MONITORING DESIGN THINKING THROUGH IN-SITU INTERVENTIONS

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ABSTRACT
Building on existing knowledge of design and design thinking we apply several other fields of knowledge such as emotion coding, improvisation, ethnography, social psychology, and decision analysis into key metrics we call Design Thinking Metrics (DTM). We applied these metrics to analyze and assess videos of software design teams. We then conducted a workshop series with a professional software design team to use DTM as a perceptual tool to test a number of action-repertoires that could be used to improve Design Thinking practice. The result is multi-disciplinary perceptual monitoring of design thinking activity in professional software practice.

Keywords: interaction analysis, team performance, design metrics, software design

1 INTRODUCTION
Design thinking [1] is the way designers approach messy situations [2] in order to create radical innovations. With the messiness of the situation and designers' intention to realize novel ideas, design thinking is a unique practice without rigid procedures. How do we understand such a complex dynamic activity? Furthermore how do we engage with practitioners in improving this complex dynamic activity?

Researchers trying to understand design thinking are much like the blind men trying to make sense of an elephant in a popular par-able. We are blind on two fronts: first is the limit of our disciplinary lens used to study design thinking, and the second is an insistence on using third person methodology that eliminates one from actively engaging with the phenomenon to be studied. In this chapter, we present an attempt to overcome these two limitations through the combined used of a concurrent multi-disciplinary approach, and in-situ interventions into the practice of design thinking in software de-sign teams.

We chose software design as a domain for our inquiry. While traditional product development teams have experienced success at adopting design-thinking methods, software development teams have encountered difficulty. Investigating the reasons for this phenomenon and developing effective interventions could potentially propel radical innovation in software. This could have far reaching impact on society given how software, in particular enterprise software, has transformed the way people work and has contributed immensely to economic progress.

2 RESEARCH QUESTIONS
The research focus for this study evolved out of authors' desire to take their academic perspectives from the laboratory into the field. The questions that initiated the study were generative design questions [3] intended to build new observations and hypotheses.

The research team focused efforts from their multiple perspectives. Spurred by the nature of doctoral work of the researchers that emphasized direct empirical observation and a software design focus by the nature of this research program, the research team converged on the following guiding questions:

> *Research Question 1: What can we learn about Design Thinking by having a team of researchers with multiple perspectives observe practitioners in action and conduct real-time interventions in professional design teams?*

Research Question 2: What does Design Thinking look like in professional software design practice?

To develop an empirical understanding of design thinking, the re-searchers combined four different perspectives on design. Design Conceptualization, Co-creation, Decision Analysis and Affect are the set of Design Thinking Metrics (DTM).

3 RESEARCH METHODS

As researchers, we tackled two cases of experimental observation and analysis. Case 1 Laboratory Analysis of Software Design Practice consisted of video interaction analysis of three professional software design teams. This case followed a methodological approach rooted in video ethnography [4] and in sequential analysis of video data [5]. Case 2 Field Probe of Software Design Practice consisted of four workshops that were facilitated by the research team for a software design team in a Fortune 100 software company. This case followed a methodological approach rooted in action research [6] and participatory action research [7].

Both cases were informed by the doctoral work of the four researchers with regards to design learning [8], co-creation [9], decision analysis [10] and emotions [11]. This created a unified underlying frame for the two cases and led to a synthesis of findings across the laboratory and the field of practice.

4 CASE 1. LABORATORY ANALYSIS OF SOFTWARE DESIGN PRACTICE

Context of study

The research team participated in a National Science Foundation sponsored workshop on "Studying Professional Software Design" in February 2010 at UC-Irvine [12]. Three pairs of software designers were recorded by the workshop organizers of a shared set of DVDs with these videos and transcriptions was distributed in Fall 2009 to research groups around the world in a similar manner to the ongoing series of Design Thinking Research Symposia [13] [14]. The research team participated and presented at the Studying Professional Software Design workshop.

Study design

Three software teams - all professional software designers at large software companies - participated in the study. The three participating design teams were from Adobe, Amberpoint and Intuit. These names will be used to refer to the two-person design teams.

The pairs worked at a white board to address a design prompt for a "Traffic Signal Simulator." Participants were given an identical three-page design brief with the problem description, requirements, desired outcomes and timeline. The teams were given two hours to develop the user interaction and basic code structure for the imagined software application. Of the three video segments, Intuit lasts for approximately one hour and the other two go on for almost two hours.

Data analysis

The research team first power browsed [15] the first half of the video sessions to get a feel for the presentation and subject matter covered. We piloted our individual qualitative coding schemes and set up a dedicated space in the Design Observatory [16], see Figure 1.

Figure 1. Set-up in the Design Observatory

The research team watched the complete set of 3 video sessions on consecutive days to capture our observations and assessments within the real-time watching of the design activities. The concept of real-time analysis of design activity is part of the design instrumentation framework that motivates the research. The intention was to identify in real-time, the process metrics that can be predictive of design outcome in order to be able to provide appropriate feedback to the design team as to positively influence design activity.

The researchers attempted a version of real-time coding which meant that once we started playing the video, we did not stop or re-play it. We categorized behavior as it played out on the videotape at a normal playback speed. The real-time coding activity was supplemented by a deeper dive into certain sections of the video that we identified as interesting. Taken together these analyses resulted in the identification of certain patterns of behavior that we describe in the next section.

The result of this analysis was a near real-time identification of events in team interactions using our four key metrics called Design Thinking Metrics. The metrics cover the following critical aspects of team interaction: divergence (generating ideas) and convergence (evaluating alternatives); managing disagreement [17] that invariably arise in teams; design conceptualization assessing values and ways of thinking about design activity [8] and shared design values that persist in the group. The following table 1 indicates the coding scheme from each of the four perspectives.

Table 1. Coding Schemes

Design Conceptualization

Design Thinking Activities:

Idea: new words or descriptors

Conceptual prototype: conceptual modifications, definitions

Experience prototype: scenario of use

Engineering Thinking Activities:

Functional prototype: implementation, math estimates

Co-creation

Product concept: verbal representations of possible product arrangements that occur in the present or future

Process concept: verbal representations of possible process arrangements that occur in the present or future

Conditional utterance of a concept: concepts uttered with language cues that denote a conditional possibility; *could, can, I guess, I imagine, I suppose, we probably, kind of.*

Forceful utterance of a concept: concepts uttered with language cues that denote a certainty; *need to, have to, have got to, should, must,* or use of present tense implying an already existing reality

Decision analysis

Instances of discussing the design basis

Frame, Preferences, Alternatives, State of information

Affect

SPAFF simplified	SPAFF original Adapted from Simplified Specific Affect for emotions [18]
High Negative	*contempt, belligerence, criticism, anger, defensiveness, disgust, domineering, threats, stonewalling*
Low Negative	*fear/tension*
Neutral	*neutral*
Low Positive	*validation*
High Positive	*affection, enthusiasm, humor, interest*

Team Performance

Another aspect of data analysis was the evaluation of team performance. In order to contextualize our insight in terms of team performance, it was necessary to get an evaluative ranking of the three teams along meaningful criteria of team effectiveness. In terms of outcome of the software design activity, the three teams had representations on the whiteboard at the end of their session; though it was hard to identify a distinct deliverable that could be objectively judged. Nonetheless, we developed criteria relevant to the design task that could be used to rank the three teams. These are:

1. Human-centeredness as evidenced by the attention given to user interaction in their activity
2. Modeling ability as evidenced by the coverage of aspects of the traffic situation being discussed and the simplicity of abstraction.
3. Documentation as evidenced by the quality and quantity of whiteboard representation conveying the key points discussed during designing.

The first two criteria are directly derived from the desired out-comes mentioned in the design brief. In terms of the documentation, we attempted to isolate the Unified Modeling Language diagrams are rank them according to cue-based criteria. This did not enable us to develop a distinct team ranking. Hence we followed a more subjective route. As a team, we discussed our subjective impressions as to how the teams fared on these three criteria. None of us are domain experts in terms of software engineering, however it was interesting to note that we each arrived at similar ranking for the teams. Table 2 below lists the team rankings according to the three criteria.

Table 2 Team performance rankings by criteria

Company	*Human-centered*	*Modeling*	*Documentation*
Adobe	Medium	High	Medium
Amberpoint	High	Medium	High
Intuit	Low	Low	Low

Findings

Key findings are reported from each of the four perspectives that make up Design Thinking Metrics.

Design Conceptualization

When ratios of Design Thinking Activities to Engineering Thinking Activities, Table 3, are calculated the picture then becomes much clearer. The Adobe team is almost half that of the other two; they bounce back and forth much more often. The actual number of switches between the Design Thinking and Engineering Thinking Activities is listed in Table 3. Again it shows the Adobe team moving more regularly and consistently among the Design and Engineering Thinking spaces, possibly addressing both the problem space and solution space more evenly and in tandem. We would then predict higher performance for the Adobe team based on this analysis.

Table 3 Ideation densities for teams per design thinking and engineering thinking activities; Switches between activities

Company	*design thinking activities /min*	*eng. thinking activities /min*	*DT:ET ratio*	*Switches gross / net*
Adobe	2.8	0.5	5.3	58 / 36
Amberpoint	3.0	0.3	11.6	22 / 15
Intuit	3.7	0.4	9.0	28 / 16

Co-creation

Considering a ratio of conditional to forceful concepts, Adobe has the highest ratio of 1.38, followed by Amberpoint with a ratio of 0.86 and Intuit with a ratio of 0.47. Adobe has greater number of conditional concepts than forceful concepts while other two teams have the opposite characteristic with Intuit having half as many conditional concepts as forceful concepts.

So what can we infer from this analysis? One hypothesis is that conditionally expressed concepts are more conducive to co-creation as they enable the other participant to build-on and contribute to the concept. Forcefully expressed concepts on the other hand enforce a certain concept and do not leave room for improvisation. Prior work by Wilson [19] seems to point in the same direction. Wilson studied the learning and sense-making behaviors of teams as they engaged in extreme adventure racing. Wilson observed that in conditions of uncertainty, high performing teams made tentative claims that allowed their team members to negotiate and participate in the sense-making, while low performing teams made assertive claims that suppressed such participation.

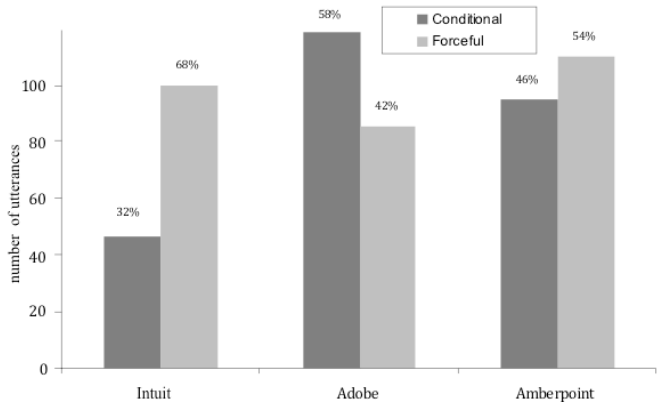

Figure 2. Graph of conditional and forceful utterances in each team. The Y-axis denotes the number of utterances in each category

Based on this hypothesis, one could suggest that Adobe is a high performing team while Intuit is a low performing team.

Affect

The results of the simplified SPAFF [18] coding are summarized in Figure 3. Each pie chart shows what percentage of the overall time a team displayed one of the five behavior types. Overall high negative behavior patterns such as contempt or belligerence and high positive behavior patterns such as excitement and humor were rarely displayed. The only team that showed some high negative behavior was the Amberpoint team, of which one team member showed domineering behavior during several moments. The high positive behavior patters consisted mostly of display of interest. Other high positive behavior patters such as humor and excitement were rarely observable across all three teams. The differences between the three teams from a specific affect perspective are mainly based on differences in the expression of tension (low negative) and validation (low positive). Ranking the three teams by the amount of positive affect expressed Adobe leads with 58%, followed by Intuit (45%) and Amberpoint (43%). Ranking the teams by the amount of negative affect expressed, Intuit leads with 25%, followed by Amberpoint (10%) and Adobe (7%).

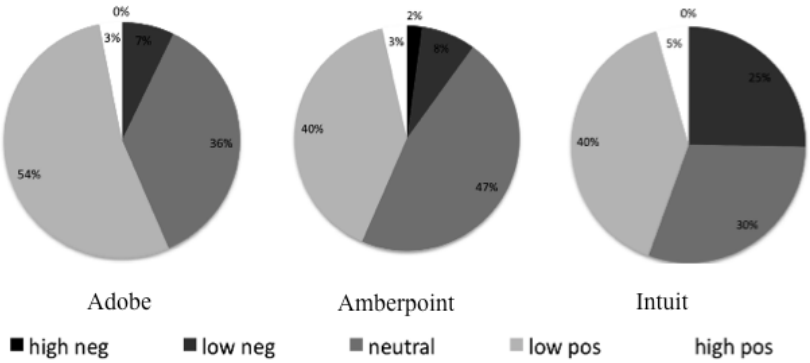

Figure 3 Specific Affect Coding

The results of the Motivating Engagement Behavior coding are summarized in figure 4. Each line displays the cumulative sum of positive/motivating (+1 to +7) and negative/demotivating (-1 to -7) behaviors over time for each team. A positive slope means that there are more positive than negative behaviors per time-unit, which indicates an engaging interaction style. A negative slope means that there are more negative than positive behaviors per time-unit, which indicates a disengaging interaction style. A positive slope for a certain segment indicates that positive or motivating behavior dominates during that segment. A negative slope for a segment indicates that negative or demotivating behavior dominates during that segment. All three teams show slightly positive slopes, which means that in each team there is more positive behavior displayed over time than negative behavior. All three teams are similar in terms of this measure.

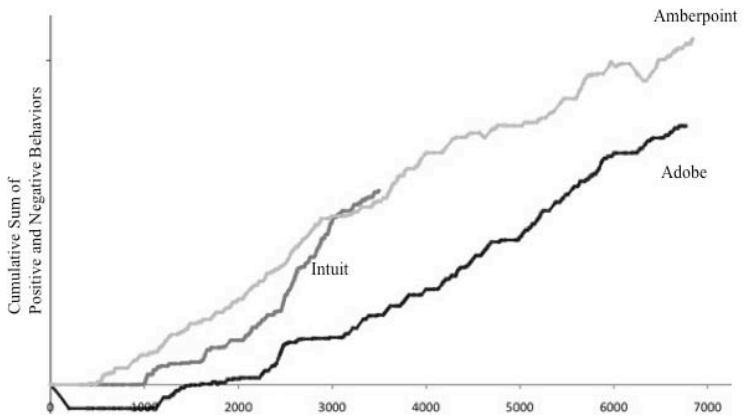

Figure 4: Summarized results of Motivating Engagement Behavior coding for each of the three teams.

Rankings

Overall, we found a convergence in the four perspectives that we used to analyze the data. The design conceptualization perspective found that Adobe transitioned more often and more evenly over time between Engineering Thinking and Design Thinking. The co-creation perspective also found that Adobe had a greater ratio of conditional to forcefully expressed concepts. This leads us to suggest that conditionality in expression could influence transitions between Engineering Thinking and Design Thinking or vice versa.

Similarly there was convergence in the affective perspective and co-creation perspective as well. Intuit had the lowest conditional to forceful concept expression ratio. Intuit also had the lowest positive to negative affect ratio. It is conceivable that a negative affective climate has an influence on how a team perceives uncertainty. Also a forcefully expressed concept could communicate dominance and lead to a negative affect in a team.

The design basis could also be influenced by affect and conditional language. Understanding and developing a design basis occurs through a conversation between team members. If negative affect is

expressed in a conversation, it could have a detrimental effect on the ability of a team to probe the design basis. Similarly the use of forceful language prevents exploration of alternatives in a conversation thus negative influencing the design basis.

Comparing the four perspectives with the team effectiveness ranking, we found similarities in the way each perspective ranked the teams and the way the teams were ranked through the team effectiveness criteria. Based on the similarities observed, we suggest the following hypotheses:

H1: The rate of transitions between Engineering Thinking and Design Thinking activities is directly correlated to team effectiveness.

H2: The failure to address each aspect of design basis is inversely correlated to team effectiveness.

H3: The ratio of conditionally to forcefully expressed concepts is directly correlated to team effectiveness.

H4: The ratio of positive to negative affect expressed in an interaction is directly correlated to team effectiveness.

5 CASE 2. FIELD PROBE OF SOFTWARE DESIGN PRACTICE

The first case study enabled us to probe design activity as it was happening and test if we could perceive elements of design thinking in action. We used four different dimensions - design conceptualization, co-creation, decision analysis, and affect - to guide our perception of design activity. The experience resulted in a sharpening of our own perceptual fields and noticing capabilities, as well as, in a set of testable hypothesis. The next question before us was - could we take these perceptual capabilities, and translate them into meaningful improvement of design activity in a professional setting? Could we create a model that would allow practitioners to do the same? The second case study presents our attempts to answer these questions.

Context of study

This study was conducted in collaboration with a large enterprise software company. We collaborated with a software design team that was tasked with developed a novel concept and generating UI designs for it. Since the team was involved in early conceptual de-sign, their activities gave us a meaningful context to engage in with our DTM framework and develop a model of perceptions influence design action.

Theoretical Approach

The theoretical approach we took builds on Schön's elaboration of knowing-in-action and reflection-in-action [20]. Schön proposed that the professionals don't just apply technical knowledge to situations of practice which are generally messy and ambiguous, but rather their knowing is situated in and linked to their doing of professional activities - their knowing-in-action and reflecting-in-action. Schön further elaborates on the 'seeing-as', framing, moving and reflecting that happen in "action-present" and result in an inter-action - a give and take, or a conversation with the evolving situation of practice. Ingold [21] proposes a similar emphasis on "practices of skills" rather than "products of intelligence". Ingold considers the coordination of perception and action at the core of a skill. He argues that we need to "shift our analytic focus from problem solving, conceived as a purely cognitive operation distinct from the practical implementation of the solutions reached, to the dynamics of practitioner's engagement, in perception and action, with their environments."

Deriving from Schön's and Ingold's work, we identified three key elements of such conversation with the situation that forms the core of a professional's practice (Jung et al. 2010):

1. Perception, and perceptual field - Perception is the activity of sensing and naming a certain phenomenon. Perceptual field is a collective of such perceptions that have been acquired to be

meaningful to a certain context of practice. It can be defined as sensing organized around a purposeful activity.

2. Action, and action-repertoire - Action is the activity of moving in a purposeful way. An action-repertoire is collection of such actions that have been acquired in the context of practice.

3. Theory - implicit and explicit - An implicit theory refers to the heuristics, beliefs and expectations associated with particular perceptions and actions in the context of practice. An explicit theory on the other hand is a codified understanding of phenomenon that has been learned in the technical context of practice.

The following diagram, Figure 5, refer to the relationship between perception-action occurring around an implicit theory in practice. Explicit theory can be derived from this practicing.

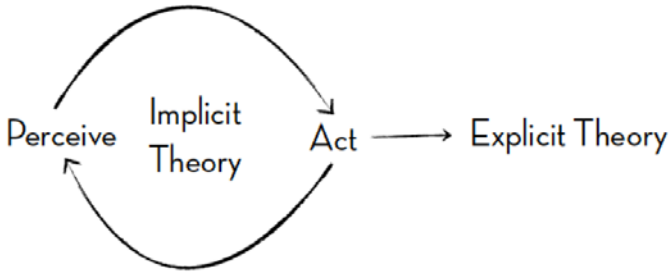

Figure 5 Perception action theory loop with implicit and explicit theory

Study design

The study was designed as a series of four workshop interventions with the team of software designers. These interventions were a collaboration between the team of researchers and the team of software designers. The software designers brought in content relevant to their design task. The researchers brought in a set of activities to the structure and probe engagement with the design content. These activities centered around the content brought in by the design team, gave us an opportunity to probe the perception-action and implicit theories that both the designers and the researchers held about de-sign thinking. We as researchers followed the model of perceiving - assessing the need for intervention - acting out an intervention - and then assessing the effect. This at one level, enabled the designers to become more aware of their own implicit theories and modify their perceptual fields and action-repertoires, and another level enabled the researchers to test out the model of perception-action in a professional setting. The following diagram, Figure 6, visualizes the engagement with the design team.

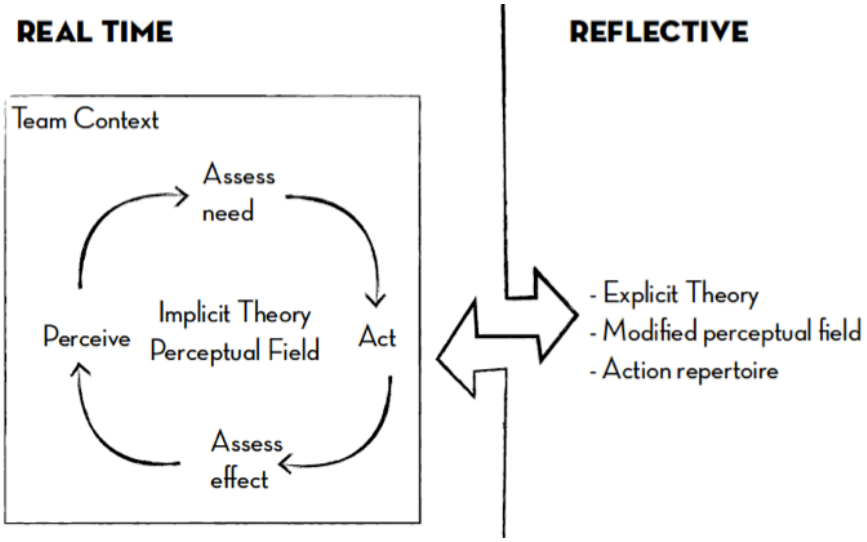

Figure 6: Modeling engagement with the design team

Data analysis

Data was collected during the 4 sessions in the form of photographs and notes, and after the session in audio recordings and notes of the research team's post-debriefing. The first workshop was a visioning workshop that involved the use of Legos as tangible media for illustrating design concepts and scenarios for future. The second workshop was focused on stakeholder analysis for the design project. The participants sketched out their understanding of the project space. The third workshop was a continuation of the second. The participants developed the point of view in terms of stakeholders of the project. The fourth workshop involved further planning of their design activity. The researchers facilitating a particular session met immediately afterwards and discussed their perception-action interventions and the theory behind their interventions. These debriefing researchers discussions were audio recorded after the session. Data analysis consisted of consolidating and analyzing the perception-actions pairs along with their implicit theory. The following table is sample of the analysis conducted.

Table 4 Perception, Theory and Action Effect Examples

Example 1	
Perception	Tense behavior from SB communicated orally as a wish or non-verbally – fidgeting, back and forth focus on a particular thing, shifting around.
Theory	I wanted participants to be at ease when doing the Lego activity. It was my responsibility as the facilitator to put them at ease and if I noticed unease, I wanted to act in a way so as to remove it.
Action	I suggested that SB get his phone left in the car and which may have causing him distress.
Effect	SB uttered his thanks and went off to get his phone.
Example 2	
Perception	Awareness of time it took to complete different activities
Theory	My goal was to be able to complete the activities we had planned for the 2 hrs.
Action	Either a self-regulation of my own expectation or an external intervention to speed things up.
Effect	I become less anxious with an internal intervention and allowed the activity to go on in a different direction. With an external intervention the activity was kept on an expected path.
Example 3	
Perception	Verbal expression to hold on to the model
Theory	The team would own the model and it would be more likely to enter their practice is it has persistence in space.
Action	Giving the team permission to keep the Legos for a week.
Effect	The team was verbally enthusiastic about the model and about sharing it.

The perception-theory-action-effect pairs occurred at different levels of in-the-moment analysis. Most of them were focused on the design team and their behaviors. However some of them as noted in the table above were also focused on perception of researcher's own emotional and cognitive state.

Findings

The workshops were acknowledged to be successful by the design team in enabling them to engage with their design project in a different way. The Lego visioning workshop was especially well received with the team inviting the researchers to do a similar activity in a session with their clients.

The key findings from the research perspective were more methodological in nature. We implemented a perception-action approach to intervening in a design situation and at the same time building a set of theories tied to the perceptual field and action-repertoire meaningful in the context of practice. The results were encouraging. We were able to adapt a coding scheme - the Design Thinking Metrics, draw out the perceptual units of design thinking behavior and intervene successfully by developing an action-repertoire in a con-text of professional practice.

6 CONCLUSIONS

This research study opens up a discussion for developing a new epistemology of design research. One that is based not on a methodology derived from natural sciences or social science, but rather from a

methodology of design practice that emphasizes linking perception-action of a human with the theories derived and implemented in a given situation.

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REFERENCES

[1] Dym C, Sheppard S, Agogino A, Leifer L, Frey D, and Eris O (2005) Engineering Design Thinking, Teaching, and Learning. Journal of Engineering Education.
[2] Rittel H and Webber M (1973) Dilemmas in a General Theory of Planning. Policy Sciences. Vol 4, pp. 55-69.
[3] Eris O (2002) Perceiving, Comprehending, and Measuring Design Activity through the Questions Asked while Designing. Dissertation, Stanford University.
[4] Jordan, B and Henderson, A (1995) Interaction analysis: foundations and practice. The Journal of the Learning Sciences, 4(1), 39-103.
[5] Bakeman, R, & Gottman, J (1997) Observing interaction: An introduction to sequential analysis. Cambridge Unit Press.
[6] Lewin, K (1946) Action research and minority problems. Journal of Social Issues, 2(4), 34-46.
[7] Whyte, W (1989) Advancing scientific knowledge through participatory action research.
[8] Lande M & Leifer L (2010) Incubating engineers and hatching design thinkers: mechanical engineering students learning design with ambidextrous ways of thinking. American Society for Engineering Education Conference.
[9] Sonalkar N (2010) Co-creation for engineering design. ACM Creativity & Cognition.
[10] Han C (2010) Design basis and other useful distinctions for creativity and cognition. ACM Creativity & Cognition.
[11] Jung M and Mabogunje A (2008) Emotion-dynamics in multi-disciplinary design teams. Symposium on cognitive, social and emotional processes in creative teams. International Conference of Psychology.
[12] Petre, M, van der Hoek, A and Baker, A (2010) Editorial. Design Studies. Volume 31, Issue 6, Pages 533-662.
[13] McDonnell J and Lloyd P, eds. (2009) About design: analysing design meetings. Taylor & Francis, London.
[14] Cross, N, Dorst, K and Roozenberg, N, eds. (1992) Research in design thinking. Delft University Press, Delft, The Netherlands.
[15] Sonalkar N, Mabogunje A, Leifer L, Eris O and Jung M (2007) Powerbrowsing: a method to accelerate designers' familiarity with video information in digital libraries. Proceedings of the International Conference on Engineering Design.
[16] Carrizossa K, Eris O, Mabogunje A, Milne A and Leifer L (2002) Building the design observatory: a core instrument for design research. Design 2002 Conference.
[17] Jung, M, Sonalkar, N, Mabogunje, A, Banerjee, B, Lande, M, Han, C and Leifer, L (2010) Designing perception-action theories. DTRS8 Design Thinking Research Symposium.
[18] Coan J and Cottman J (2007) The Specific Affect Coding System (SPAFF). In: Handbook of emotion elicitation and assessment.
[19] Wilson D (2007) Team learning in action: an analysis of the sensemaking behaviors in adventure racing teams as they perform in fatiguing and uncertain contexts. Dissertation, Harvard University.
[20] Schön, D (1983) The reflective practitioner: how professionals think in action: Basic Books.
[21] Ingold, T (2001) Beyond art and technology: the anthropology of skill. Anthropological perspectives on technology, 17-31.