we build on the "linguistic turn" in social science research (Alvesson and Kärreman 2000) wherein language and vocabularies are constitutive of meaning (e.g., Douglas 1986; Knorr-Cetina 1999; Wittgenstein 2009). Not only are practices implicated in the language we use (Loewenstein et al. 2012; Pickering 1993, 1995), but, in addition, language and vocabularies constitute the orders of worth (Boltanski and Thévenot 2006; Stark 2009) by which a community values what it does and establishes its identity (Garud and Rappa 1994; Jones and Livne-Tarandach 2008).

Based on this understanding, we explored the *vocabularies*, *practices* and *orders of worth* employed by individuals affiliated with a *Center for Design* at a large public university. The *Center* attracted the participation of individuals from different disciplines with self-declared interests in exploring questions around design as it relates to education and research. Consequently, this setting served as an exemplary case (Yin 2003), one that allowed us to investigate how design could provide both interpretive flexibility, and yet still hold value for interdisciplinary interactions to emerge.

The findings from this study confirmed our assumption that individuals across disciplines differed in the meanings they accorded to design. Building on Wittgenstein's notion of language games, we label the combination of vocabularies, practices, and orders of worth around which differences in meanings surfaced as constituting *design games.* Yet, we also found "common ground" (Puranam et al. 2009) and "interlacing" (Tuertscher et al. 2014) across design games. Besides this glue holding them together, we found individuals to be "reflexive" (Cunliffe 2003; Cunliffe and Jun 2005) in their accounts of what it meant to design. Specifically, our informants highlighted an incompleteness in their own understandings of design. Such reflexivity allowed them to appreciate the value of others' expertise, which, in turn generated interactions.

By highlighting how design can induce such a culture of interdisciplinary interactions, our findings speak to the link between design and emergence (e.g., Elsbach and Stigliani 2018; Garud et al. 2008; Hunter et al. 2020; Koçak and Puranam 2018). Specifically, polycentricity implicated in the notion of design enabled a culture of reflexive interactions wherein design served as an interactive boundary object allowing different meaning structures to co-exist. Most importantly, the actors were able to continue interacting with one another not despite but because of the overlapping structure of similarities and differences in the vocabularies, practices, and the orders of worth used by them across the different disciplines.

These findings hold practical implications. Design's capacity to foster interactions among individuals across diverse disciplines can be used to approach complex problems such as sustainability, which requires the inputs and participation of various stakeholders. Such design-induced collaboration can enable joint problem definition as well as the co-creation of solutions that balance the competing demands of the different interest groups involved (Garud and Karnøe 2003; Garud et al. 2015; Tuertscher et al. 2014).

To develop these points, we begin by considering different notions of design, starting with a definition that emerges from the work by Simon (1996), a scholar who has played a pivotal role in shaping management thinking in general, and design in particular. After reviewing subsequent management thinking on design, we present our inquiry framework comprising vocabularies, practices, and orders of worth. We then detail the research site and methods guiding this inquiry before outlining the findings. Finally, we theorize that design is an interactive boundary object that allows different meaning structures to co-exist and co-inform across disciplinary boundaries generating meaningful interactions.

Background and inquiry framework

In *The Sciences of the Artificial* (Simon 1996), Simon offered a theory of design as a scientific enterprise for the creation of artifacts that are adapted to human goals and purposes. Given bounded rationality, Simon (1996) formulated "near decomposability" as the principle underlying the partitioning of complex systems into sub-problems (Alexander 1964; Parnas 1972) held together by an architecture (Baldwin and Clark 2000; Garud et al. 2008). Though such an approach to design finds its early roots in the management writings on the division of labor and administrative hierarchy (e.g., Simon 1947; Taylor 1911), the literature on organization design (Burton and Obel 2018; Miles and Snow 1978; Nadler and Tushman 1997) and product design (Baldwin and Clark 2000; Sanchez and Mahoney 1996; Ulrich 1995) highlight the concept of modularity as a distinguishing facet of this approach. Modularity, which draws on the mirroring hypothesis (Colfer and Baldwin 2010), advocates "information hiding" such that "each module is informationally self-sufficient, [and] hence can be designed independently of the rest of the system" (Colfer and Baldwin 2010: 4). Once interface specifications between modules have been specified, modularity will lead to reduced dependencies or need for communication across design teams.

Though design using the principles of modularity has received empirical support (Colfer and Baldwin 2010), studies show that self-organized groups also make contributions across the entire system (Garud and Kotha 1994; Tuertscher et al. 2014). Moreover, certain technological problems may not be decomposable (Colfer and Baldwin 2010), and hence require not "information hiding", but "richly connected contributions" (Colfer and Baldwin 2010: 19) across participating actors. Indeed, modularization, if taken too far, may also make the design process predictable, and so reduce the likelihood of breakthrough innovations (Fleming and Sorenson 2001). Furthermore, robust designs (Hargadon and Douglas 2001) do not emerge in splendid isolation, but in and through interactions with other participating actors.

These observations suggest that design, rather than being a stable architecture built around pre-specified "design rules" (Baldwin and Clark 2000), is instead an evolving system (Simon 1996) where new goals constantly emerge through interactions between human and material artifacts. Such a focus is also implicit in an approach to design that seeks to harness the benefits of multiple interacting perspectives (e.g., Boland and Collopy 2004; Martin 2009), with "social interaction [seen as]…a key resource of design processes" (Hatchuel 2001: 261). Individuals are "not drawn together because they share a common definition of design, a common methodology, a common philosophy, or even a common set of objects to which everyone agrees that the term "design" should be applied" (Buchanan 1992: 14), but because they are motivated to learn from and meaningfully contribute to each other's perspectives. Organizational forms such as *TopCoder* and *Wikipedia* wherein multiple parties from "experts" to "hobbyists" work collectively embody such a design approach (Garud et al. 2008; Kolbjørnsrud 2018).

Design seen from such an interactional perspective is not just a set of principles, structures and tools for problem solving, but equally importantly implicates the cultural components enabling generative interactions across different stakeholder groups and material artifacts leading to the emergence of innovative outcomes (Elsbach and Stigliani 2018; Garud et al. 2006). For instance, Tuertscher et al. (2014) showed how a culture of collaborative participation across groups of scientists and engineers distributed all over the world led to the design of an innovative particle detector capable of identifying the elusive Higgs boson particle. Relatedly, Garud and Karunakaran (2018) detailed how product design (Gmail and AdSense) and an organizational culture of participative experimentation co-emerged at Google.

However, such an interactional approach to design also surfaces a paradox. Specifically, in interdisciplinary interactions, the term design takes on a global meaning, which has interpretive flexibility (Pinch and Bijker 1987). At the same time, though, design is also inherently local, tied to the practices within specific disciplines. While we expect a global meaning of design to render it a "boundary object" (Star and Griesemer 1989) that enhances co-ordination across disciplinary boundaries, the local meanings that become salient during interdisciplinary interactions could on the other hand be a source of fragmenting and conflict. Indeed, conflict arising from differences in meanings across disciplines have been the subject of books such as *Architect and Engineer: A Study in Sibling Rivalry* (Saint 2007) and *Bridging the Gap: Rethinking the Relationship of Architect and Engineer* (Building Arts Forum 1991).

What is it then about design that enables interdisciplinary interactions to emerge even when the term itself implicates different meanings across multiple disciplines? To gain an understanding of these dynamics, we used Wittgenstein's notion of language games, i.e., "language and the activities into which it is woven" (Wittgenstein 2009: 8) to investigate into the vocabularies, practices and orders of worth of individuals from different disciplinary backgrounds affiliated with an interdisciplinary *Center for Design*.

Vocabularies not only constitute language, but also provide the cultural toolkits (Swidler 1986) with which social collectives constitute their identities within professions such as architecture and medical care (Dunn and Jones 2010; Jones and Livne-Tarandach 2008). They do so by functioning as "terministic screens" (Burke 1966), guiding individuals to consider what is important within their profession (Jones and Livne-Tarandach 2008). Professional architects, for instance, use vocabularies from certain cultural registers to appeal to their clients and audiences (Jones and Livne-Tarandach 2008). Thus, examining vocabularies provides a window into the values and practices of collectives shaping their thoughts and actions (Loewenstein et al. 2012). Indeed, translating the importance of studying vocabularies in the context of design, Boland and Collopy (2004: 14) noted: "engaging in good design is choosing a vocabulary or language to use in defining the design task, generating alternatives, and making judgments of balance, fit, and scale."

Boland and Collopy's (2004) observation regarding defining the design task and generating alternatives speaks to the *practices* implicated in the vocabularies used in design. A consideration of practices goes beyond a representational view of language as a mirror of reality by taking a performative turn wherein words 'do things' (Austin 1975), and where such sayings and doings involve interactions with material tools (Barad 2003; Pickering 1995) generating "different domains of possible action" (Nicolini 2011: 616). In the context of design, these material tools may involve the use of persuasive material artifacts that "carry conviction for the design of a particular solution, invite others into a dialogue, stimulate their imagination, and facilitate and accommodate their contributions" (Wagner 2004: 159). Consequently, by examining the vocabularies used by those engaged in design, it is possible to gain an appreciation of interwoven practices [i.e., gain "interactional expertise" (Collins and Evans 2002)].

In addition, underlying vocabularies are deeper axiological considerations (Hart 1971) that are manifest in the values that individuals across different disciplines associate with design. This relates to the second observation of Boland and Collopy (2004) regarding making judgments on design. The judgments that individuals make while evaluating or justifying the outcomes of any activity invoke "orders of worth" (Boltanski and Thévenot 2006) employing different "evaluation criteria" (Garud and Rappa 1994) (such as efficiency, market success, innovation, public recognition, family tradition, and collective interests, respectively). When it comes to design, an interdisciplinary concept, orders of worth are all the more salient, as individuals must be accountable to others during their interactions, i.e., justify their "beliefs, feelings, and actions to others" (Ferraro et al. 2005: 17). Moreover, as Wittgenstein (2009: 94) noted: "It is not only agreement in definitions, but also (odd as it may sound) agreement in judgments that is required for communication by means of language." Finally, it is in these values that a "design attitude" is thought to manifest and distinguish itself from more mainstream modes of engagement such as those guided by a "decision attitude" (Boland and Collopy 2004; Michlewski 2008).

In sum, *vocabularies, practices* and *orders of worth* form the three elements of the framework that we employ in this study to inquire into the meaning of design. By examining these dimensions at an interdisciplinary *Center for Design*, we explore the different meanings accorded to design by the different actors involved, as well as inquire into how interdisciplinary interactions emerged despite the differences that existed between the individuals. Contributing to the growing interest in design and the emergence of collaborative organizational cultures (Elsbach and Stigliani 2018; Garud et al. 2008; Koçak and Puranam 2018), this study showcases the possibility of reflexive individuals engaging in interdisciplinary interactions not *despite* but *because of* the diversity in meanings associated with the term design, providing them with the opportunities to learn from one another.

Research site and methods

Using a case study design (Yin 2003), a *Center for Design* at a large public university served as the research site for this study. The *Center* was founded in 2008 through an NSF grant investigating "interdisciplinary design as instructional discipline" with four national workshop locations. Both the grant and the *Center* aimed to promote interdisciplinary education and collaboration across individuals from different disciplines with expertise on different areas of design such as innovation, decision-making, organizations, products, systems, visualization, etc. The *Center's* vision was articulated in one of its inception documents:

> *Design is an intellectual fulcrum that integrates concepts and skills across disciplines and professions to shape and reshape the world. We live in an age of design. Most disciplines practice some form of it, but in order to create truly effective solutions we need people skilled in its practice who can master the breadth*

> *and depth of technical knowledge and skills in the context of diverse and subtle human and societal issues. The Center will bring together diverse faculty and leverage, integrate, and expand a wide range of on-going interdisciplinary Design research. (emphasis added).*

Over the years, the collaborations among individuals affiliated with the *Center* have resulted in numerous publications on topics such as the logic of design, bridging design cultures, product design, additive manufacturing, in addition to initiatives to launch a university-wide interdisciplinary graduate degree program in Design. Besides, the *Center* has also been organizing workshops on design thinking, featuring speakers from the academia and the industry. Because of the *Center's* commitment to design as an interdisciplinary activity, we took advantage of this unique context—a particular exemplary case (Tsoukas 2009) to generate "theoretical refinement" on how individuals from different disciplines can come together to interact on a hybrid forum (Callon et al. 2009).

Data collection

We started our data collection in March 2012 in the backdrop of some familiarity with the research setting. Two among the three of us were members of the *Center* and had already attended some of their meetings and interdisciplinary workshops. Indeed, it was at these events that we were struck by the multiple and sometimes competing meanings of design that arose during the discussions. This piqued our interest into understanding how despite the differences in meaning across disciplines 'design' enabled individuals from multiple disciplines to come together to interact with each other. In order to investigate this, we began approaching individual members from the *Center* and started to interview them. For our interviews, we theoretically and purposively sampled our informants (Glaser and Strauss 1967; Lincoln and Guba 1985) ensuring that the individuals we interviewed were from different academic disciplines. We continued interviewing individuals at the *Center* until further interviews yielded no further insights, reaching theoretical saturation (Glaser and Strauss 1967; Strauss and Corbin 1998). To supplement our analysis, we analyzed the resumes of the people that we interviewed; details of our informants are in Appendix A. In all, we conducted in-depth interviews with 14 members at the *Center* between March and November 2012. The interviews were semi-structured, consisting of open-ended questions such as: "What do you do as a designer?", "What words come to mind when you think about 'design'?" (Appendix B). The interviews that we conducted lasted approximately 45 min on average, and were all audio recorded and subsequently transcribed.

Data analysis

We content analyzed vocabularies (Krippendorff 2004) and generated first- and second-order codes (Gioia et al. 2012) from the data. Examining vocabularies enables analysis of data at the level of individual words to surface a semantic network of design vocabularies. Thematic analysis by coding makes it possible for us to understand the larger theoretical categories that the vocabularies were constitutive of.

Content analysis

We generated a list of individual words from the interview transcripts using the WordStat text analysis module of QDA Miner (Péladeau 2004), a process that resulted in a large number of words. In line with prior studies that have analyzed vocabularies, we then identified words that were frequent enough (Jones and Livne-Tarandach 2008; Nag et al. 2007) in the interview transcripts to meaningfully constitute the distinctive lexicon of a topic—design in our case. Following Merleau-Ponty's (2012) "Phenomenology of Perception", we found that a cutoff frequency of five occurrences of a word (in total across the 14 informants) offered a level of granularity and parsimony that generated a gestalt understating of the meaning of design as accorded by the informants. Using this cutoff, we generated an initial list of words for each informant.

We then looked at these words in context, excluding those occurrences that were unrelated to our informant's meaning of design, including words such as common prepositions, articles, common descriptors, and proper nouns. We consolidated the remaining words by their commonly occurring variant or stem (Nag et al. 2007), for example 'create', 'creative' and 'creativity' collapsed into their stem 'create'. Using this process, we came up with a distinctive list of 116 words that our informants used while talking about design, which we also verified as appropriate by reading the interview transcripts. Following this, we organized this list of words as vocabularies related to practices, and orders of worth. Separately, we also classified words that were more general to the notion of design. Table 1 shows the complete list of words across all informants that surfaced from our analysis of the interview transcripts.

Additionally, we sorted these words alphabetically and transferred them into a two-mode matrix wherein the rows correspond with the individual words and the columns with informants. In other words, the cells contain the frequency of use of individual words across informants. We used the two-mode matrix as input to UCINET NetDraw (Borgatti et al. 2002) to generate a semantic network that mapped individual words to each informant as shown in Fig. 1.

Coding

Besides generating this network as a tool to visualize the different meanings associated with design, we also analyzed the data to generate first-order and second-order codes (Gioia et al. 2012) following the conventions of grounded theory (Glaser and Strauss 1967). While the first-order codes were based on informants' statements, the second-order codes distilled and assembled the first-order codes into higher order themes. The first-order coding process involved reviewing the interview transcripts to identify initial concepts and ideas of the informants that were significant, using labels in the terms actually used by the informants. This process of coding continued via the constant comparative method (Glaser and Strauss 1967) whereby new data units over time and across informants were either categorized under existing codes, or with new codes when themes analytically different from existing codes surfaced.

In all, our analysis yielded 14 first-order codes. We collapsed these 14 codes into five second-order themes, which in turn were parsed across the two aggregate theoretical categories of *practices* and *orders of worth*. Tables 2 and 3 present a summary

Table 1 Vocabularies of practices, orders of worth, and general design terms

Practices

ALGORITHM
APP
ARCHITECT
BIM
BRAINSTORM
CAD
CIRCUIT
CIVIL
CODE
COGNITIVE
COMPLEX
COMPUTER
CONSTRUCTION
CONTRACTOR
COPYRIGHT
DEVICE
DIAGRAM
DISSECTION
DRAW
ELECTRICAL
ENGINEER
EXPERIMENT
GRAPH
HUMAN
INDUSTRY
ITERATE
JAVA
LAB
LAYOUT
LICENSE
MAP
MATH
MECHANICAL
MOCKUP
MODEL
MODULE
OBJECTIVE
OPTIMIZE
ORGANIZATION
ORGANIZE
PATENT
PREDICT
PROBLEM
PROCESSOR
PROGRAM
PROTOTYPE
PSYCHOLOGY
QUALITATIVE
QUANTIFY
REDESIGN
REPRESENTATION
REVIEW
ROBOT
SATELLITE
SCHEDULE
SIMULATE
SKETCH
SOFTWARE
STATISTIC
STRATEGY
STUDIO
SYSTEM
TECHNIQUE
TECHNOLOGY
VIRTUAL
VISUALIZE
WELD

Orders of worth

AESTHETICS
BEAUTY
BUDGET
BUSINESS
COMFORT
COST
CUSTOMER
EFFICIENCY
ELEGANT
ETHICS
FUNCTION
INNOVATE
LEGAL
LOGIC
MARKET
MONEY
NEW
NOVEL
PERFORM
PROFIT
QUALITY
RATIONAL
RELIABILITY
RISK
TRADEOFF
USE
UTILITY

General design terms

ART
ARTIFACT
BUILD
CLIENT
CREATE
CRITIQUE
FEEDBACK
FORM
IDEA
INTERACT
INTERFACE
MAKE
OWNER
PATTERN
PLATFORM
PROCESS
PRODUCT
PROJECT
SPACE
STAKEHOLDER
THEORY
TIME

of this data analysis, highlighting the supporting illustrative quotes (column 1), the informant-based first-order codes (column 2), and the induced second-order themes (column 3), under each of the two aggregate theoretical categories of practices and orders of worth, respectively.

Findings

In this section, we provide details of the vocabularies, practices, and orders of worth used by the members of the design *Center*. The findings show that different disciplines have their own distinctive set of vocabularies, practices, and orders of worth associated with their understanding of what it means to design. They also show a structure

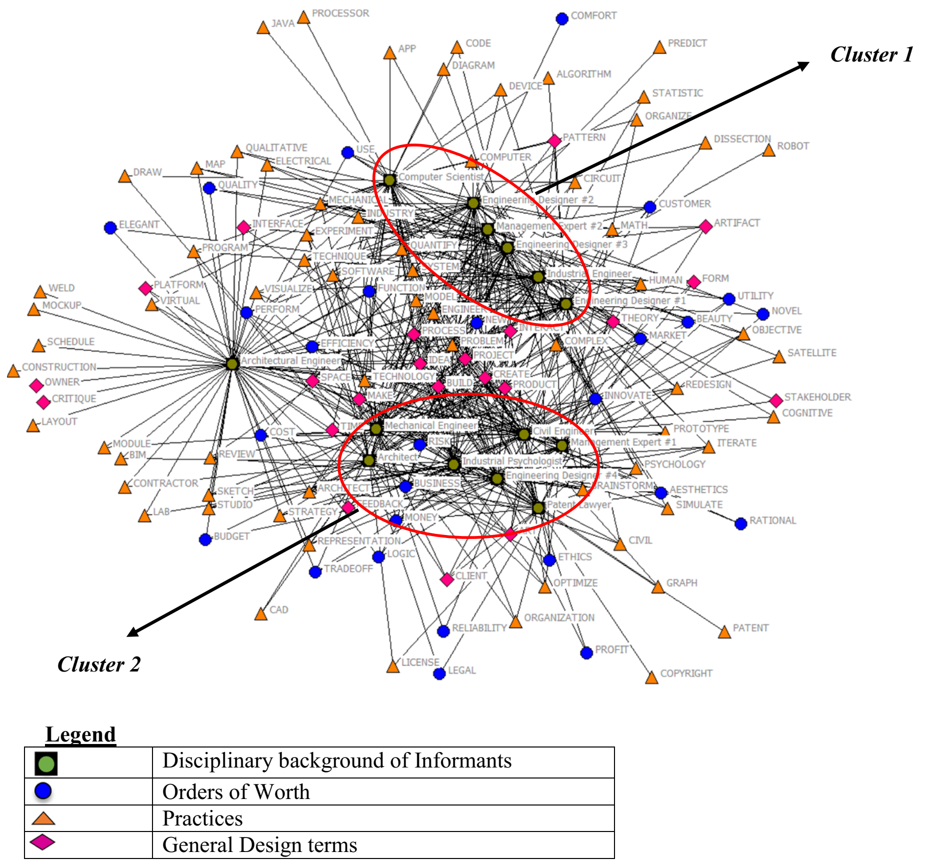

Fig. 1 Semantic network showing interlacing of vocabularies, practices and orders of worth across informants

of overlapping similarities and differences across the vocabularies, practices, and orders of worth in use.

Vocabularies

For illustrative purposes, we zoom into the vocabularies of two of our informants, *computer scientist* and *architect* as shown in Fig. 2a, b, respectively. As anticipated, data analysis revealed that the vocabularies used by these informants were consistent with their disciplinary training. For example, the vocabulary of *computer scientist* (Fig. 2a) includes words such as 'code', 'platform', 'program', 'app', 'circuit', 'efficiency', etc., while that of *architect* (Fig. 2b) includes words such as 'sketch', 'art', 'representation', 'studio', etc.

Moreover, as noted earlier, the vocabularies of both informants contained the practices (tools and artifacts such as 'code', 'sketch', etc.) and orders of worth (such as 'efficiency', 'beauty', etc.) of their discipline, and are hence constitutive of their *design games* in the discipline of computer science and architecture, respectively. Yet, as Fig. 2c shows, words such as 'idea', 'make', 'build', 'model', 'process', 'theory', 'project', etc., were common to both the *computer scientist* and the *architect*.

This structure of overlapping similarities and differences in vocabularies was common across other informant pairs as well. To make sense of this structure of similarities and

Table 2 Data structure underlying theoretical category of practices

Illustrative quotes	First-order codes	Second-order themes
When we teach design as a faculty group one of the funniest things is we hate projects that don't have spreadsheets, graphs and equations. We don't think its design unless it has spreadsheets, graphs and equations and analysis and stuff like that. (*engineering designer 4*) [What are the words that come to your mind when you think about design?] Innovation, time to innovation, evaluation, simulation, fidelity of representation, understanding, risk—so all these things. (*civil engineer*) [H]ow do you drive that model to explore the different options and tradeoff between this set of features versus that set of features, the costs, reliability. And so from a—from a design perspective—it's optimization, it's visualization, those sort of things (*mechanical engineer*)	Design using *quantitative tools* such as 'equations', 'simulations', statistical 'models', 'algorithms', 'optimization', etc.	Design tools
My training was hand drawing entirely, and doing everything through sketching. (*architect*) [S]o you have to design a site layout, that would allow for you to deliver the project per your schedule but also make sure you don't violate anything that the owner may have as a requirement or a need (*architectural engineer*) I try to create an environment where when we brainstorm ideas the weirdest and goofiest ones are welcomed. (*industrial psychologist*)	Design using *qualitative tools* such as 'sketches', 'studio', 'brainstorming', 'diagrams', 'maps', 'layouts', etc.	
We're trying to make students understand that before you can actually get to a physical design you have to understand the problem. (*engineering designer 1*) Design is just making an attempt to meet some objective (*management expert 2*) [D]esign is part of the process of both understanding the user's needs and requirements (*industrial engineer*)	Design as *problem solving* including meeting 'objectives' and 'requirements', and establishing functionality	Design approaches
I think it's a constantly evolving process and no—even legally it doesn't end. I mean there are ways the legal process keeps moving not just with a single idea that might get litigated but ideas can be pursued as follow-on inventions and creativities that iterate a process (*patent lawyer*) It's really emphasizing how important design is, to get it right, because it's something you're going to live with—for any of the long-lived software (*computer scientist*) You can evaluate a design after three months, after six months and after a year and after ten years and it can succeed in a lot of different ways and fail in a lot of different ways. So you cannot anticipate all the ways in which the design will get used. (*engineering designer 4*)	Design as *open-ended engagement* and constantly 'evolving', 'changing', having a 'life', etc.	

Table 2 (continued)

Illustrative quotes	First-order codes	Second-order themes
And, how do we convert those [customer needs] into requirements to drive the design? By having some processes to develop various concepts, selecting those concepts, prototyping them and eventually to the final design. And, it is highly iterative. I mean at any point you may need to go back. (engineering designer 3) [I]nnovation is defined as the implementation of creative ideas, [you] come up with a new and different idea, sketch it out, prototype it, [and then] actually see it made, implemented and tested. (*industrial psychologist*)	Interaction with *material artifacts* such as 'prototypes', and 'mockups'	*Interactions*
So I interact with a lot of discipline specific designers, so circuit designers, mechanical hardware designers, spacecraft mechanism designers [and] with other systems engineers. (*engineering designer 3*) We led—the series of workshops a couple of years ago on interdisciplinary design [which] was really good exposure to—how does architecture come at the problem versus industrial design versus engineering design versus IST or somebody else? (*mechanical engineer*) I study designers …And so my interaction with them is really learning what they do and what their process is like and how it differs from the traditional engineering model and how it can kind of incorporate some of that back together. (*engineering designer 2*)	Interaction with *designers outside of one's own discipline*	

differences, we examined how these words were tied to the *practices* and *orders of worth* of design across disciplines.

Practices

We first identified and elaborated on the *categories of practices* that emerged from our grounded analyses of the data. This step then served as the basis for examining the *similarities and differences* in the practices across members of the design *Center*.

Categories of practices

Table 2 highlights illustrative quotes supporting three major categories of practice that emerged—*design tools* (quantitative and qualitative), *design approaches* (problem-solving and open-ended engagement), and *interactions* (with material artifacts and individuals outside of one's own discipline). We describe these in greater detail below.

Design tools It is not surprising that design tools emerged prominently as one of the categories of practice. Consistent with the performative turn (Pickering 1993, 1995), design is to be understood in its implementation, and from this vantage point, the "tools of the trade" (Beunza and Stark 2004) are central. We found two kinds of design tools being

Table 3 Data structure underlying theoretical category of orders of worth

Illustrative quotes	First-order codes	Second-order themes
A number of aspects [define a good code]. One [is] efficiency in terms of the amount of memory or processor time—space–time are [the] two aspects of efficiency. (*computer scientist*) We've got too many products already out there. There's not enough commonality. How do we get better? How do we standardize that? How do we consolidate it?" …to try and get cost savings that are efficiency-reduced complexity? (*mechanical engineer*) There's no reason you couldn't do that to say "is this an efficient courtroom design layout" from some automated calculation. (*architectural engineer*)	Product efficiency	Product oriented orders of worth
But I like the idea that we concentrate more on designing fewer things and more beautiful things (*engineering designer 4*) If you look at what goes into a really polished app, it would include things like good artwork (*computer scientist*) So design typically involves coming up with something that has maybe an aesthetic appeal (*industrial psychologist*)	Visual and symbolic beauty	
So a design is a new description, so there is a concept of newness. (*management expert 2*) Maybe the redemption of the computer is that we need to find ways to—to tweak it and use it in ways that it was never intended to be used. (*architect*) But what I really like studying is the people and places that come up with new and different things and to me that's always going to be interesting. (*industrial psychologist*)	Novelty	
There is a philosophy that is aligned with the research that I do that says at least some aspects of design can be driven by what customers want. (*management expert 2*) Then we go look [to] capturing customer needs—how do we convert those into requirements to drive the design (*engineering designer 3*) I am trained to help people conceptualize what their inventions—and in this case we might even extend that to designs—help capture them as property rights and potentially exploit them. I also think about how that is likely to impact business (*patent lawyer*)	Market success	
We'll look at the interaction of the product and the person. So it can be anything from comfort—to the interaction in terms of fun factor. Engagement is a really important factor. (*engineering designer 2*) Another aspect of design that I've gotten into more [is] user interface design, you've got to think about "well, how is the user going to interact with this? How is that going to happen?" (*computer scientist*)	Interactivity	

Table 3 (continued)

Illustrative quotes	First-order codes	Second-order themes
I do engineering design research. And to me, that means what methods and tools, [and] processes make designers more efficient or effective. (*mechanical engineer*) [I have] done a lot of research in building information modeling providing practical guidance to project teams to design efficient BIM implementation strategies [and] written and developed guides that allow people to design a process for modeling for a project. (*architectural engineer*)	Process efficiency	Process oriented orders of worth
We did the creative campus project—it was engineering, architecture, landscape architecture and dance …very interesting project of trying to get all those groups working together [which] was fun. (*mechanical engineer*) Well I think what [interactions have] done is it's helped me understand design as done in different disciplines (*engineering designer 3*)	Interdisciplinary interactions	
Engineers are notoriously bad [laughs] at understanding how important design is, because most of our curriculum here never addresses that. (*computer scientist*) Design specifically, I think I didn't understand as much. And so that's kind of what motivated me towards thinking about design and things like that more formally. (*civil engineer*) I think if it [design] ultimately lies somewhere it's at the overlap of disciplines. I don't think any discipline owns it nor should they, with it being as broad and applicable as it is to everyone. (*industrial psychologist*)	Reflexivity	

alluded to—what we label as *quantitative* and *qualitative*. Quantitative tools include mathematical and statistical representations such as 'equations' (*engineering designer 4*), 'simulations' (*management expert 2, civil engineer*), statistical 'models' (*management expert 2, engineering designer 1*), 'algorithms' (*computer scientist*), 'optimization' (*mechanical engineer, civil engineer*), etc. For example, an *industrial engineer* described the use of statistical tools in the design process:

> *[Our] design problem basically was grounded in a lot of statistical comparisons. So we look at risk perceptions between different stakeholders and boil them down in terms of statistical comparisons—whether it be inferential statistics like t-tests, ANOVAs or clustering methods. (industrial engineer).*

Quantitative tools also assumed a wide variety of functions such as: predicting the performance of a design (*management expert 2*), converting customer needs into requirements (*engineering designer 3*), generating tradeoffs in designs (*civil engineer*), etc. For some, quantitative tools were central to their practice of design. As an *engineering designer* mentioned:

> *The engineering design process can be quantified and replicated, and there is evidence that it actually influences solutions. So, when people do not try to move*

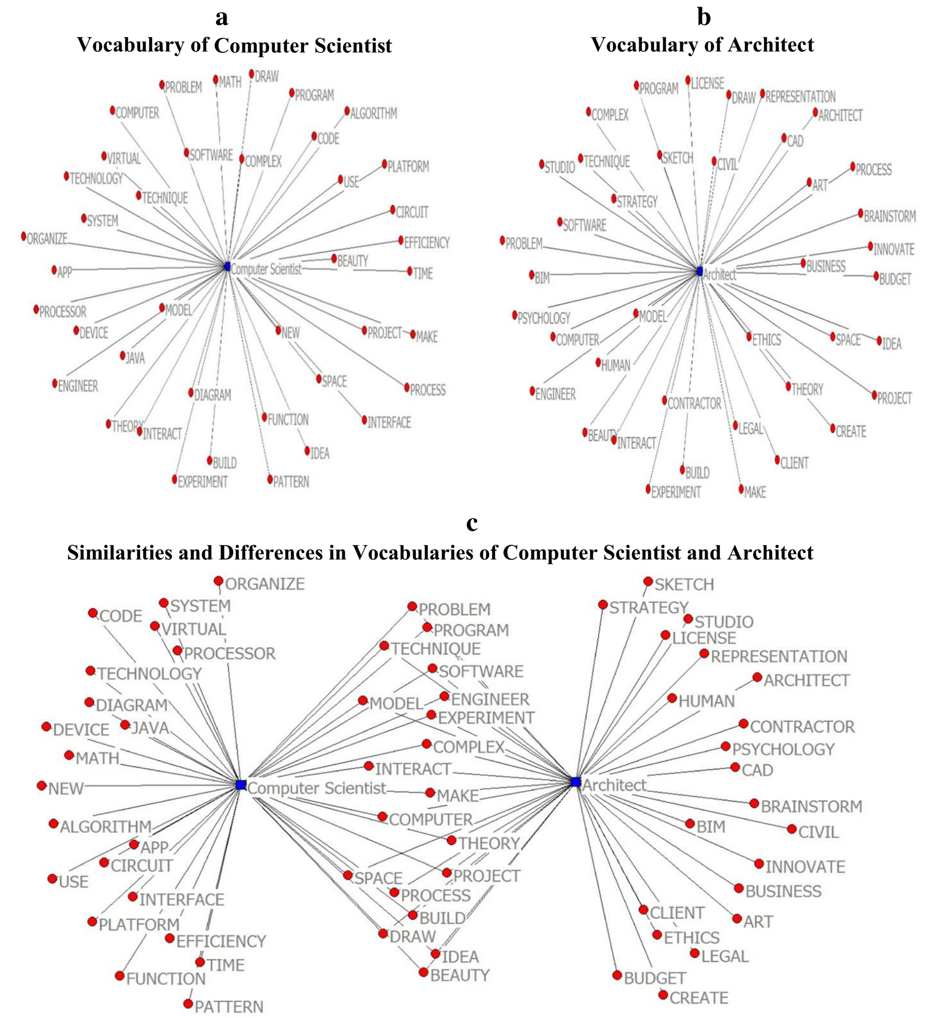

Fig. 2. **a** Vocabulary of computer scientist. **b** Vocabulary of architect. **c** Similarities and differences in vocabularies of computer scientist and architect

> *towards quantification gives me cause for concern. (engineering designer 1).*

In addition to quantitative tools, the data also showcased the use of multiple *qualitative tools* such as 'sketches' (*architect*), 'diagrams' (*computer scientist, engineering designer 3*), 'maps' (*architectural engineer, management expert 2*), 'layouts' (*architectural engineer*), 'word cards' (*engineering designer 2*), 'brainstorming' (*architect*, *industrial psychologist*, *engineering designer 1*, *engineering designer 3*, *mechanical engineer*), 'studios' (*architect*, *architectural engineer*, *mechanical engineer*), and 'interviews' (*engineering designer 2, architectural engineer*) in the design practices of informants. As an example, an *architect* described the use of sketches in aiding improvisation:

> *I intentionally only had a very rough sketch [of a tree house] and tried to build it like a kid would build it, which was mostly improvisational. (architect).*

Other qualitative tools such as diagrams, maps, and layouts aided visualization of the design process by "map[ping] out modeling tasks that are going to be performed, and identifying information exchanges that go between those tasks" (*architectural engineer*). These tools also enabled effective translation of ideas to other individuals. To illustrate:

> *So one of the tools that we use is what's called a concept of operations diagram. It's essentially like an executive summary of how the system is working…it's almost like a pictorial of some complex thing and it's got 'Here's how this whole thing works.' It takes a while to develop that, and when you have that tool, it's used to communicate between the system acquirer or the person that wants the system and the people that are developing the system to make sure that they're on the same page. (engineering designer 3).*

Informants also used 'studios' in their design practices. An *industrial psychologist* distinguished it from quantitative engineering tools:

> *Studio approaches always fascinated me–just so much hands on and so much constant feedback and it's just so different from what we do and what the engineers do. (industrial psychologist).*

Engineering designer 2 mentioned the use of 'word cards', and 'interviews' to enable the designer to get better feedback on user engagement with the design:

> *We draw from industrial design too where people pull in words [from word cards] that they think represented their experiences with it [the design]…Or you can interview them afterwards and ask them "How did you feel about your engagement with this device? (engineering designer 2).*

In summary, the analysis of the data showcased both quantitative and qualitative tools. While the former set of tools was based on measurable facts, the latter set was based on intuitive approaches that enabled visualization, facilitated improvisation, and generated feedback during the design process. It is in the combination of these two types of tools that design appeared to unfold.

Design approaches A second category of practice had to do with the approaches participants used to design, which were manifest as *problem-solving* and *open-ended engagement*. The problem-solving approach to design was 'rational' (*management expert 1*), 'logical' (*engineering designer 1*) and focused on arriving at a desirable 'solution' to the 'design problem' at hand (e.g., *computer scientist, architectural engineer, engineering designer 1, management expert 1,* etc.). An *engineering designer* best described the problem-solving approach in the following terms:

> *The engineering design process—what we do is we try to define the problem. So first we've got to figure out what the problem is…[then] you need to solve it…So scoping that problem is a very critical part. What is it that you are working towards? (engineering designer 3).*

For the *engineering designer*, the practice of design begins with problem definition and then moves onwards to find a solution to the problem. Another *engineering designer* we spoke to contrasted a *problem-solving approach* with the practice of design in fashion design:

> *I view design more as working towards a problem that I can understand. When I look at a catwalk, I don't understand it, and I know that [fashion] designers design these things. Of course, there is value in there, but I think it's just a different use of the term [design] than how I use it. (engineering designer 2) (emphasis added).*

As evidenced, for *engineering designer 2*, what fashion designers do is not a facet of design he understood, as it lacked an emphasis on problem solving. Yet, he saw some value in fashion design, even though he did not fully understand it. We return to this notion of reflexivity, an attribute that we found in all the people we interviewed, later in the document.

The focus on problem solving also extended to disciplines outside of engineering. To illustrate:

> *I clearly think of my concept of design as a pretty rational kind of process. What are you trying to achieve and how should you go about it? ...There is the beast on the table. What's the best design that we can come up with so that it has a good chance of being successful in its environment? (management expert 1).*

Management expert 1 likewise associated design with first identifying and defining the problem, and then generating the 'best' solution to address the problem. Reflecting his background, he offered that an organization must be designed to increase the likelihood of its success in competitive environments.

However, there were informants who were critical towards the 'problem solving' approach. For instance, an *engineering designer* considered this approach as limiting the scope of what could be achieved through design as an activity:

> *[Design] is not just problem solving, which is engineering culture. So engineers in the design process—they view it as a problem and solve it in 30 min... Engineers have no clue what a vision is. Their vision—is a neat little technical problem they have to solve. (engineering designer 4).*

This observation draws attention to a second approach to design, one characterized by greater *open-endedness*. To illustrate:

> *[Design] is a projectile thrown into the future. I don't like the problem-solving definition that often is used...to me it's always somewhat provisional...You make design proposals, but I never necessarily assume they're right or perfect—so they're always open to modification, to rethinking. (architect).*

The above quote highlights that design is always provisional and open to modification, in contrast to being a final solution. Such an open-ended approach to design was also emphasized by a *computer scientist* who emphasized the constantly changing nature of software designs:

> *One of the aspects of software is that it's not a static object. It's something you build once but it will have a life of its own. It's going to go into production, it might be used for 10, 20 years. Someone else is going to look at it and modify it, extend it. So you can't just have something that works, it's also got to be able to live, in terms of other people looking at it, modifying it, extending it, changing it. (computer scientist).*

Other informants attributed to design a ‘living quality’ in the following terms:

> *I believe that design is something that maybe starts with some initial ideas but gets developed and changed and grows and sometimes retracts over time. (patent lawyer).*
>
> *I think it’s a lot like life—a building has a life. It’s not a static thing. (architect).*

In sum, we found two approaches to design: *problem solving*, which prescribes completeness in problem definition and aims at arriving at the ‘optimum’ or ‘best’ solution, and *open-ended engagement,* which anticipates designs to be always incomplete and “perpetually in the making” (Garud et al. 2008: 356).

Interactions Besides the tools of the design trade and the approaches to design, the data revealed another important facet of the design process: *interactions* with material artifacts and with designers outside of one’s own discipline. Interaction with material artifacts such as ‘prototypes’, (*engineering designer 1, engineering designer 3, engineering designer 4, mechanical engineer, industrial psychologist*), and ‘mockups’ (*architectural engineer*) enabled iteration and feedback in the design process. An *engineering designer* explained the use of prototypes in the design process:

> *You brainstorm and think of things that you hadn’t thought about. You build a couple prototypes. You test. You see the things about the final solution that weren’t in the problem statement and then you continue to iterate until you actually end up with…[the solution] (engineering designer 1).*

Another informant, an *architectural engineer* highlighted the use of ‘mockups’ to improve the quality of feedback received from prospective users of the design.

> *We’ve done a lot of virtual mockups that allow a user group to live navigate those models inside of an immersive display on a one-on-one scale. They can walk around, look at the space and get a better sense of scale and the environment and can provide better feedback. (architectural engineer).*

Interaction with material artifacts such as ‘prototypes’ and ‘mockups’ helped designers concretize design concepts. They also enabled meaningful iterations by “expressing, developing, detailing, communicating, and presenting an evolving design concept” (Wagner 2000: 379) for testing and feedback in the design process, and thereby enabling different stakeholders to easily understand the design:

> *I think we’ve found that having the models can be a very productive communication tool…I think it … levels the playing field for everyone’s understanding of what the design actually is. (architectural engineer).*

Interactions were not just limited to material artifacts, but also extended to interactions with designers from other disciplines. This was manifest in the references informants made to design projects involving collaboration with individuals outside of their own discipline. *Engineering designer 1* described in the following terms one of his collaborative projects:

> *I am collaborating with computer scientists, neurologists, artists... It's one of those things that we're synthesizing knowledge and creating new ideas. (engineering designer 1).*

An *architect* reflected that collaboration with engineers made him fluent in their design practices and the terms to use that they would value:

> *In the last four or five years I've been doing a lot of collaborative research with engineering faculty, so I'm getting to the point where I speak engineer ... but obviously I still root it in architecture (architect).*

Such interactions arose because design projects such as buildings "[are] too complex for any one person to understand all aspects of it" (*architect*), and also because the outcomes of interdisciplinary interactions in collaborative projects were likely to be new to all. A *civil engineer* shared with us the novel outcome of an interdisciplinary collaboration with aerospace engineers:

> *I talked to some aerospace people [to design] the software, a primary design tool for US satellite assets ... it wouldn't happen without collaboration, openness, going across disciplinary boundaries. (civil engineer).*

Similarities and differences in practices across disciplines

So far, we examined the design practices used by the members of the *Center*. Our investigation revealed that these practices varied across members we investigated. Although we already alluded to some similarities and differences, it is useful to explore them in greater detail. For instance, how did different disciplinary groups use the practices they mentioned? Did practices neatly separate out across the individuals, or were there some commonalities?

The results of our analysis are summarized in Table 4. Specifically, the table highlights the similarities and differences in the practices across all informants. As an illustration, consider the practices of an *architectural engineer* (Table 4) and those of an *industrial engineer* (Table 4). Both share commonalities in practices such as in their problem-solving approaches to design and in their use of quantitative tools. However, *architectural engineer* used qualitative tools and interactive material artifacts, which were absent in the practices of *industrial engineer*. This pattern of similarities and differences in practices exists across all informants as illustrated in Table 4.

Whereas the differences in practices are a result of differences in disciplinary training and orientation of informants, the similarities point to overlaps in some of the practices across different disciplines. For example, informants from the mainstream engineering disciplines placed emphasis on quantitative tools and a problem-solving approach (e.g., *engineering designer 1, engineering designer 3, civil engineer, mechanical engineer*). By contrast, other informants emphasized qualitative tools (e.g., *architect, industrial psychologist, architectural engineer*) and open-ended engagement (e.g., *architect, patent lawyer*).

These differences in orientations were persuasively articulated by the *architect* who challenged the assumption that every aspect of the design could be quantified. To illustrate:

Table 4 Similarities and differences in practices across informants

Practices	Informants													
	Computer scientist	**Management expert 1**	**Management expert 2**	**Architect**	**Architectural engineer**	**Engineering designer 1**	**Engineering designer 2**	**Engineering designer 3**	**Engineering designer 4**	**Industrial psychologist**	**Patent lawyer**	**Civil engineer**	**Industrial engineer**	**Mechanical engineer**
Design tools														
Quantitative tools	×	+	×	+	×	×	+	×	+	+		×	×	×
Qualitative tools	+		+	×	×	+	×	+		×	×			+
Design approaches														
Problem solving	×	×	×	–	×	×	×	×	–	×	×	×	×	×
Open-ended engagement	×	+		×		+			×		×			
Interactions														
Interaction with material artifacts					×	×		×	×	×				×
Interaction with designers outside of one's discipline	+	+	×	×	×	×	×	×	×	×	×	×	+	×

Biographical sketch of each informant is summarized in Appendix A

> *[The assumption] that everything can be measured and everything can be put in some kind of numerical form... I don't think that's actually true. (architect).*

The same architect also critiqued the problem-solving approach to design advocated by others:

> *I know a lot of people like to talk about 'we solve problems.' But, I don't think everything that we do, intends to be a solution—certainly not a final solution. To me, [the notion of a] problem always has some difficult connotations. It's a very technological world view. I design and build a tree house for my son, and at no point in that process did I ever consider it a problem. I considered it an opportunity, I considered it a challenge, I considered it a chance to express. (architect).*

Notwithstanding these differences, an emphasis on *interactions* with designers outside of their own discipline was common across informants. Indeed it was such an emphasis that led these individuals to interact with each other. Informants across disciplines emphasized such interactions in their design practices in the following ways:

> *Interdisciplinary work is very important. Just working with a bunch of engineers doesn't excite me as much anymore (mechanical engineer).*

> *We don't embrace technology in the way that architects and engineers do and so spending time with folks outside of my discipline makes me realize that there is a rapidly changing world and we need to pay better attention to it to understand really what's truly happening now—right now—in the creativity world (industrial psychologist).*

> *I was looking at collaboration between architects and engineers. What were the issues? What were the barriers? What were the impediments to more effective collaboration between architects and engineers? (architect).*

In sum, although we found less convergence on the practice dimensions of *design tools* (quantitative and qualitative), and *design approaches* (problem-solving and open-ended engagement), we found convergence on the degree to which informants across disciplines emphasized interdisciplinary interactions in their design practices. These findings suggest that the desire to interact is important for these individuals despite and even because of differences in design practices across disciplines. Together these practices, i.e., design tools, design practices and interactions inscribe the horizon of possibilities (Nicolini 2012) of design outcomes across disciplines such as buildings (*architect, architectural engineer*), surgical tools (*engineering designer 2*), organization designs (*management expert 1*), apps (*computer scientist*) and others.

Orders of worth

Just as with practices, we first identified from the interview data the orders of worth surfaced by our informants. This step served as the basis for examining the similarities and differences in these orders of worth across members of the design *Center*.

Categories of orders of worth

Our data analysis revealed two major categories of orders of worth—*product oriented* and *process oriented* (Table 3). Product oriented orders of worth covered facets of the designed product such as 'product efficiency', 'visual and symbolic beauty', 'novelty', 'market utility', and 'interactivity'. Process oriented orders of worth had to do with 'process efficiency', 'interdisciplinary interactions' and 'reflexivity' in the design process.

Product oriented orders of worth Informants invoked 'product efficiency' as an order of worth in the design of various artifacts such as: programming codes that efficiently utilized memory space and processor time (*computer scientist*), risk management tools that optimized search and visualization of tradeoffs (*civil engineer*), product designs that enabled cost savings (*mechanical engineer*), and courtrooms and work environments designed for efficiency (*architectural engineer, industrial engineer*). Or, they alluded to designs that effectively performed some function (*management expert 2, engineering designer 1, engineering designer 3*). A *management expert* alluded to the effective design of organizations in the following way:

> *[We] are designing, for example, organizations that have desirable properties that we believe will make them effective in their environments and can accomplish their purposes…What are the desirable properties that you want to try to build in to the artifact called …an organization (management expert 1).*

Informants also invoked 'visual and symbolic beauty' as an order of worth, mentioning designs such as '[user] interfaces' that looked beautiful (*computer scientist*), or generally advanced the value of beauty and aesthetics (*engineering designer 4, industrial psychologist*). Symbolic beauty as an order of worth was strongly invoked by an *architect* who championed its intrinsic importance, challenging the premise that designs should be based only on functional utility. To illustrate:

> *Drawings have symbolic importance as well. They are beautiful in their own right. But, if a drawing is just an instrumental representation of something that can be made, then it eliminates our ability to think of things that can't be made. It constrains your imagination, I think, in not good ways. (architect).*

Novelty also emerged as an important order of worth across informants. Informants who valued 'novelty' emphasized its importance observing: "if you were just doing what has already been done, you're not designing" (*civil engineer*), "so when I think about somebody designing something, or creating a design, or participating in the design process, it's about creating something new that hasn't existed before" (*patent lawyer*), "when you are doing design you are trying to build things that never existed before" (*engineering designer 4*). Recalling his interactions with a circuit designer, *management expert 2* also emphasized novelty as a virtue that distinguished design from other activities:

> *The guy [circuit designer] pulls out a book, flips to the page where that circuit is and says, "There it is." So I thought, I wanted to be a designer; I don't want to be a cook. This guy has a cookbook and any time he needs a circuit he opens up the cookbook and there is the circuit. He just has to plug in the numbers for his particular use. … So a chef could create something, a chef is a designer, a cook is not a designer. (man-*

> *agement expert 2).*

Across informants, ‘market utility’ of the design emerged as an important order of worth. For instance, informants mentioned design as the creation of products acceptable to customer needs (*management expert 2, engineering designer 3*), or even exploiting a given market (*civil engineer, patent lawyer*). To some informants, market utility assumed utmost priority. For instance, a *mechanical engineer* noted:

> *In product family [design] amazingly, the Best Buys and the Targets and the Walmarts of the world are dictating the entry-level product on the shelf. A company has to figure out what features need to be packed into the product given that the only way it is on the shelf is if it sells for $[x]. (mechanical engineer).*

Management expert 2 also called for the need to appreciate market-oriented design as a welcome correction to the conventional performance-oriented design. To illustrate:

> *So, all the engineering models work in the wrong direction—from design to performance to market acceptability. Instead it should be from market acceptability to performance to design. (management expert 2).*

Closely related to the market, informants invoked ‘interactivity’ of the product as an important order of worth related to comfort (*engineering designer 2*) and ease of interaction (*computer scientist*) with the designed product. To illustrate this order of worth, an *Engineering Designer* pointed out the interactive features of the Apple iPhone:

> *The first iPhone revolutionized the industry as a whole; it was a paradigm shift in how people interacted and how they perceived phones. It became more than just a phone. (engineering designer 1).*

Informants also mentioned “drawings that have changed the way we think about space” (*architect*), “technologies that have transformed what it means to be human” (*engineering designer 4*), or “design of user experiences” as examples of interactive designs.

Process oriented orders of worth Informants valued efficiency in the design process in terms of ‘optimization’ to get the best product design (*mechanical engineer*), ‘minimizing’ the number of iterations to generate a solution (*engineering designer 1*), effective design processes founded on design principles (*management expert 1, computer scientist*), and the use of statistical models and algorithms (*management expert 2, civil engineer, engineering designer 3*). An *architectural engineer* highlighted making ‘efficient’ use of resources as a distinguishing feature of the construction design process:

> *The construction process is probably much more specific and discrete. Certainly, efficient use of resources is probably one of the keys. From a construction standpoint, how effectively are they using equipment, crews, materials? How effectively are they meeting the budget for that project? (architectural engineer).*

Informants also valued their ‘interdisciplinary interactions’ in the design process. An *engineering designer* commented that working with interdisciplinary teams generated multiple ways of approaching the ‘design problem’. To illustrate:

> *When I’m hiring…, I’ll have mechanical engineers, computer scientists, industrial*

> *engineers all working together…I believe that any good design starts from viewing the problems in a different way. This is central to the design process; you have people in varying degrees of expertise that come together and show different outlooks on the problem. (engineering designer 2).*

A *mechanical engineer* mentioned how interactions with architects had enhanced his learning about the design process in architecture:

> *It was very interesting working with a different group. I was surprised how much I learned and got out of interacting with the architectural design process in comparison to the engineering one. (mechanical engineer).*

Interdisciplinary interactions were also the focus of various design workshops organized by the *Center*. These workshops focused on topics such as designing an interdisciplinary graduate design curriculum and fostering better collaboration on design research across disciplines. For example, one workshop organized by the *Center* in 2010 titled: *"When Engineering Design Meets Architecture"* focused on overcoming the "language barriers" that impeded successful collaboration between architecture and engineering disciplines, and recommended the development of design curriculum that led to "T-shaped people", who not only had in-depth knowledge of design within their own discipline, but were also knowledgeable about design as practiced across other disciplines.

Supporting these interdisciplinary interactions was the notion of *reflexivity* (Cunliffe 2003; Cunliffe and Jun 2005) in the design process, i.e., an awareness of the assumptions and biases in any design approach, and a realization that any notion of design is always incomplete. To illustrate:

> *For me, design is like an elephant. Each blind man comes up to the elephant and gets a different perspective on what design is. There are many different characteristics of design. I have two or three blind men's views of the elephant. So I can appreciate multiple perspectives, but they are still incomplete. Each one [perspective] is incomplete. (management expert 2).*

By invoking the parable of *The Blind Men and the Elephant*, the *management expert* was acknowledging incompleteness of his own viewpoints on design. The fact that any perspective on design is partial was also echoed by the *architect* and an *engineering designer*:

> *Design is too slippery a human activity for anyone to claim that they own or control it (architect).*

> *I've always known that different disciplines sort of viewed it [design] in different ways. ((engineering designer 3).*

We found such reflexivity in all members of the design *Center* we interviewed. Because of such reflexivity, informants respected others' perspectives on design despite disciplinary differences. We illustrate this with a set of remarks offered by a *mechanical engineer* to open a design workshop organized by the *Center* that we attended:

> *We come here to become aware. We don't have agreement [on design], but we respect each other's positions. (mechanical engineer).*

Table 5 Similarities and differences in orders of worth across informants

Orders of worth	Informants													
	Computer scientist	**Management expert 1**	**Management expert 2**	**Architect**	**Architectural engineer**	**Engineering designer 1**	**Engineering designer 2**	**Engineering designer 3**	**Engineering designer 4**	**Industrial psychologist**	**Patent lawyer**	**Civil engineer**	**Industrial engineer**	**Mechanical engineer**
Product oriented														
Product efficiency	X	X	X	−	X	X	+	X	+	+		X	X	X
Visual and symbolic beauty	X	+	+	X	+	+		−	X	X	+	+	+	+
Novelty	+	+	X	X		X	+	X	X	X	X	X	+	+
Market utility	+	X	X	+	+	+	+	X	+	−	X	X		X
Interactivity	X	−	+	X	X	X	X	+	X			X	X	
Process oriented														
Process efficiency	X	X	X	−	X	X	+	X	+	+		X	X	X
Interdisciplinary interaction	+	+	X	X	X	X	X	X	X	X	X	X	+	X
Reflexivity	X	X	X	X	X	X	X	X	X	X	X	X	X	X

X: Primary emphasis; +: subordinated emphasis; −: negative emphasis

Similarities and differences in orders of worth across disciplines

Table 5 provides a summary of the orders of worth across informants. For example, we see from Table 5 that m*anagement expert 2* (Table 5) places primary emphasis on 'product efficiency', 'novelty', 'market utility', and 'process efficiency' besides valuing 'interdisciplinary interaction' and 'reflexivity' in the design process. The other orders of worth namely 'visual and symbolic beauty' and 'interactivity' are subordinate in importance for m*anagement expert 2.* Thus *management expert 2* invokes multiple orders of worth simultaneously, and also has in place a hierarchy of values (Henn 2013). We see this pattern in the orders of worth of all other informants.

Table 5 also highlights the structure of similarities and differences in these orders of worth across informants. As in the case of practices, we found these orders of worth to be closely tied to informants' disciplinary training. For example, we found both 'product efficiency' and 'process efficiency' to be orders of worth of primary emphasis amongst informants from the engineering disciplines (e.g., *engineering designer 1, engineering designer 3, mechanical engineer, civil engineer,* etc.). In contrast, an *architect* questioned the very premise of efficiency as a driver of design, attributing negative value to it in his practice.

> *If efficiency puts lots of people who formerly enjoyed their jobs out of work, and makes them do drudgery work, then have you actually improved the world? My feeling is, even if they can do it more efficiently, who cares? I want to have fun. The reason I'm an architect is because it's fun, not because it's efficient. (architect).*

However in contrast to practices, we found greater variability across orders of worth even among individuals from the same discipline. For example, *engineering designer 2* also placed 'product efficiency' lower in her ordering vis-à-vis 'interactivity' with the design. To illustrate:

> *In software design [computer engineers are] just thinking about processing speed and nothing to do with the human behavior [and interaction]. (engineering designer 2)*

Further while informants from the engineering disciplines placed 'visual and symbolic beauty' lower down in their hierarchy of values referring to these values as "those kind of things that don't let you make a phone call" (*engineering designer 3*), and "that's not so important" (*mechanical engineer*), other informants, such as *computer scientist* and *engineering designer 4,* placed primary emphasis on these attributes within their hierarchy of values.

We found such pattern of similarities and differences in the orders of worth cutting across disciplinary boundaries. For example while novelty as an order of worth was regarded highly by informants across disciplines (e.g., *civil engineer*, *patent lawyer*, *engineering designer 4,* management *expert 2), industrial engineer* did not consider 'novelty' as a necessary hallmark of design. To illustrate:

> *I actually think that those things that emerge—so even self-replicating patterns that emerge to be functional [to be] design. So, it doesn't necessarily require that element of either novelty or innovation, in terms of something that's completely new. (industrial engineer).*

Likewise while 'market utility' was valued by individuals from different disciplinary backgrounds (e.g., *management expert 2, civil engineer, management expert 1, mechanical engineer), industrial psychologist* attributed negative value to it as illustrated below:

> *And so where a lot of organizations make their mistakes is on the idea evaluation side… they apply financial metrics to new and different things, and the fact is when something is new and different it's not clear that it's going to make money, and if those are the only metrics you apply they typically throw out the best ideas. (industrial psychologist).*

Across such patterns of similarities and differences, a striking commonality across informants was their appreciation of the value of interdisciplinary interactions. Such appreciation reflected reflexivity on the part of the participants—that their notion of design was incomplete. We will explore further the implications of such reflexivity in the discussion section. Before doing so, we will provide an overall summary of what we found.

Design games

We summarize our findings by returning to the semantic network of vocabularies that include practices and orders of worth across the fourteen informants (Fig. 1). The figure shows the presence of two clusters labeled *Cluster 1* and *Cluster 2.* While informants in *Cluster 1* are engineers representing disciplines such as engineering design, computer science and industrial engineering, informants comprising *Cluster 2* represent a more heterogeneous mix of disciplines such as law, architecture, psychology, management, and engineering. Not surprisingly, common to informants in *Cluster 1* are design practices such as 'problem solving', the use of 'quantitative tools', and the orders of worth of 'product efficiency' and 'process efficiency'. In contrast, design practices across informants in *Cluster 2* emphasize 'open-ended engagement' and the use of 'qualitative tools', in addition to also valuing 'visual and symbolic beauty'.

However, despite these differences we also seen interlacing (Tuertscher et al. 2014) in the vocabularies, practices, and orders of worth of informants both across and within the two clusters. For example, the semantic network reveals common ground (Puranam et al. 2009) in the vocabularies related to practices and orders of worth, as well as design vocabularies such as 'idea', 'create', 'build', 'product', 'process', 'project', etc., across informants. Overall this pattern of similarities and differences corresponds to what Wittgenstein observed in the context of language games as "a complicated network of similarities overlapping and criss-crossing" (Wittgenstein 2009: 36). Design is similarly an interconnected network of *design games* with connections constituted by an overlapping structure of similarities and differences in the vocabularies, practices, and orders of worth of design across the different disciplines.

Discussion

We began the article by asking the question: *What is it about design that makes it possible for interdisciplinary interactions to emerge given that the term itself has multiple meanings?* Confirming the polysemy of this term our investigation revealed that the meaning accorded to design depends on the context of its use—i.e., the vocabularies, practices, and orders of worth that constitute the various design games at play. By itself, such polysemy ought to generate isolated pockets that only *interface* with one another, with design serving as a boundary object enabling co-ordination without the need for consensus and intense interactions among individuals across different disciplines (Star and Griesemer 1989). The conceptual underpinning for such an approach is the decomposition of complex problems into parts (Simon 1996), with each part addressed by a specific group that only interfaces with others across standardized boundaries. Such a view of design continues to function as an important organizing principle in management, ranging from the design of assembly lines using principles of scientific management (Taylor 1911) to the development of products and services following modularity principles (Baldwin and Clark 2000; Sanchez and Mahoney 1996; Ulrich 1995).

However, our analysis revealed a different notion of design, one in which individuals do not just *interface* but instead *interact* with one another, and in the process, open up the black boxed design module. In this design approach, individuals come together not despite but *because of* differences in their vocabularies, practices, and orders of worth. So, what motivates these individuals with different notions of design to come together and interact? Our analysis suggests that individuals do so because design evokes reflexivity (Cunliffe 2003; Cunliffe and Jun 2005), i.e., an awareness of the assumptions and biases in one's own design approach leads to a realization that any notion of design is always incomplete, and design initiatives are always ongoing and full of future potentialities (Garud et al. 2008).

This interactional view of design resonates with the second notion of design in Simon's work, i.e., the emergence of design options in and through interactions, a notion also pursued by scholars in management studying design (e.g., Boland and Collopy 2004; Dunbar and Starbuck 2006; Gruber et al. 2015). Not surprisingly, Simon called his work on design as the *Sciences of the Artificial* focused on "devis[ing] courses of action aimed at changing existing situations into preferred ones" (Simon 1996: 111). More recently, scholars building on Simon's second view of design have also explored how such interactions function as a social resource that holds the capacity to expand rather than bound rationality (Hatchuel 2001).

Such interactional views of design have also been advocated in practice. For instance, Takeuchi and Nonaka (1986) contrasted the linear interfacing approach that emerges from classical notions of design against a more complex interactional approach. Using sports metaphors, they likened the former to a relay race and the latter to a rugby game. Similarly, Romme and Endenburg (2006) offered the notion of organizational decisions occurring through a "circular design" process, wherein the inputs of individuals from one circle links with other circles to generate informed consent. Fostering continued interactions among parties (with often competing interests) is also central to the design and formation of collaborative communities for business development in non-preferential economic zones such as Greenland (Kadenic 2017).

The interactional view of design surfaces its own complexities though. For instance, the rugby approach to design is messy and inherently unstable, as the authors themselves point out (Takeuchi and Nonaka 1986). So, what then allows such an interactional process to cohere? Our analysis of the data from the *Center* suggests several related mechanisms. One of them is the presence of common vocabularies across individuals from different disciplines. The other is the presence of overlaps in the practices and the orders of worth of design. Together, these attributes result in the emergence of robust designs (Hargadon and Douglas 2001), i.e., designs that are both a participative process and an interactional outcome, one that bear the imprints of designers from multiple disciplines and social groups.

What are the implications of these findings? The world increasingly confronts "wicked problems" (Buchanan 1992; Rittel and Webber 1974), i.e., problems that have no definite formulation and are characterized by complex interdependencies, such as the challenges posed by sustainability (Reinders et al. 2012), innovation and new product development (Brown 2009; Takeuchi and Nonaka 1986). Such problems demand a pragmatic focus on generating actionable knowledge (Romme 2003) that takes into consideration worldviews shaped by different practices and orders of worth. It is to address issues of this kind that design has surfaced in popularity, allowing individuals from different social groups to meaningfully interact and generate discussion over "matters of concerns" (Latour 2004) as much as over "matters of facts". Design is a concept that sets the stage for reflexive individuals to come together because of their differences to jointly formulate and explore problems and solutions.

Contributions

The finding of this study on how design manifests itself as a complex network of similarities and differences in the vocabularies, practices, and orders of worth across disciplines offers several contributions to the literature on design, which we highlight below. Design scholars emphasize the need to pay attention to vocabularies that designers use (Boland and Collopy 2004). We extend this conversation through a more systematic examination of vocabularies used by designers across different disciplines to highlight the similarities and differences in how they understand design. An important contribution of this study is to introduce the concept of design games, which alludes to not just vocabularies, but also the practices and orders of worth that they constitute. Further, inquiring into how it is that designers from different disciplines cohere in interdisciplinary forums despite their disciplinary differences, we found designers to be reflexive (Cunliffe 2003; Cunliffe and Jun 2005), an attribute that complements the presence of common ground and the interlacing of practices and orders of worth of design across disciplines. Reflexivity consists of the recognition by individuals that any notion of design is incomplete, and therefore the importance of inputs from people with other disciplinary backgrounds. By incorporating reflexivity into design games, we advance one compelling reason why interdisciplinary forums and projects on design cohere and do not fragment.

Our findings integrate the growing literature on the design approach focusing on interdisciplinary interactions with the literature on boundary objects (Star and Griesemer 1989). However, in contrast to boundary objects, we found that design is an *interactive boundary object* that not only coordinates the activities of individuals across disciplinary boundaries but also induces interaction. Whereas boundary objects were conceptualized to enable interfacing of individuals from different social worlds or communities of practice (Brown and Duguid 1991; Lave and Wenger 1991; Wenger 1998) *without* the need for intense interactions, interactive boundary objects such as design view intense engagements not to be problematic, but instead generative of novel outcomes. Such interactions do not just transfer knowledge from different perspectives, but also enable knowledge transformation whereby the meaning of design is always emerging in and through interactions as designers co-orient and co-inform each other across disciplinary boundaries.

Overall, these findings shed light on the link between design and emergence (Garud et al. 2008; Hunter et al. 2020), and how particular cultures can be created through design (Koçak and Puranam 2018). Through our study of an interdisciplinary *Center for Design*, we found that design can foster a culture of interdisciplinary interactions by invoking reflexivity. This is because design functions as an interactive boundary object, wherein individuals are motivated to interact with one another not despite but *because of* their differences in meaning. As there is no one meaning of design, individuals are attentive to the design practices and the orders of worth of others that they are interacting with. Such interactions provide the foundations of a culture centered on collaboration and learning (Elsbach and Stigliani 2018). Indeed, such reflexive interactions extend beyond the collaborating individuals to also include the perspectives of others (such as users) in ways that the future possibilities that are emerging and being co-created bear the inputs of all stakeholders:

> *Dealing with emergence requires designers and managers to understand their designs in relation to those who will enact them in practice. It requires a commitment to co-create with these others whose lives will be shaped and changed by their engagement with the designed world. It requires an inquiry into what and whose desired futures are to be enabled and a willingness to be open to and be changed by that understanding. It suggests engaging the respectful interaction among people that can lead to transformed meanings, identities, and intersubjectivity. (Orlikowski 2004 : 94).*

Indeed, the increasing use of the term 'design' by academics and practitioners alike when engaging with issues such as environmental sustainability and public health concerns speaks to this promise of design to generate meaningful solutions to these world's complex problems (e.g., Centers of Disease Control and Prevention 2018; TUDelft 2020; United Nations Environment Programme 2009). In this regard, Garud and Karnøe (2003) showed how a design approach facilitating interactions between actors with different perspectives was critical for the emergence of wind turbines in Denmark.

Boundary conditions, limitations and future research

The empirical site for our study was a *Center for Design*, which was established to promote interdisciplinary collaboration. Hence, the individuals at the *Center* that we interviewed were self-selected individuals interested in exploring interdisciplinary work. While an openness and commitment to interdisciplinary collaboration is an important boundary condition for the set of findings we have presented, our study offers a model *of* interdisciplinary collaboration to serve as a model *for* other settings, especially ones where such interdisciplinary collaboration is missing. A key ingredient for success, as the findings highlight, is the cultivation of reflexivity to the perspective of others by the individuals involved, which emerges through frequent interactions.

Our study has other features that present opportunities for future research on design. First, we have shown how interlacing (involving similarities and differences) in vocabularies, practices and orders of worth, served as a glue which held members of an interdisciplinary design *Center* together to foster generative collaborative interactions. It might be the case that such interlacing could also lead to fragmenting and conflict. While we did not observe this outcome, future studies could examine how similarities and differences in the vocabularies, practices and orders of worth might lead to generative or problematic interactions. Second, our findings related to design games presents an opportunity to study the evolution of the interlaced structure involving the vocabularies, practices and orders of worth such as those used by the informants we studied. This is an important question, which future research can also explore. Third, our findings around reflexivity suggest that the desire to collaborate is not wholly determined by a logic of consequences based on success or failure alone. However, future studies could explore whether and how collaboration in the context of interdisciplinary design is contingent on the outcomes realized during the design process. Fourth, given our focus on analyzing individual designers, we have emphasized reflexivity as the generative mechanism inducing interdisciplinary interactions while underplaying the role of organizational processes, protocols and infrastructures that generate and sustain such interactions (Snow et al. 2017). Future research can investigate how these organizational structures enable or constrain such mechanisms of self-reflexivity.

Conclusion

We close by returning to the question that motivated this study—*What is it about design that makes it possible for interdisciplinary interactions to emerge given that the term itself has multiple meanings?* The findings from this study confirmed the presence of differences in meanings across disciplines. At the same time, it also showcased agreement amongst participants that design is an activity that benefits from the interactions between actors who approach the activity from different vantage points. Driving such interactions is reflexivity on the part of actors—they all realize that their expertise is but one part of a larger puzzle, which itself emerges in and through interactions. Future studies can further examine the nature of such boundary interactions and how they can generate novel outcomes to complex problems.

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Competing interests
The authors declare that they have no competing interests.

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Appendices

Appendix A

Details of informants

Informant	Designation	Area of research
1	Computer scientist	Programing language design, mathematical logic
2	Management expert 1	Organization design, innovation management
3	Management expert 2	Customer driven design, simulation, new product development
4	Architect	Architectural design, sustainable design, green design
5	Architectural engineer	Construction visualization research
6	Engineering designer 1	Complex system design, product family design, design optimization
7	Engineering designer 2	Human factors, human computer interaction, innovative engineering design
8	Engineering designer 3	System design, innovation in engineering design
9	Engineering designer 4	Design theory, social ethics of design, open source design
10	Industrial psychologist	Creativity, innovation management, organizational climate
11	Patent lawyer	Intellectual property law, technology law, patent law
12	Civil engineer	Water resource management, visualization of risks and tradeoffs within complex systems, decision support, multi-objective optimization
13	Industrial engineer	Human factors, human machine interaction, display visualization, discrete events simulation, human in the loop
14	Mechanical engineer	Product design, product family design, engineering design

Appendix B

Interview protocol

We followed an open-ended semi-structured interview protocol that were guided by the following questions:

1 What do you do as a designer?
2 Can you describe what it means to 'design' in your field?
3 What words come to mind when you think about the word 'design'?
4 How do you evaluate designs?
5 How is your role as a designer seen by others? Is it accurate?
6 What other kinds of designers do you interact with? What is the nature of that interaction?
7 Is there a notion of design that is not consistent with yours? Antithetical to yours?
8 Who do you compete with?
9 What enables your work?
10 What constrains your work?

In all interviews, there were two people present. All interviews were recorded and transcribed.

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