ICED13
INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN, ICED13
19-22 AUGUST 2013, SUNGKYUNKWAN UNIVERSITY, SEOUL, KOREA

CONTEXT, COLLABORATION AND COMPLEXITY IN DESIGNING: THE PIVOTAL ROLE OF COGNITIVE ARTIFACTS

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ABSTRACT

Designing progresses through continuous refinement of models. In today's design practice, these models get created and refined by multi-cultural, multidisciplinary teams that speak different languages, whether these languages are spoken language, disciplinary, or organizational language. When these people come together, they create, negotiate, evolve, and manage a nascent language with which they communicate the meaning of the product they design. The nascent language is a pidgin articulated through cognitive artifacts. Thus their role is essential to designing and their management is critical to successful completion of the process. In contrast, their mismanagement quickly presents itself as design failures, sometimes catastrophic. Given their role, it is critical to understand what cognitive artifacts are, how they are constructed, and how they should be managed. This marks a shift from focusing on the artifact to the process of designing as a social, negotiated process. Such a view results in conceiving designing as a complex and emergent process with implications for design research, practice and pedagogy.

Keywords: design theory, collaborative design, knowledge management

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1 INTRODUCTION

> "We didn't realize that pillowcases are a different size in Germany." This is what the former head of the now defunct German operations of a retail giant from USA had to say about their failure (Ghemawat, 2007).

The last few decades have transformed the world of design from localized markets to globalized markets for products and services. No product today created for one market can be plopped into another society without localized knowledge as well as local skills. This shift in mobilization of knowledge has the dimensions of culture, language, and work practices that have to be taken into account in creating new products and services. The imperative to manage this new level of complexity is primarily driven by the need to avoid design disasters and to remain innovative and competitive.

What this means is to understand and shift the focus on cross-cultural communication and coordination using cognitive artifacts.

This paper looks at the role and nature of cognitive artifacts in mediating social interactions across disciplinary, social, geographic and cultural boundaries. Given the level and kinds of social interactions and underlying knowledge bases in managing and innovating in global enterprises, this paper provides an opportunity to address the nature of these cognitive artifacts, with a focus on computational cognitive artifacts. Further, this paper will address what insights can design theories provide and what they lack in explaining and guiding the development of these cognitive artifacts.

2 DIVERSITY OF COGNITIVE ARTIFACTS IN GLOBALLY DISTRIBUTED ORGANIZATIONS

Social interactions in designing endeavors have been mediated by cognitive artifacts since time immemorial. Cognitive artifacts include drawings, sketches, and the rules of layout of buildings in systems such as Hammurabi's building codes, Vaastu from India and Feng Shui from China; they are encodings of the practices of engineering houses, towns, and cities. Cognitive artifacts are representations of design knowledge and methods, prototypes, past designs and other representations created during designing. They convey knowledge embedded in them; act as languages to transmit that knowledge between people. Traditionally artisans and guilds maintained many of these representations; over time some of these cognitive artifacts have become more formal, and some have disappeared. The importance and historical role of drawings, sketches and visual representations in engineering is best recounted in Eugene Ferguson's book, "The Engineer and the Mind's Eye" (Ferguson, 1994). He claims that the rise of the engineer from the artisan can be linked to the introduction of this mediating visual representational language. An investigation of the world of engineering drawings has demonstrated the existence of different dialects, such as first angle projection versus third angle projection that are followed in different parts of the world (Belofsky, 1991; Mori & Belofsky, 1992). Their usage illustrates the cultural origins of these dialects including colonization that shaped the adoption of these dialects. Different dialects in cognitive artifacts are to be expected as we have different spoken languages and their dialects.

Brunelleschi, the great Italian architect of the Church of Santa del Maria in Florence, was the first to take advantage of the development of linear perspective and other developments in representing geometrical objects of his time to distribute and divide the labor to realize his competitive advantage and preserve it (Ferguson, 1994). Brunelleschi clearly understood the value of cognitive artifacts such as drawings in coordinating work and divided it to retain control over his design. Today the scale and scope of distributed work is vastly more complex, requiring the need for cognitive artifacts not just for the exchange of knowledge structures but also, cognitive artifacts for co-ordination of work and subsequently, for the synchronization of systems of systems.

In collaborative work not just artifacts such as drawings and process plans play the mediating role but so do other cognitive artifacts, such as information, formal and physical models of the artifacts that represent the knowledge structures whose vocabulary may vary across cultures (Subrahmanian, 2007). In our earlier work, we identified the role of boundary objects (cognitive artifacts) that bridge across functional and disciplinary boundaries and the consequences of their failure and reconstruction (Subrahmanian 2003a; Eckert and Bojout, 2003). There are other documented failures when the cognitive artifacts were misaligned (CAD Systems) as in the case of production glitches during the development of the Airbus A380. So the issue of dialects, tools and variation in skills and local training across the globe plays a critical role in the ability to use and interpret these cognitive artifacts.

Two questions are critical to addressing the use of these cognitive artifacts in the context of global design and engineering. They are: 1) what is the nature of these cognitive artifacts and their variations? and 2) what are the needs of designers in creating and managing these variety of cognitive artifacts for mediation in such complex organizational structures? In addressing these questions, we need to examine what light can design theories provide and what they lack in explaining and guiding the development of these cognitive artifacts. We address these questions based on our studies of globally distributed companies such as ABB and ADTranz (Subrahmanian, 2000) and other studies. We also reference and draw from a number of studies in cognitive science, sociology, anthropology and software engineering on the nature of representations and collaborative work to answer our questions.

2.1. Nature and diversity of cognitive artifacts

Most conceptions of classification of objects in cognitive science subscribe to the Aristotelian conception of an existing predetermined order. This discovered order becomes the cornerstone of the organization of objects (Fodor, 1983). This assumption has dominated the idea of representations of knowledge and goes even further to argue that these representations also correspond to the internal representations in the mind. The assumption of a natural order of things has been challenged within cognitive science and by more recent conceptions of pragmatic philosophy. In cognitive science, the work of Rosch, Lakoff, Varela, and others make the case from empirical studies that classificatory structures as cognitive artifacts are socially and culturally determined and are purposeful from a particular perspective (Lakoff, 1987;Varela et al., 1991).

Unger, a pragmatic philosopher and jurist, has argued that even the pragmatic philosophy of Pierce and Dewey are trapped in their view of the existence of the natural order of things (Unger, 2007). He, in line with cognitive scientists such as Rosch, contends that classificatory structures are constructed for pragmatic purposes based on the needs and perspectives within a cultural social context. Jay Gould, a paleontologist, has also identified through fossil records that the traditional classification of species, the assumed 'predetermined' order, does not correspond to classification based on the appearance of the species (Gould, 1983).

A very familiar cognitive artifact we are aware of is Mendeleev's periodic table of chemical elements. The periodic table provides us with classification of materials that occur in nature. However, there are other classifications that emphasize different properties (Scerri, 2008) and consequently, the classification is not unique, nor necessarily reflects something built-in in nature. Our own studies of materials' properties and engineering practice have confirmed these observations (Sargent et al., 1992).

Beyond classificatory structures, representations that are formal such as mathematical equations, rules and logic, and numerous other graph based representations of knowledge have multiple ways of presenting themselves as cognitive artifacts for use in social interactions. For example, Reich and Shai show that systems and methods in many engineering and other disciplines could be encoded with different combinatorial representations (Reich and Shai, 2012). The encoding of formal and informal representations, sketches, drawings, including physical objects pervade in enabling social interactions in the act of designing and there is clearly no single accepted way to classify and represent them (Subrahmanian et al., 1993).

Recent cognitive studies of software engineering, where design uses mainly symbolic and diagrammatic cognitive artifacts that are translated into symbolic structures for processing them, have shown the creation and use of cognitive artifacts as mediators in software design (Visser, 2006). For example, in his work with software engineers, Edelman has moved away from using representations on the computer to the use of shapes and their arrangement in mediating and arriving at the requirements specification of software (Edelman & Currano, 2011).

The above role of diversity and multiplicity of cognitive artifacts constructed for the pragmatic purposes of mediation and creation of shared meaning leads us to the following question: "When multiple perspectives and disciplines come together in design, how do they coalesce together to synthesize the *known* with the *speculation of the unknown* and its verification in the creation of designed artifacts?"

2.2. Needs of designers in creating and managing cognitive artifacts

We have shown that throughout the design process a diversity and variety of these cognitive artifacts are created, modified and evolved. It is not possible to anticipate all the requirements for cognitive artifacts as they emerge as needed in a discipline or a domain. These representational cognitive artifacts historically were encoded on paper, parchment and other physical forms using diagrams, text and formal symbols. The ability to manipulate them was localized and the inter-linkages between the different representational structures were cumbersome and difficult to manage. With the advent of computers and geographical dispersion of work the need for new and varied cognitive artifacts have increased, making it even more difficult to anticipate the cognitive artifact needs in designing. To satisfy the need for managing cognitive artifacts, any information model based support will have to be flexible, malleable and provide the ability to go across one set of abstractions to create other set of cognitive artifacts. In turn, this new cognitive artifact will serve the purpose of encoding a particular perspective and meaning that was not known before.

3 A MULTI-DISCIPLINARY CONVERSATION

A socio-linguistic view of human communication provides us the following insights into the communication process. In this conception, each discipline can be seen as a language with its own vocabulary and when these languages talk to each other, a common ground is created (Clark, 1996). As these different languages try to communicate with each other, what arises is a pidgin that could transform into a creole, a nascent language. In other words, the common ground that manifests in a pidgin/creole.

In his analysis of the evolution of Physics, Bruce Gregory, traces the evolution of physics from Copernican world view of physics to the modern high energy physics as the evolution of a language that traces the reconciliation of the models of the universe with the anomalies that force the creation of a new language for the new model of the universe (Gregory, 1988).

Galison, in his exploration of anthropological account of high energy physics argues that physics, from the days when it was the work of individual physicists, has moved to be a collaborative effort of physicists, computational modelers and engineers to verify their theories (Galison, 1992). He claims that the interpretation of the patterns of events in images that are created by large scale experiments verify theories on comparison with patterns created through computational modeling and logic. Galison gives importance to the role of image beyond logic in high energy physics. Further, while identifying the role of the image as a cognitive artifact, his account recognizes that practitioners of different disciplines come together with different languages including when designing the experiment, and they bridge the gap through the creation of pidgins that may take the form of creoles.

How is this pidgin/creole generated? Theories from cognitive science provide insights into this process. This common ground is created through the process of c-induction and n-induction where n-induction provides the basis for observation of phenomena (natural and otherwise) and c-induction leads to co-operative alignment of language and linguistic structures to be able to participate in the community (Chater and Christiansen, 2010). The evolution of language takes place through these two processes operating together to identify and incorporate new phenomena that have been observed into the language. Recently reported work by Dong et al. (2012) used methods such as latent-semantic indexing from linguistics to characterize evolving team mental models as shared linguistic terms. While being classroom studies, they support our view of emergent linguistic structures.

The communication and the ensuing negotiation that happens during shared language creation give rise to a rhetorical view of the designing process (Bucciarelli, 1994; Buchanan & Margolin, 1995). The pidgin/creole here is not restricted to words. It includes all kinds of representations such as drawings, visual aids, numeric data, questionnaires, and all other such media that can help further the dialogue - in essence, all cognitive artifacts. These cognitive artifacts allow designers to make sense of what is going on; in other words, designing is a process of sensemaking. What is the result of such a process?

4 ARTIFACT AS A NARRATIVE

This transdisciplinary pidgin/creole is used to articulate a narrative – the narrative of the artifact, of the system being designed. We call this a ‘theory of the artifact’ (Reddy et al., 1998). This narrative is held collectively – it drives sensemaking, it helps dialogue, it allows designing to progress. As designing progresses, the theory of the artifact constantly undergoes changes, reflecting the continuous refinement of what is being designed. Not only that, the theory of the artifact reflects the constant shift in what is known and what is unknown, in other words the state of the theory of the artifact maps to the knowledge available for that design.

Condensed matter physicist Ziman calls for such a transdisciplinary narrative building in addressing complex problems that necessarily involve multiple disciplines (Ziman, 2003). The philosopher of science Feyarabend, in turn, calls for an approach that views science as poetics, as a rhetoric encompassing multiple sources of knowledge (Feyerabend & Oberheim, 2011). Their views find resonance in the work of sociologist of science Morin, who conceived of science itself as a complex and emergent process (Morin, 2007). Instead of breaking a system into its constituent parts, Morin calls for focusing on the relationship between order and disorder mediated by the principle of organization, which means looking at the implications of the part and the whole simultaneously influencing each other. Our conception of designing, as a complex and emergent process involving multiple disciplines, is similar.

5 EXAMPLES

Interaction design is a very recent design discipline. We use the work of Moggridge, a pioneer in the creation of interaction design with numerous others. The evolution of this field is quite revealing in its progression as recorded through recollections of the pioneers and his commentary in Moggridge's book on "Designing Interactions" (Moggridge, 2007). The field as seen through the evolution of IDEO and other entities in California illustrates the interaction of different disciplines of cognitive science, ergonomics, computer science, electrical engineering and more recently human computer interaction. In describing the evolution, Moggridge points out that in the early days when he introduced a human ergonomist, very few of the projects were willing to engage her besides his project but over time, many other projects also started using the ergonomist. As more disciplines started integrating onto this effort of interaction design, his group at IDEO catalogued 50 methods that were being used. They made a pack of cards representing the methods. Thereafter, all projects were described through the set of cards that were used in a particular interaction design project. Each of these methods derived from the multiple disciplines had its own set of representations and purpose it served. This example is just the tip of the iceberg as the discovery of the known and unknown went beyond in the work of Brenda Laurel, who used methods from theatre such as 'improv' to imagine the unknown (Laurel, 1991).

This conception of design as a narrative when seen through the creative act of a famous Bollywood music director R.D. Burman is one of his ability to take different orders of musical structures that were present in Western classical, folk and popular music along with Indian classical and folk music to create mixtures (reordering) of rhythm and melodies that enchanted the Indian public across linguistic boundaries as shown in the movie Pancham Unmixed. We have recently uncovered a similar approach through a preliminary set of interviews and observations of a dance company Nrityagram whose recent production Samhara was a conversation between Odissi, an Indian classical dance form, and Kandyan, a Sri Lankan dance form.

6 FUNDAMENTAL THESIS

The fundamental thesis of this paper is that designing an artifact as seen from multiple cultural knowledge and disciplinary perspectives brings together multitudes of classifications and cognitive artifacts from its own conception of mediation and purposefulness. The result of the designing process is a narrative that is causal and meaningful but not necessarily formal, rather, often informal. This narrative is articulated through a pidgin and/or creole that crosses boundaries along with its attendant classifications and new classifications and representations.

These cognitive artifacts, these classificatory structures and models, can be divided into two categories: ones that are used in the design process and ones that are used for designing. An example of the first category would be timesheets and process charts and of the other would be sketches and plans. Both these classes of artifacts are intimately linked to each other and so any support for the designing process should acknowledge and embrace these cross-linkages as well as be flexible to let these cognitive artifacts change and evolve.

Our own studies point out to the insufficiency of most computational representational structures adopted by computer scientists to correspond to the cognitive needs of design work practice (Krogh et al., 1996). Beside our own studies, other studies too have made the case that what engineers need are flexible and malleable cognitive artifacts that reflect the variety of local practices that are part of the complexity of globalized enterprises. The enormity of this demand is referred to as 'Asking for the Moon', in a recent paper (Schmidt et al., 2009).

While pointing to their insufficiency for most part, it is interesting to note that within computer science the debate over flexible and malleable classificatory structures can be seen (Taivalsaari, 1996). This debate exists in the sub-communities of computer science such as programming languages, data base integration and design and less so in the world of ontologies in artificial intelligence.

For the most part, especially academic communities working on computational support for engineering design have adopted without questioning predefined classificatory structures from computer science in dealing with knowledge structures without looking into engineering practice. Most early empirical studies were rooted mainly in studying individual designers; subsequently, some were on information exchange and communication, and for most part they being classroom studies did not have sufficient empirical basis to enter this debate. This has led to proliferation of several toy systems and very rigid structures in the development of computational design support systems. They have the same fate as many expert systems approaches that were rigid and brittle due to their assumptions about knowledge work (Hatchuel & Weil, 1995). The use of rigid classificatory structures continues in spite of early work on the need for a different model of computational knowledge structures from an engineering perspective especially that of Borning's work on ThingLab (Borning, 1981).

The richness and dynamics of cognitive artifacts in social interactions in design of any kind come from the cognitive ability to operate and compose at different levels of abstraction simultaneously. The process of creating knowledge in science, design or arts is a complex dynamic evolving system that when subjected to different kinds of perturbations will lead to different states that are new and unpredictable. This is in order to *assemble the known*, with the creation of structures and processes required to *discover the unknown*. How they evolve depend on how they come together rhetorically, propositionally, and formally in creating a narrative of the artifact that is causal and meaningful in the context of its use.

Today computational support has enhanced the propositional and some formal narrative ability for concept design, engineering analysis and design and production in segments. This is primarily at the level of detailing through the use of CAD tools, but less in the ability to compose, recompose, revise, and standardize at the centralized level, with decentralized flexibility of composition of new cognitive artifacts across the abstraction levels.

7 *N*-DIM

What is needed is a design support system that allows for flexibility and cross-linkages in developing and maintaining both classes of cognitive artifacts, those used in designing and those for designing. This need was recognized by studies in engineering without having a singular theoretical lens that could explain the observed processes. Given the richness of the act of designing we have drawn up on a number of theories to create a narrative that explains and describe the spectrum of designing from the mundane to the magnificent (Subrahmanian et al., 2011). The unquestioned role of cognitive artifacts as information bearing entities that mediate communication and creation of shared meaning brings us to the question of how we may support their creation, evolution and, use.

Cognitive artifacts participate in multiple classificatory structures and classificatory structures are themselves cognitive artifacts. In a sense, this is similar to the dynamics between different parts that constitute multiple partial wholes. The parts influence the whole and vice-versa. These dynamics has to be facilitated in the designing process. Given these dynamics, the ability to create inter-linkages has to be flexible. The inter-linkages are nothing but informal and formal modeling languages or pidgins and creoles. This requirement stems from the human ability to compose things from disparate levels in abstraction and granularity. In design, when humans confront complex problems requiring creative solutions, they exercise their representation and compositions abilities to extremes. The implications of these observations have led us to conceive of a conceptual *flat space* of objects.

The function of a conceptual flat space is twofold. First, it puts all objects on a similar status, without predetermined order or structure. Second, it provides the ability at the individual and the social level to compose formal and informal structures on demand from components whose granularity and abstraction levels can be determined as needed. These components can be in a variety of media, including text, sketch, images, voice, and so on. The compositions created out of these components can be domain-based classifications, descriptions in the form of information models, and new components based on existing ones (Levy et al., 1993; Reich et al., 1999; Subrahmanian et al., 1997). One designer from an organization could create for her own use a personal process language, using some structured composition of objects, called modeling language in *n*-dim. She could then share it among her team members, making it a pidgin. At the same time, members of other teams in the same organization could create their own pidgins – other models of processes. At some point, the organization adopts one of these languages, and further refines it to become the organization best practice – a creole.

By adopting such an approach, *n*-dim allows for, creating, managing, sharing and reusing of artifact theories. It even allows for creating and evolving the languages for creating artifact theories. In fact, it is not a surprise that the same capabilities apply to the creation of languages and products as languages are themselves products. In other words, *n*-dim allows for both knowledge use as well as knowledge building, while we are not aware of any other system with similar capabilities.

With these capabilities, *n*-dim allows designers to manage the process of designing without neglecting the needs of the people designing together. The repository that gets created by designers using *n*-dim is a trace of all activities exercised in developing a product and the variety of information objects forms rich theory of the artifact. All this richness of information can then be studied to improve our fundamental thesis as well as *n*-dim (Subrahmanian et al., 1997; Reich et al., 1999). As such, *n*-dim also helps bridging the research-practice gap; again, this is not a surprise, our thesis is again a product and its creation is done and supported similarly to other products.

Some of the underlying principles of *n*-dim were incorporated in a collaborative shared design space that was transferred for use in practice in the company that sponsored the research (Davis et.al, 2001). The work of Wynn, Nair and Clarkson (2009) on the P3 platform for a modeling environment shares a lot of its characteristics that are a part of the n-dim approach to modeling. Currently the work on *n*-dim is an attempt at a formal definition of *n*-dim structures to move towards a platform for the experimentation in flexible organization of multiple sources of information.

8 WHAT CAN DESIGN THEORIES TELL US?

Thus far we have described the design process as managing the known, transforming the unknown to the known and synthesizing the new known. This process involves social negotiations and interactions mediated by underlying cognitive artifacts. The process of designing therefore necessarily includes the creation, modification, maintenance and evolution of these cognitive artifacts.

Universal design theories abstract certain universal aspects of designing, each from a different lens. GDT is a topological mapping from functional requirements to attributes (Yoshikawa, 1981). This is in similar spirit to design as a generalized problem solving mechanism of Simon where the attributes are the ends and the functions are the means. The theory of Braha and Reich is a more elaborate version where the co-evolution of the requirements (functions) and the solution is addressed (Braha & Reich, 2003). Recognizing that the earlier theories do not explain the process of innovation has resulted in the identification of the interplay between concept and knowledge space, which is addressed by C-K theory (Hatchuel & Weil, 2003). C-K theory has been successful in practice because of its focus on knowledge and its assemblage through its KCP method. KCP method has recognized the importance of diversity of knowledge and its propensity for new concepts. More recent work by C-K theorists in connecting cognition has recognized that stimulus in the form of exemplars from other disciplines or perspectives enhance the potential for novel and creative solutions (Agogue et al., 2011). This is an important contribution as it points to the role of introducing new perspectives and knowledge to create new concepts based on the knowledge space. Nevertheless, C-K and all other theories mentioned do not delve into the role of cognitive artifacts that are critical in practice and for continuous innovation, especially in a globalized environment. It is not surprising because it is not under the scope of these theories. Visser's work in software engineering design has recently moved in this direction; however, they do not have an explicit theory of design beyond the recognition that design is one but has many forms and different sets of cognitive artifacts and that they evolve over time (Visser, 2009).

We view these different theories and their attendant models as being cognitive artifacts themselves. They aid in deepening our debates around designing and they evolve as we test them against practice and against each other (Hatchuel et al., 2011). For instance, C-K theory has created a cognitive artifact that describes the C-space and the K-space populated by their respective topological structures that cross different levels of abstractions of knowledge. In doing so, C-K theory has opened the door for elaborating the process of new knowledge creation, adding to the vocabulary and cognitive structures we use to understand the designing process.

Just as the theory of the artifact is a contextual theory that is a causal and logical narrative, what we are building toward is a similar narrative to describe the designing process. The process of building this narrative is mediated by cognitive artifacts that range from rhetorical perspectives on design to formal theories of design and everything in between including empirical evidence. With varying scopes, this narrative can be woven to create other composite narratives that work in guiding the practice, education and research in design. Viewed in this fashion, the creation of a design theory, a theory of the act of designing, and the theory of the artifact are different manifestations of the same act that is recursive and contextual: the act of designing. It is perhaps due to this recursive nature that the study of design is challenging and wicked.

9 DISCUSSION

The focus of the paper has been on social interactions mediated by cognitive artifacts in general and computational cognitive artifacts in specific. The thesis forwarded in this paper is that cognitive artifacts get created, used, evolved and managed as part of designing. In fact, a design before production is also a cognitive artifact, and so is the product itself; cognitive artifacts are constantly designed to further serve as tools in subsequent design steps, until design terminates with a product, only to start again with the next product version. When the common ground that sustains the meanings embedded in these artifacts is corrupted, the potential for design failures and inefficiency in the design of products increases. Further, in designing a product, the cross-disciplinary and trans-geographical nature of the product development in today's world requires that creating and maintaining these cognitive artifacts become critical. While most design theories and models of design concentrate on the characterization of the product or process as models in formal terms they have not attempted to characterize the socio-linguistic process that is at the heart of designing. This shift from *defining* these cognitive artifacts to *how they are created and used* changes the way we look at the process of designing (Subrahmanian et al., 2011). This shift in focus implies that we pay attention to cognitive artifacts on a continuous basis to maintain and evolve their meanings in the space of interactions across and within disciplinary and functional perspectives. We have identified the causes and consequences of these breakdowns in specific instances elsewhere in detail – they permeate and impact our life in ways that we can no longer ignore them (e.g., economic crisis, Fukushima disaster) (Subrahmanian et al., 2003a, 2011).

We note that the aforementioned characteristics of design cannot be escaped even for a sole designer working alone. The extended time it takes to conceive an idea and execute its design, and the learning that inherently takes place while designing, cause even a single designer to evolve her own classification structures and meaning of information objects and models - in essence, collaborating with herself.

Beyond breakdowns in industrial context, the need to educate designers in the nature of the socio-linguistic processes becomes imperative. The goal of this effort would be to teach students not only to use design methods and other cognitive artifacts but also to reflect and understand the role they play and be vigilant in their interpretations. Through this process we would have shifted the focus from just the design of a product in teaching design to the ability to reflect on the cognitive artifacts of their respective disciplines and those at boundaries between the disciplinary, functional and cultural perspectives that pervade today's global design and engineering. This approach would provide a way to operationalize Schon's notion of reflective processes in design with a theoretical underpinning.

In our engineering design courses we emphasize the importance of examining any method or representation aka cognitive artifacts for its use in the context of the design problem. We train a group of students every week to teach their peers one or more design method as applied to their project. After teaching the method, each person in the teaching group that taught the class disperse and work with each of the other individual project group teaching and modifying it if necessary with them to apply to their context (Subrahmanian et al., 2003b). These are just early experiments but further explorations are still open.

How we teach the concepts of cognitive artifacts and representations and create awareness of the theoretical understanding of the process of designing is left open and requires further exploration. We have opened the door to understanding designing as training an engineer not just in technical terms but also the socio-cognitive aspects of designing. This shift in education will lead to recognition of designer as a cognitive-sociological creature where reflections in and on practice includes the analysis, use and linguistic alignments of the cognitive artifacts at the interfaces.

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