The 2nd International Conference on Design Creativity (ICDC2012)
Glasgow, UK, 18th-20th September 2012

A VISUAL REPRESENTATION TO CHARACTERIZE MOMENT TO MOMENT CONCEPT GENERATION IN DESIGN TEAMS

N. S. Sonalkar, A. O. Mabogunje and L. J. Leifer

Center for Design Research, Stanford University, USA

Abstract: This paper aims to increase our understanding of concept generation through interpersonal interactions in a design team. Prior research has either looked into the inter-relations between concepts generated, or into identifying specific interpersonal response behaviors. There is a lack of explanation of how design concepts are generated moment-to-moment from the interpersonal interactions between designers. This paper presents the development of a visual notation called the Interaction Dynamics Notation for representing moment-to-moment concept generation through interpersonal interactions. This notation was developed through a video-observation study conducted with two teams each consisting of three engineering design graduate students engaged in a concept generation activity. Collective improvisation was used to bridge concept generation and interpersonal behaviors into a single point of view for developing the notation. The patterns of interaction revealed by the visual notation are described and the value of the notation as a representation system is discussed.

Keywords: *visual representation, interpersonal interaction, concept generation*

1. Introduction

Engineering design and development in practice is often conducted in teams. Researchers have noted this move towards team designing (Kleinsmann & Valkenburg, 2005; Valkenburg, 2000) as a way of dealing with the increasing complexity of products, and the demand for shorter product development cycles to stay competitive in the market. What do engineering design teams actually do over the period of the product development cycle to create new products? If we video record their work space over the duration of design activity and replay it, we would see team members moving around, interacting with each other and with a number of different objects and tools. Through these interactions, information and ideas circulate among the people on the team, concepts are generated, prototypes are created and tested, and products are specified. This paper presents a visual representation for analyzing how design concepts are generated moment-to-moment through interpersonal interactions in a team. We focus on concept generation because it is these concepts that hold the promise of what could potentially become innovative products. Developing innovative products through engineering design is key to a company's success because companies need to compete successfully in the changing marketplace.

2. Prior research

Most researchers aiming to study what engineering design teams actually do when they are generating concepts, have focused on the concepts themselves and their evolution through the engineering design process. For example, Cross (1997) described combination, mutation, analogy and first principles as mechanisms for evolution of concepts. Goldschmidt and Tatsa (2005) used linkography to analyze the linkages between concepts generated in a design studio and found that concepts with greater linkages have a greater influence on the final product. Van der Lugt (2003) found that concepts with greater number of associations to other concepts and which are formed by direct contribution of more participants are regarded as more creative. But again, what are the designers' behaviors that influence such concept generation patterns? A few researchers have looked into this topic. Hargadon and Bechky (2006) identified help seeking, help giving, reinforcing and reflective reframing behaviors in professional firms that influence the collective creation of concepts. Lempiala (2010) identified treating radical ideas as jokes, silencing ideas, demanding proof, and focusing on detail as obstructive practices in professional concept generation teams. Bergner (2006) identified framing, limit-setting and limit-handling as behaviors influencing concept generation performance in teams. These two strands of research - one focusing on concept generation patterns and the other focusing on designers' interpersonal behaviors in a team - have not been brought together. Our understanding of how design concepts emerge through the moment-to-moment interpersonal interactions of designers in a team remains incomplete. This paper presents a method to analyze both the development of concepts and the interpersonal interactions of designers together as they occur over the course of time in concept generation sessions.

3. Need for a visual representation

How does one capture and analyze moment-to-moment concept generation interactions? Research using a moment-to-moment analysis of how one moment leads into another with respect to idea generation activity, though less common than other approaches, does exist. For example, Matthews (2009) used conversation analysis to study how brainstorming rules affected the social order in concept generation teams. Conversation analysis (CA) is suitable as a method for a moment-to-moment analysis of changing social order in brainstorming groups because CA analyzes how conversation is organized in terms of one talk-in-turn leading to the next and so on (Schegloff, 2007). While CA provides an established way to analyze moment-to-moment progression of talk in design interaction, it suffers from the disadvantage of being text-based when it comes to capturing and representing concept generation in engineering design teams. Engineering analysts frequently use visual representations such as free body diagrams in mechanics, flow diagrams in fluid dynamics, and control volume diagrams in thermodynamics to analyze complex real world problems. Visualization, defined as a representation of information in a visual-spatial medium (Hegarty, 2004) confers many benefits over verbal representation of information. In an article aptly titled 'Why a diagram is sometimes worth ten thousand words', Larkin and Simon (1987) point out that diagrams, such as the free body diagram, provide the advantages of localization of information, minimal labeling of elements and perceptual enhancement as compared to verbal explanations. The advantage of a visual representation has not been applied in the past to capture and analyze moment-to-moment concept generation interactions in design teams. Linkography developed by Goldschmidt (1990) to assess productivity of design teams is one visual representation that has been applied to study how concepts are linked to one another over time (Van der Lugt, 2001). However, it does not address how these concepts emerge from designers' interpersonal interactions.

4. Developing a visual representation system

4.1. Collecting empirical data

The concept generation activity of two teams was observed in order to develop a visual representation of how concepts emerged through their interpersonal interactions. The study used two teams instead of one to provide a greater variety of concept generation interactions, but they were not selected to differ on any specific parameters. The study was conducted in a laboratory setting at the Center for Design Research at Stanford University because it afforded a shorter time to collect data and advance rapidly into analysis. It was also set-up for simultaneously capturing close-up videos of all participants. This enabled a detailed analysis of individual verbal and non-verbal behaviors. The participants were engineering graduate students recruited from a graduate course in team-based design that approximated industry design project conditions. The students had prior industry experience and were familiar with each other. Familiarity was considered necessary to approximate the interaction quality in a real design project. The teams were provided with Legos and were given a task to generate as many concepts as they can for a safe and entertaining toy. Legos was provided along with writing and sketching materials in order to prototype and share ideas. The duration of the task was about 40 minutes. The team design activity was recorded on video. Video is well suited to capture moment-to-moment real-time interactions between people. It provides a permanent record of the transient interactions that makes them amenable to repeated viewing and further analysis.

4.2. Analyzing concept generation interactions

4.2.1. Collective improvisation as a point of view

After gathering video data, a point of view was needed to serve as a focus of analysis. Collective improvisation was chosen as the point of view. Improvisation by definition puts an emphasis on moment-to-moment behaviors as it cannot be planned ahead of time. Moreover, improvisation has been associated with concept generation in design (Faste, 1992; Gerber, 2007, 2009). Also, the process principles from collective improvisation focus on interpersonal interaction behaviors that will enable a group of individuals to generate narratives together. Thus, collective improvisation serves to bridge concept generation and interpersonal behaviors into a single point of view.

4.2.2. Development of coding schemes to identify ideas, speaker turns and interaction segments

Coding schemes were developed to categorize verbal and non-verbal behaviors relevant to moment-to-moment concept generation. While a number of coding schemes were prototyped, the key coding schemes that were retained for further analysis were the coding schemes for identifying ideas, speaker turns and interaction segments. These coding schemes were iteratively refined through application to the video data by two independent coders. The identification of ideas and interaction segments is discussed in greater detail below.

Consecutive speaker turns that were related to one another by the virtue of one turn being a response to another, which in turn was a response to another speaker turn, were grouped together into segments called as interaction segments. Interaction segments were topically related chains of consecutive interpersonal responses. The coding of interaction segments highlighted the topical continuity element of interpersonal interaction. This topical continuity element was important to analyze how one idea expression connected semantically to future idea expressions that were related to the development of the same product concept.

Ideas were identified as expressions of possible alternatives. An idea could indicate a possible product configuration or a scenario, or even a possible process alternative. Coding of ideas involved identifying the notion of possibility in a speaker's expression. The dimension of possibility enables us to use cues of modal verbs – could, can, might, may (Halliday, 1970; Papafragou, 2006). The notion of possibility derives from Eris' work on question-asking in design activity (Eris, 2002) and the C-K (Concept-Knowledge) theory work of Hatchuel and Weil (2003; 2009). While ideas were coded from the perspective of individual expressions, concepts were coded as product solutions that were expressed through either a single idea expression or through an aggregate of idea expressions.

4.2.4. Trials of various representation systems

Once ideas, interaction segments and speaker turns were identified, the resulting data were visualized using different representation systems in order to test which representation system was suitable for identifying patterns of behavior that characterize moment-to-moment concept generation. The representation systems tested for visualizing data were cartesian graphs, state transition diagrams, concept Linkography, as well as a tabular text-based representation. Out of these, the state-transition diagram seemed promising, but it had the drawback of needing annotation to code interpersonal response types. After unsuccessful trials of existing representation systems, a new notation system, the Interaction Dynamics Notation was derived from Force Dynamics Notation (Brandt, 2004) and improvisational principles.

4.2.5. Development of a visual notation system based on force dynamics

The key principles that guide interpersonal responses when working in a improvisation group are saying 'yes and' to build on others' offers, not blocking other people's expressions, supporting your partners, not writing the script in your head, and maintaining an awareness of others' responses (Spolin, 1963). Thus, improvisational responding relies on not putting up barriers for others' ideas, and instead supporting their expressions and elaborating on their ideas. This notion of putting up barriers and overcoming barriers is well visualized in the Force Dynamics Notation from the field of Cognitive Semiotics. Force Dynamics Notation is used to visualize the meaning encapsulated in a narrative plot. We adapted the notation to visualize a concept generation conversation as a plot in which participants block each other, or say 'yes' to each other's ideas, or support each other's ideas. The following section describes the Interaction Dynamics Notation as it was called after adaptation. This notation system resulted from iterative refinement and application to the dataset of the two concept generation conversations recorded on video. Figure 1 below compares the Interaction Dynamics Notation with the different representation alternatives prototyped.

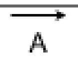
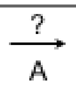
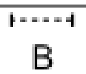
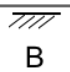
	Attributes				
	Captures sequence of events over time	Captures moment-to-moment occurrence of events	Captures links between ideas	Captures speaker turns	Captures types of interpersonal responses
Concept Linkography	Yes, units are visualized in the order in which they occur over time	No	Yes	No	No
Time series cartesian graphs	Yes, with time as the horizontal axis	No	No	Yes	Yes
State Transition Diagrams	Yes, units are visualized in the order in which they occur over time	Yes	Yes	Yes	Yes, but as annotations
Tabular text-based visualization	Yes, response types are written in the order in which they occur over time	Yes	No	No	Yes, but as annotations
Force Dynamics Notation	Yes in a narrative plot	Yes in a narrative plot	No	No	Yes in a narrative plot
Interaction Dynamics Notation	Yes, units are visualized in the order in which they occur over time	Yes	Yes	Yes	Yes

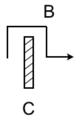
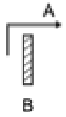
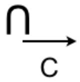
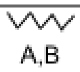
Figure 1. A comparison of different representation alternatives prototyped for visualizing the development of concepts through interpersonal interactions

5. Interaction dynamics notation

The Interaction Dynamics Notation is a visual representation of interpersonal responses in a concept generation interaction. It consists of 12 symbols. Table 1 lists the different symbols and the type of responses they represent.

Table 1. List of the symbols used in the Interaction Dynamics Notation. The alphabets below the symbols represent the different individuals participating in the design interaction

Symbol	Name	Description	Example
	Move	A 'move' indicates that a speaker has made an expression that moves the interaction forward in a given direction.	A: I need to buy Legos (at) home. Think about how therapeutic it would be.
	Question	A question indicates an expression that elicits a move. A question projects onto the next response and constrains the content of that response because the next response needs to answer the question.	A: Where should we start?
	Hesitation	Hesitation indicates an expression that is drawn out over time and is not completed. It denotes self-inhibition on part of the speaker.	B: Yeah or not erm (0.8s) there's something erm (1s) when we give (0.4s) yeah.
	Block	Block indicates an obstruction to the content of the previous move. For a block to be felt, the coder needs to feel that the response in someways obstructed the flow that was established by prior moves.	B: Maybe have something which looks like a computer but you can just type your name or do a simple math, a calculator in the shape of a computer kind of. C: Er, but I don't know, I mean, considering the age segment we are targeting 3 to 7 years.
	Support for move	Support-for-move indicates that the speaker understands and/or agrees with	C: Safe and entertaining (bending forward to write).

Symbol	Name	Description	Example
		the previous move.	B: Safe and entertaining, yes.
	Support for block	Support indicates an acceptance of a block by another person.	A: But that's also, I think that's already done. C: Yeah, its already there. B: Ok.
	Overcoming	Overcoming a block indicates that though a block was placed in front of a move, a speaker was able to overcome the block and persist on course of the original move.	C: Er, but I don't know, I mean, considering the age segment we are targeting 3 to 7 years. B: So 7 years they go to school, they would learn A,B,C right?
	Deflection	When a speaker blocks a previous speaker's move, that speaker or another can deflect the block with a move that presents an alternative direction for the interaction.	B: So when you say we need to divide the age-group, but you cannot have like 3, 4, 5. A: No, no of course not, but I mean you might have a few different (concepts).
	Interruption	An interruption is indicative of a speaker being interrupted by another speaker or at times by himself.	B: Should we start generating some concepts now? A: Yeah (interrupted by X) X: 10 min are gone.
	Yes and	A move is considered to be a 'Yes and' to the previous move if it accepts the content of the previous move and adds on to it.	A: What about... if we made a toy that incorporates girls and boys. Its like a house that has a car with it kind of like enables the guys to play with the girls? C: I think that's a good point to have some sort of a educational point in it.
	Deviation	Deviation indicates a move that changes the direction of the conversation from the one implied by the previous moves.	C: But we need to remember it. C: This is not the buildable room (deviating from previous topic)
	Humor	Humor indicates instances of shared laughter in teams.	A: I don't know I probably would have swallowed but (All of them laugh)

In Interaction Dynamics Notation, observable speaker expressions (verbal and non-verbal) are interpreted and assigned symbols to create a descriptive visual model of the interaction. The assignment of symbols is conducted based not on what the expression is from the point of view of the person making it, but on what the expression is taken to be and responded to by others in the team. So what we are modeling is not a series of speaker expressions but rather a series of speaker responses. Thus, the Interaction Dynamics Notation is a visual model of an unfolding interaction. The idea expressions that were identified earlier through the coding scheme are then colored in red in the visual representation. This facilitated the modelling of both the ideas and the types of interpersonal responses in a single representation.

6. Interaction patterns indicated by the visual representation

Figure 2 gives a snapshot of the Interaction Dynamics Notation applied to a section of the conversation of Team 1 from the study.

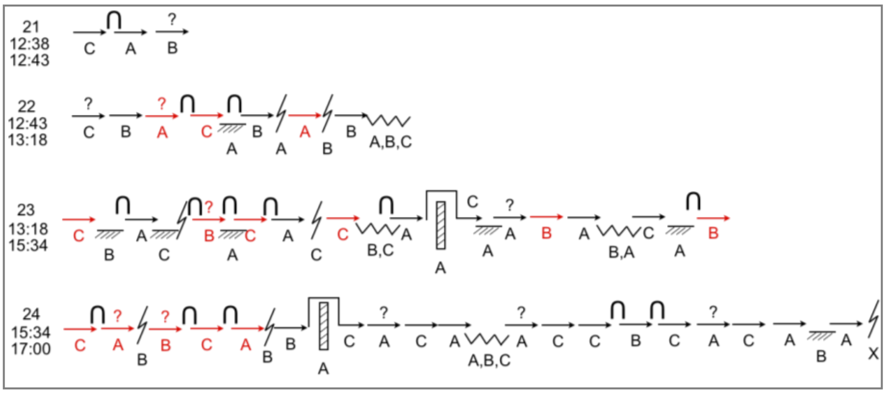


Figure 2. A snapshot of interactions occurring from 12.38 min to 17.00 min into the idea generation session of Team 1. The red responses are idea expressions. The numbers 21 to 24 indicate the interaction segments with start and end timestamps given under them. The letters A, B, C and X under the symbols indicate individuals who are giving those responses

The Interaction Dynamics Notation revealed the following patterns of interpersonal interaction.

1. Concept generation interactions propagated through transitions between ideas and facts - In concept generation interactions, not all expressions were idea expressions. Since idea expressions are expressions of possibility, the responses in black that were not coded as ideas can be called as facts or expressions of certainty. These expressions consisted of personal stories told by individuals, statements of general facts, or statements of future certainty. Thus design interactions in the two teams propagated through transitions between idea and facts.

2. There existed moments of sustained idea expression - There were moments when ideas occurred in a sequence. At the start of interaction segment 24 (Figure 2), A, B and C participated in an idea sequence where consecutive responses were ideas. This was identified as a moment of sustained idea expression. In the two teams whose conversations were studied, such moments of sustained idea expression started with a move, a question or a ‘yes and’ response. ‘Yes and’ responses, questions and interruptions were observed to occur within idea expression sequences. The improvisational response ‘yes and’ indicated building on others’ responses. However, the representation revealed that this ‘building on’ not only led into an idea sequence, but also out of it. This occurred when participants shared a personal story or reinforced the idea with a general fact that itself was not an idea expression. Moreover, sustaining an idea sequence involved much more than a ‘yes and’ response. Questions, support and humor occurred along with ‘yes and’ in idea sequences. Interruptions occurred as well. Individuals cut each other’s conversation turns, probably in an excitement to share their ideas. Of all the ideas expressed in concept generation interactions, 70 % in Team 1 and 63 % in Team 2 occurred in sequences. But this study does not indicate whether idea sequences lead to concepts that are more influential in the design process. While the representation helps in identifying moments of sustained idea expression, further research needs to be conducted to understand their role in the design of innovative products.

3. There existed moments of sustained disagreement - The representation revealed sequences of blocking in concept generation interactions indicating moments of sustained disagreement (Figure 3).

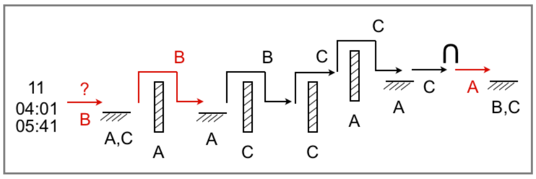


Figure 3. A sequence of blocking responses occurring in interaction segment 11 in Team 2

Blocking presents an obstruction to the preceding expression. It can be likened to limit response identified by Bergner (2006). While Bergner identified limit responses and counted them, this representation goes further to actually visualize how participants deal with blocks and resolve them in their interaction. Most blocks occurred as single expressions that were followed by overcoming or deflection response. However, at times a sequence of blocks as shown in Figure 3 was identified. Here B expressed an idea that was blocked by A. Though B tried to overcome it, he was met with persistent blocks from C, who in turn was blocked by A. In the end, A supported C's overcoming response. When the disagreement was resolved, idea expressions emerged through the interaction.

4. Blocking was not always detrimental to concept generation - Sometimes, ideas were expressed in response to a block such as in the example presented in Figure 4.

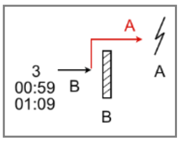


Figure 4. An idea expressed as a response to a block in Team 2

This indicated that blocks did not necessarily inhibit ideas. Methods such as brainstorming encourage individuals to withhold judgment and thus discourage blocking. However, the representation revealed that in concept generation conversations blocks did occur, they were resolved by the team, and at times they led to further idea expressions. It was observed that most blocks whether single or in sequences were resolved by the participation of the person whose response was blocked. The person either gave an overcoming or deflection response, or supported such a response given by another team member.

7. Conclusion

The Interaction Dynamics Notation when applied to the two teams in this study revealed certain patterns of interpersonal interaction such as moments of sustained idea expressions, the occurrence of improvisational 'yes and' responses within idea sequences as well as with transitions between ideas and facts, moments of sustained disagreement, and the use of ideas to negotiate blocks. However, it suffered from two limitations. The notation imposed a linearity of representation on conversations which were at times not linear with overlapping speaker turns. Also, it was limited to the relationship between consecutive responses. There were times, when a team member responded to a move, a question or an idea expressed earlier in the interaction. This relationship could not be captured as it was not between consecutive responses. Despite these limitations, the notation was effective in differentiating interpersonal interaction patterns accompanying idea expressions during moment-to-moment concept generation activity.

It is possible for researchers to not use a visual notation and go directly from video into a verbal representation of patterns through the use of appropriate coding schemes. However, by the use of an intermediate visual representation, the moment-to-moment temporality of concept generation interactions is maintained. Moreover, the Interaction Dynamics Notation uses visual symbols that represent interpersonal responses using familiar metaphors, for example blocking is represented by a wall, overcoming is represented by going over the wall, support is represented by the ground symbol used in engineering free body diagrams, and 'yes and' is represented by the using of the 'AND' symbol from logic. This makes the notation easy for humans to read and contributes to its effectiveness as a visual record of concept generation interactions.

The value of the Interaction Dynamics Notation then lies in its ability to model ideas expressed through moment-to-moment interpersonal interactions in a lucid visual manner. It contributes to design research by providing a representation system that enables a combined analysis of concept generation and interpersonal behaviors in design teams.

References

Bergner, D. (2006). *Dialog Process for Generating Decision Alternatives.* Stanford University.

Brandt, P. (2004). *Spaces, domains, and meanings: essays in cognitive semiotics*: Peter Lang.

Cross, N. (1997). Descriptive models of creative design: application to an example. *Design Studies, 18*(4), 427-440.

Eris, O. (2002). *Perceiving, Comprehending, and Measuring Design Activity through the Questions Asked while Designing.* Ph. D. Thesis, Stanford University.

Faste. (1992). The Use of Improvisational Drama Exercises in Engineering Design Education. Unpublished Working Paper. Design Division, Stanford University.

Gerber, E. (2007). *Improvisation principles and techniques for design.* Paper presented at the SIGCHI conference on Human factors in computing systems, San Jose, California, USA.

Gerber, E. (2009). *Using improvisation to enhance the effectiveness of brainstorming.* Paper presented at the Proceedings of the 27th international conference on Human factors in computing systems, Boston, MA, USA.

Goldschmidt, G. (1990). Linkography: assessing design productivity. *Cyberbetics and System, 90*, 291-298.

Goldschmidt, G., & Tatsa, D. (2005). How good are good ideas? Correlates of design creativity. *Design Studies, 26*(6), 593-611.

Halliday, M. (1970). Functional diversity in language as seen from a consideration of modality and mood in English. *Foundations of language, 6*(3), 322-361.

Hargadon, A. B., & Bechky, B. A. (2006). When collections of creatives become creative collectives: A field study of problem solving at work. *Organization Science, 17*(4), 484.

Hatchuel, A., & Weil, B. (2003). *A new approach of innovative design: an introduction to CK theory.* Paper presented at the International Conference on Engineering Design, Stockholm, Sweden.

Hatchuel, A., & Weil, B. (2009). CK design theory: an advanced formulation. *Research in Engineering Design, 19*(4), 181-192.

Hegarty, M. (2004). Diagrams in the mind and in the world: Relations between internal and external visualizations. *Diagrammatic representation and inference*, 121-132.

Kleinsmann, M., & Valkenburg, R. (2005). Learning from collaborative new product development projects. *Journal of Workplace Learning, 17*(3), 146-156.

Larkin, J. H., & Simon, H. A. (1987). Why a diagram is (sometimes) worth ten thousand words. *Cognitive Science, 11*(1), 65-100.

Lempiala, T. (2010). Barriers and obstructive practices for out-of-the-box creativity in groups. *International Journal of Product Development, 11*(3), 220-240.

Matthews, B. (2009). Intersections of brainstorming rules and social order. *CoDesign, 5*(1), 65-76.

Papafragou, A. (2006). Epistemic modality and truth conditions. *Lingua, 116*(10), 1688-1702.

Schegloff, E. A. (2007). *Sequence organization in interaction: A primer in conversation analysis I* (Vol. 1): Cambridge Univ Pr.

Spolin, V. (1963). Improvisation for the Theater: A Handbook of Teaching and Directing Techniques: Northwestern University Press. Evanston, Illinois.

Valkenburg, R. (2000). *The reflective practice in product design teams.* Delft University of Technology, Delft.

Van der Lugt, R. (2001). *Sketching in idea generation meetings.* Ph. D. Thesis, TUDelft.

Van der Lugt, R. (2003). *Relating the quality of the idea generation process to the quality of the resulting design ideas.* Paper presented at the International Conference on Engineering Design Stockholm, Sweden.