Collaborative Design Knowledge Construction and Measuring Shared Understanding

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Abstract: This paper describes a pilot test conducted as part of the ongoing research project. The performed pilot test describes the collaborative knowledge construction under two conditions: i) Collaborative knowledge construction in a traditional brainstorm setting ii) Collaborative knowledge construction in a proposed method (section number) described further in the paper. The pilot test focuses on measuring the shared mental model of a multi-disciplinary design team involved in a problem solving session. The approach to the study to predict shared understanding was to measure overlapping of mental models on a set of concept construct pairs of individuals during the design session. The findings of the pilot test were that the shared understanding in the proposed condition was better compared to the traditional means of brain storming.

1. BACKGROUND

The ongoing research project Collaborative Design Argumentation Space (CDAS) aims at supporting multi-disciplinary and collaborative design teams. The CDAS (Deshpande et al. 2006) project results in i) developing a formalism to capture arguments; ii) developing a technique that can process arguments in real-time; iii) developing a representation technique to show the arguments to the participants. The focused domain of the project is architectural, urban design and construction.

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One of the reasons for the complexity of understanding decision making in such domains is simply they are collaborative in nature. Within the complex collaborative dynamism, design problems and solutions evolve through a series of sessions where knowledge is elicited and shared, interdependencies among tasks and conflicts among perspectives are identified. New independent issues are raised from knowledge generated. They are defended, debated and decisions are made on them. Issues are raised from new knowledge or old decisions. Deadlocks are revisited and decisions are made on future tasks. As a response to the above acts, the members in a design session pose questions such as – what is the status of the current design, what did we discuss and what is the outcome in the last meeting, why is 'that' important anyway, what can we learn from the past sessions? The important aspects in collaborative session can be seen as – developing shared understanding about the issues involved, recording of the design process to understand what happened earlier.

Answers to questions of complex nature can be explained by capturing design rationale (DR). The design rationale expresses elements of the reasoning which has been invested in the design of an artifact. The DR answers *Why..?* questions of different sorts (Shum, 1996). We believe that the shared understanding in a team equals the construction of design rationale and that argumentation is the main way to discussing points between the team members. Most of the research efforts are largely artifact oriented where the focus is on tracking design artifacts throughout the design cycle – specifications, requirements, alternatives, decisions etc. However, the process by which the artifact is in its present state is left out implicitly. In particular what collaborative knowledge elements and their dependencies contribute to the 'arguable' issues and why some decisions were taken is not made clear.

There exist tools and approaches (Moran and Carroll, 1996) to capturing design rationale which differ in terms of the processes, representation formalisms involved and the interface and interaction methods applied. CDAS project represents collaborative knowledge, arguments, and evidences as the main elements of the design rationale. We believe this can explain the individual perspectives and their knowledge dependencies, why particular decisions were taken, and so has the capacity to justify recent decisions, inform future decision making and build shared understanding.

This paper only looks at the first stage of any collaborative design session which is pooling-in collaborative knowledge. Perspectives and other proposed contributors to shared understanding such as arguments, evidences will be presented in future publications. Collaborative knowledge construction can be seen as a pre-argumentative period and a major contributor to developing shared understanding. It is also seen as the 'meta knowledge filter' before making any informed arguments and decisions thus eliminating unwanted overhead during the actual argumentation and decision capture.

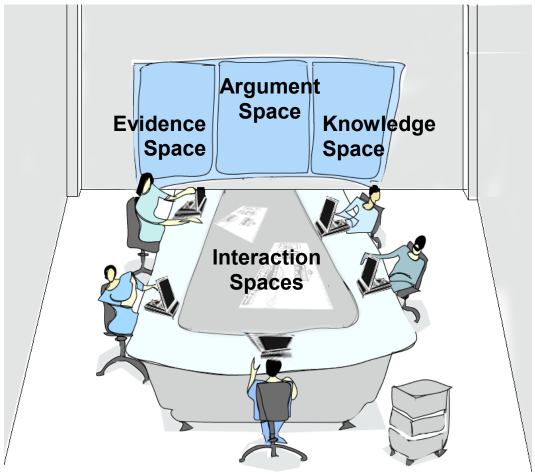

Figure 1. Proposed CDAS.

The rest of the paper explains collaborative knowledge construction and representation of it by 'causal mapping' approach. It further describes the pilot test and its results in measuring shared understanding during the pre-argumentative phase of a collaborative design session.

2. COLLABORATIVE DESIGN KNOWLEDGE

In collaborative design problem solving meetings, argumentation in general is used to improve ones own work, share knowledge and understand existing artifact or design state from collaborative point of view. Any collaborative design session uses the individual and collaborative *design knowledge* generated as a resource to build an argument. During the collaborative knowledge construction process, tacit knowledge is made explicit and things are made transparent. Formalizing tacit knowledge and structuring and questioning explicit knowledge results in building much needed shared understanding in collaborative design sessions.

Typically, when a problem is presented to a team, *members* (representing a discipline) try to figure out their positions and their roles to play based on their own knowledge or experience. Eventually, they start to develop hypothesis, intentions, alternatives, beliefs or perspectives, criterion, and constraints etc. All these are uttered as *statements*. Ex: 'the new student facility should be a recreation area' or 'it must be a knowledge centre'. When individual statements are created and shared, members involve in activities to converge those statements such as, combining similar interests (compound statements) or grouping a set of statements into a *concept*. A concept is a single ideational category (Carley and Palmquist, 1992). It has no general meaning. A concept can be a single word or composite word or even a phrase. Ex: considering the statement examples above, 'function' can be a concept. Herein knowledge types are related to each other or expanded further. A concept function can have *values*. Ex: bar, library etc. These values reflect the individual statements uttered earlier.

While explicating collaborative knowledge or perspectives, there exist dependencies among each other members' discipline. For example, two concepts can be linked by *causal relation*. A causal relation is the tie that links two concepts together. Ex: the concept 'function' can be causally related to another concept 'costs'. Causally connecting all the applicable concepts results in a 'causal map' which is a directed graph that represent the cause-effect relations embedded in a team members' thinking (Fiol and Huff, 1992). The advantage of constructing a causal map is that all the elicited collaborative knowledge can be seen as the teams' understanding on the whole situation at hand. Figure 2 explains the proposed collaborative knowledge structure. Causal maps have been used extensively in the areas of problem solving, policy analysis and management sciences to represent salient factors, knowledge, and conditions that influence decision making. Another advantage of constructing collaborative knowledge as a causal map is that causal maps are useful tools to construct Bayesian networks (Bayes nets) on which probability encoding techniques can be used to assess the numerical parameters of the resulting Bayes nets. Causal maps make the following assumptions in context of collaborative design and decision making (Nadkarni and Shenoy, 2000). i) Causal relations are a major way in which collaborative design decision problems can be described and understood; ii) Causality is the primary form of post-hoc explanation of decision outcomes; iii) Choice among alternative decision actions involves causal relations.

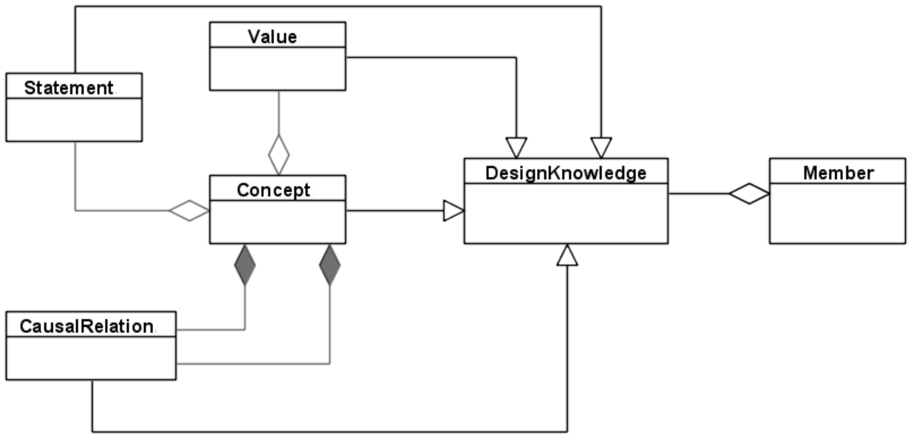

Figure 2. Collaborative knowledge structure and knowledge elements.

3. PILOT TESTS

With initial brainstorms and conceptualized ideas, we conducted two pilot tests. The idea was to probe more into the collaborative design knowledge construction process and subsequent argumentation in general. We were also motivated to observe the requirements in terms of interface and interaction during the process. The whole collaborative session was divided into two sessions, session-I and session-II. For the session I, a wizard-of-oz style prototype system was employed for the purpose of the study. This session was focused on the issues related to the development of an argument such as knowledge construction. For the second sub session, a facilitator mediated process was employed to construct the argument structure. This session focused on the identified elements in session-I and the subsequent flow of the argumentation process. A team of 7 members belonging to the Design Systems Group assumed the roles of 'experts' to participate in the test sessions.

4. SESSION-I

4.1 Method

Objective: To see whether the proposed method of constructing collaborative knowledge as a causal map influenced the shared understanding on the collaborative situation at hand when compared to a traditional knowledge construction method of brainstorming.

Session-I was conducted in *two sittings*: Sitting 1 and sitting 2. Sixty to ninety minutes were allotted to each of the sittings. The first sitting (sitting 1) followed the process of argumentation on the given problem with traditional means such as brain storming approach. In this sitting, the team members were asked to work on the problem presented to them in a traditional brainstorming approach. As the result of the brainstorming and deliberations, the team pooled in many key concepts related to the problem. All the concept sets were constructed using post-it notes. When the brainstorming was over, from the lot of generated concepts, 10 set of concept pairs were selected as samples and presented to the team. They were asked to rate on the relatedness of presented concepts to each other. 1 for loosely related to 7 for strongly related.

Figure 3. Result of sitting 1 as concepts.

The second sitting (sitting 2) followed the process of causal mapping approach. In this sitting, the team was directed in a step-wise process to construct a causal map in a natural and non expert fashion. Steps and elements include, creating statements (diverge), combining statements into compound statements, converting statements into concepts (converge), weighing the concepts generated to assign values, and finally, identifying causal relations among them. A previously distributed set of verbal commands were used to communicate with the wizard-of-oz. For example, 'CREATE a CONCEPT' or 'ATTACH S1 to C2' where S1 and C2 are a statement and a concept. In response to the members' commands, the wizard created graphical representation of elements on the display screen acting as a communication space.

The constructed causal map was converted into a Bayesian network manually during a session break. Member's preferences were used as 'cases' to be incorporated into the network. The completed Bayesian Network was used in the next sub session as a platform for argumentation. The BN tool Netica (Norsys, 2006) was employed for formal representation of the Bayesian network. See figure 3 for sitting 1 result, 'knowledge elements as concepts' and figure 4 for sitting 2 result, 'knowledge elements as concepts and values' shown as nodes. The arrows show their relation to other elements resulting in a Bayesian Network.

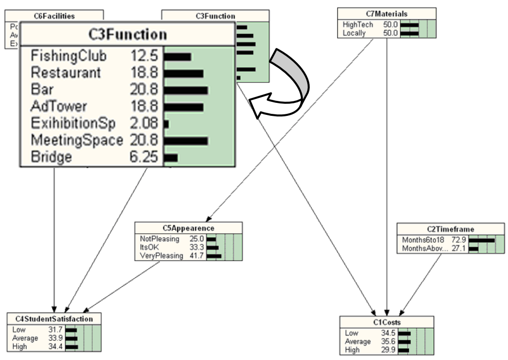

Figure 4. Result of sitting 2 as Bayesian Network with weighted values for concepts.

At the end of each sitting, relatedness rating was performed on the similar set of related concepts. The team members were asked to rate on the relatedness scale (Langan-Fox and Code, 2000, Langan-Fox et al., 2001) as strength on a given number of concept sets. Here the nature of mental models of a problem domain is inferred by collecting relatedness ratings on a list of concept pairs. In both sittings the same problem was presented to the team of experts.

5. RESULTS

We hypothesized that *sitting 2* will result in better shared understanding; hence behavior of the team in rating concepts will be similar when compared to sitting 1.

We compared the results of the one sample T-test for concept ratings in sitting1 and for concept ratings in sitting 2. We conclude that in sitting 2 the team has performed well, in the sense that they have behaved similar in rating concept sets hence, building a better shared understanding. Out of chosen 8 concept sets, team members behaved similar for 4 concepts, behaved different for 3 concepts and there was no difference in behavior for 1 concept. In sitting 1, team members behaved similar for 1 concept, behaved different for 5 concepts and there was no difference in behavior towards 2 concept sets. Figure 5 explains the one sample T-test results of sitting 1 and sitting 2 for concept 5 – '*signage and costs*'. Figure 6 shows the over all results of the concepts in sitting 1 and 2.

Table 1. Concept 5 / Sitting 1 One-Sample Statistics.

	N	Mean	Std. Deviation	Std. Error Mean
Concept 5 Sitting 1	6	3.17	1.602	.654

	Test Value = 3.17					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Concept 5 Sitting 1	-.005	5	.996	-.003	-1.68	1.68

Table2. Concept 5 / Sitting 2 One-Sample Statistics.

	N	Mean	Std. Deviation	Std. Error Mean
Concept 5 Sitting 2	6	2.17	.408	.167

	Test Value = 2.17					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Concept 5 Sitting 2	-.020	5	.985	-.003	-.43	.43

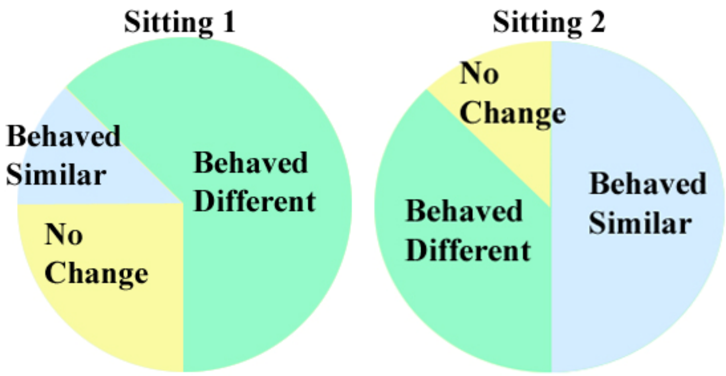

Figure 5. Behavior of the team in sitting 1 and Behavior of the team in sitting 2.

6. CONCLUSION

The study and the concepts presented in this paper is work in progress. We are in the stage of developing system components. In this paper we presented initial pilot tests conducted to gain insight into the aspects of collaborative design sessions. Initial results were discussed. The main perspectives for further research concern issues encountered during the knowledge construction and argument construction process of the collaborative design session.

We have to find efficient ways to minimize the existing gap between the informal knowledge representation methods and formal decision network representation and construction methods for an ideal usage of the resulting network.

Further study must be conducted to eliminate the existing and considerable overhead for the members because of a number of elements and members involved in collaborative construction. We intend to develop a hybrid style of interaction such as GUI based direct manipulative and speech interface for knowledge construction and a tangible interface for argument construction.

Apart from shared understanding, the observation on interaction during the process among the team members suggest that auto-arrange support in graphically representing the created elements would be greatly beneficial and in an ideal sense, the speech interface has a great potential in providing an unobtrusive interaction and knowledge construction.

7. REFERENCES

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