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Collaborative Stimulation in Design: A Retrospective Protocol Analysis Approach

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Studying collaborative creativity in design requires an understanding of how individuals' creativity relevant cognitive processes are influenced by design interactions. Investigating the occurrences of cognitive processes in design is challenging. Investigating cognitive processes occurring in collaborative design is even more difficult. This paper discusses a retrospective protocol analysis approach used to study cognitive processes in collaborative design. Unlike past approaches, the proposed approach analyzes both individual verbalization and group dialogs. This allows for the identification of both internal (private) and external (shared) thoughts.

1. A Model of Collaborative Cognitive Stimulation

The Collaborative Cognitive Stimulation (CCS) model explores how collaboration stimulates generative creativity relevant cognitive processes. It extends the Generate, Stimulate, Produce model (Benami & Jin, 2002) of creative cognition in design to collaboration. The model proposes that external (shared) design entities stimulate cognitive processes through collaborative stimulation. It draws specific relationships between the cognitive processes of memory retrieval, transformation, and association and the collaborative stimulations of seeding, memory stimulation, accommodating, clarifying, and collaborative completion.

To evaluate the model, an experimental methodology must be used which allows for the observation of individual cognitive processes in the collaborative setting. A typical approach would be to use protocol analysis (Cross, Christiaans, & Dorst, 1997), where subjects think aloud while they are working through a design process. Their verbalized thoughts are then transcribed, divided into episodes and segments, and then a coding scheme is applied to identify thought processes. However, protocol analysis has focused on the individual verbalizing their thoughts when working alone (van Someren et al., 1994). Much less work has analyzed design activity in the collaborative environment (Cross & Clayburn Cross, 1997).

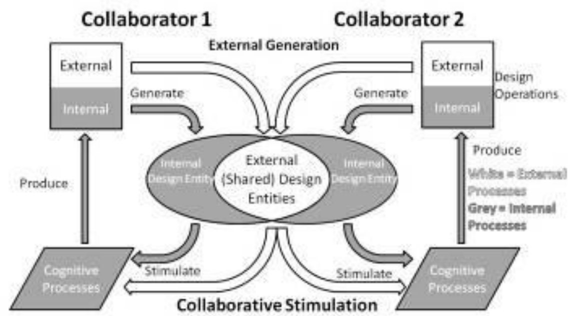

Fig. 1 A Collaborative Cognitive Stimulation Model

2. Past Approaches to Analyzing Collaboration

Using dialog transcripts is the typical approach to analyze collaborative activity. Sometimes, actual protocol analysis is done, applying a coding scheme to dialog transcript (e.g. Artzt & Armour-Thomas 1992; Stempfle & Badke-Schaub, 2002) while other times the conversation is just analyzed for social interactions (e.g. Cross & Clayburn Cross, 1997). However, these approaches do not identify specific cognitive processes occurring in the mind of the individual.

There are several examples of conversation analysis. Brereton, Cannon, Mabogunje and Leifer (1997) investigate how collaborative interactions influence the design process by either focusing it on a specific concept or transitioning to a new idea. Cross and Clayburn Cross (1997) explore the aspects of roles and relationships, planning and acting, information gathering and sharing, problem analyzing and understanding, concept generating and adopting, and conflict avoiding and resolving in collaborative design. Other times, protocol analysis is applied to the dialog to identify cognitive interactions. Stempfle and Badke-Schaub (2002) specifically apply protocol analysis to a team's dialog transcript, identifying basic underlying thinking operations. They state it is valid to use protocol analysis on conversation to observe thinking operations because of the work by Goldschmidtt (1997) which compares individual verbalizations to group dialogs. Goldschmiddtt (1997) states that the intimate nature of sharing that occurs in design conversations in the design team are close to the internal speech individual verbalizations produce.

3. Concurrent vs. Retrospective Protocol Analysis

None of the past collaborative approaches obtain individual protocols over the length of the design process. In order to identify specific cognitive processes and how it is stimulated, as occur in the CCS model, it is necessary to obtain protocols from each subject, in addition to the group dialog. Goldschmidtt's (1997) and Stempfle and Badke-

Schaub's (2002) approach of only analysing the conversation transcript does not work, as the CCS model explores both external (shared) and internal (private) thoughts. Therefore a modified protocol analysis approach is required.

One of the reasons full individual protocol have not been obtained in the collaborative setting, is because of the challenges faced. There are two key challenges which exist in obtaining individual protocols in the collaborative setting:

- *C1: How can a subject's verbalized thoughts (when they are not talking to their partner) be prevented from influencing their collaborator?*
- *C2: How can cognitive processes be observed, when individuals are required to talk with each other, and thus cannot continuously verbalize their thoughts?*

Two different methods were developed from current protocol analysis techniques to solve C1 and C2 so individual protocols in the collaborative setting could be obtained.

Concurrent Collaborative Protocol Analysis

Concurrent collaborative protocol analysis used a physical barrier between designers that allowed communication to flow but prevented verbalized thoughts from being communicated. This was accomplished by having two designers work remotely using Skype, using screen share and a push to talk feature. The screen share was used with an electronic sketchpad, allowing designers to share images. The designer used the push to talk feature when they wanted to communicate with their collaborator, which provided an interaction similar to a walkie-talkie. This allowed the designers to verbalize their thoughts continuously while working through the design problem, but prevented the collaborator from hearing their verbalizations, thus solving C1. Both the verbalized thoughts and the conversation were recorded through the computer's microphone. It was theorized that C2 would not be an issue, as when a designer was talking, what they were saying is what they would be thinking about. The interface is shown in figure 2.

Retrospective Collaborative Protocol Analysis

Retrospective collaborative protocol analysis took a different approach to solve challenges C1 and C2. Designers were allowed to collaborate in person as they normally would have, and then performed retrospective thinking aloud after completing the experiment. This was accomplished by having the collaboration session videotaped while the designers were working together. After the session was complete, designers watched the video and retrospectively verbalized their thoughts that were occurring during that portion of the video. Retrospective protocols have been found to produce similar results to concurrent protocols (Gero & Tang, 2001). Conducting the thinking aloud after collaborating on the design problem allowed the designers to collaborate in a natural environment, and allowed for continuous verbalization of their thoughts (solving C2). As the verbalizations occurred after collaborating on the design problem, there was no way for the designer's verbalizations to impact their collaborators thoughts (solving C1). The interface the designers used to retrospectively verbalize their thoughts is shown in figure 3.

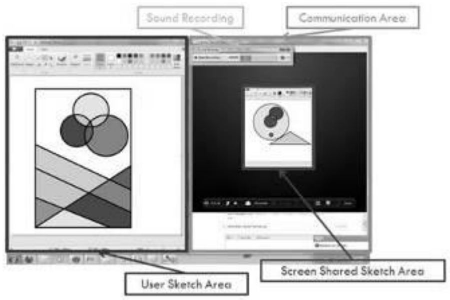

Fig. 2 Concurrent think aloud experiment interface

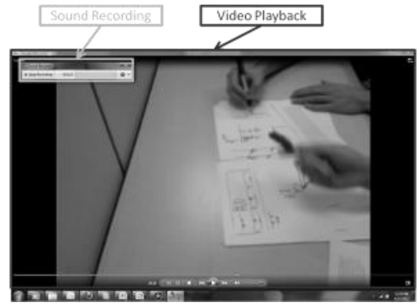

Fig. 3 Retrospective think aloud interface

Methodology Comparison

Two pilot experiments were conducted to test both methodologies. The first pilot experiment consisted of six participants and tested the concurrent think aloud method. The second tested the retrospective think aloud methodology and had seven participants (four of whom were collaborating and three who were in a control condition working alone).

While the concurrent approach obtained protocols successfully and the designers were not influenced by each other's protocols, there were several issues. First, individuals had a hard time verbalizing their thoughts when the other designer was talking to them. This was because it was too difficult to listen to what the other designer was saying while also trying to verbalize their own thoughts. Thus, the verbal protocols were discontinuous. Secondly, trying to work together via Skype and an electronic sketchpad made the collaborative design process complicated and reduced efficiency. It did not allow designers to collaborate as if they could have if they were in person. However, this approach may be beneficial if better collaboration tool were developed.

It was found using the retrospective approach designers were able to collaborate naturally. Also, the video provided adequate cues to the designers so they would not forget what they were thinking (designers were also allowed to look at their sketches which provided additional assistance in remembering). Subjects self reported that they were able to remember 90% or greater of their thoughts for design processes which lasted under thirty minutes. One of the challenges this methodology faced was that occasionally while designers were retrospectively thinking aloud, they would slip into describing the task they were doing, instead of describing their thoughts. To correct this, the experimenter reminded the designer to verbalize their thoughts, not just their actions.

The two pilot experiments demonstrated that the retrospective methodology provided better data and allowed for more natural design conditions. Therefore, it was decided to use collaborative retrospective protocol analysis in the experiment evaluating the CCS model.

4. CCS Model Evaluation- A Retrospective Protocol Analysis Approach

Subjects

Subjects for this experiment consisted of senior undergraduate students and master's level graduate students in mechanical engineering at the University of Southern California. All students were in classes focused on the engineering design process, and had group projects in those classes. Therefore, they were familiar with participating in collaborative design and had been taught basics on engineering design methodologies. All subjects signed a consent form when arriving at the study. They were compensated by being entered in a drawing for an iPod. The study was reviewed and was approved by the institutional review board.

Experiment Design

The dependent variable was the occurrences collaborative stimulation and cognitive processes. These were identified by applying a coding scheme to transcripts of the conversation and individual protocols.

The independent variable in the experiment was whether the designer was collaborating (the experimental group) or was working by their self (the control group). The experimental group members collaborated with each other in teams of two on the design problem, where as the control group worked alone. The control group was be used to compare and contrast the results the experimental group. The experimental group and control group were made up of ten and seven subjects, respectively. It was randomly determined to which group each subject would belong.

The control variables in this experiment design were the design problem, general background of the subjects, and think aloud method/training. All the subjects were given the same design problem and thinking aloud training regardless of the experimental condition. Also, each subject had a similar mechanical engineering background. The experiment design is shown in figure 4

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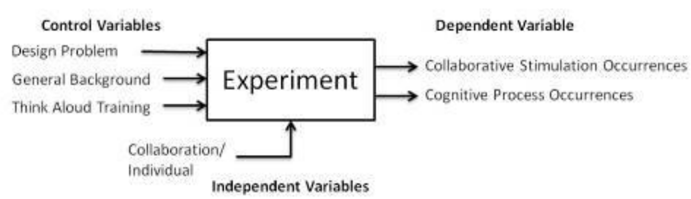

Fig. 4 CCS model evaluation experiment design

Procedure

All participants were randomly assigned to the control or experimental group, which was used to control for any variable which was not able to be accounted for (e.g. past design experiences, detailed class history, personality). Each designer then went through the experiment by first taking a Biographical Indicator of Creative Behaviors (BICB) test, being trained to think aloud, working on the design problem, retrospectively verbalizing their thoughts. Each step of the experimental procedure is summarized in figure 5.

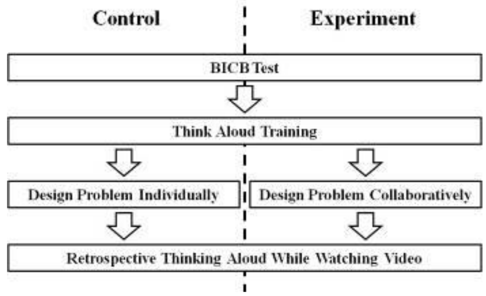

Fig. 5 Step-by-step experimental process

BICB Test

Before coming to the study, participants were given the Biographical Inventory of Creative Behaviors (BICB), to determine their individual creative potential (this test was reviewed with other creativity tests by Silvia, Wigert, Reiter-Palmon, & Kaufman (2011) and found to be both quick and effective). The results of the BICB were used as a covariate when comparing the results from the control and experimental groups, to control for the influence that past creative experience of each individual had.

Think Aloud Training

When first arriving at the study, participants were given training in verbalizing their thoughts. The training started with verbalizing a simple process, and then continued to get harder until the subject was verbalizing while performing a practice design problem.

Design Problem

Designers in the experimental group were given a design problem with their partner; where as individuals in the control groups were given a design problem to work through alone. Designers were provided with pencil, paper, and the design problem statement. The design problem given was to develop a device that would securely store skateboards, so students would not have to stack them up against the walls in class. Both the control and experimental groups were recorded on video as they worked through the problem.

Retrospective Thinking Aloud

Immediately after the subjects completed the design problem, they were asked retrospectively verbalize their thoughts from the design process. This was done while watching a video of the design problem, which provided verbal and visual cues. If the video moved too fast for the subject to provide a complete verbalization, they could pause the video to complete their thought. The retrospective verbalizations were recorded in an audio file for later transcription.

While the control subjects could have done the more traditional concurrent think aloud technique while going through the design problem, in order to ensure similarity between the control and experimental groups, they performed retrospective thinking aloud as well. This also eliminated any issue with the control group's design process being altered by thinking aloud.

Measurements and Data Analysis

The goal of this experiment was to observe creativity relevant generative cognitive processes and the various types of collaborative stimulation. This required that first the cognitive processes and secondly the collaborative stimulation be identified by using a coding scheme. The data from each experiment were two audio files and a video file from the experimental group, and a video file and audio file control group. To analyze these files using protocol analysis a coding scheme was developed which will later be applied to the transcripts of the files. The coding scheme mirrored the model, translating the abstract experimental data such that it can be compared with the model (van Someren et. al. 1994). The three main parts of the coding scheme consisted of the identification of design entities, cognitive processes, and collaborative stimulation.

Design Entities

A design entity was identified as a potential or partial solution having a form, function, and/or behaviour. Forms consist of the physical shape of an object. A behaviour consists of how an object interacts with its environment. A function is the purpose that an entity serves, generally related to the problem. Any time a form, function, or behaviour is mentioned, it is classified as a design entity. Initially, design entities start out as only a partial solution, but later develop into full solutions (Benami & Jin, 2002). Sometimes, design entities are accompanied by sketches, which made them easier to identify.

Cognitive Processes

After the design entities have been identified, all the cognitive processes occurring in the transcript were identified. Cognitive processes relevant to the CCS model in design consist of the generative processes of memory retrieval, association, and transformation (Benami & Jin, 2002). The identification of each cognitive process is mentioned below:

- Memory Retrieval: Can be an experience or design entity which occurred in the past and is remembered.
- Association: Identified as drawing connections between two design entities.
- Transformation: When a design entity is altered or changed.

Collaborative Stimulation Processes

Next the collaborative stimulation processes were identified by examining how cognitive processes came about, and if they could be attributed to a collaborative stimulation. The identification of each collaborative stimulation is listed below:

- Memory Stimulation: When an external design entity leads to a new memory retrieval. It can occur collaboratively or non-collaboratively.
- Seeding: When a collaborators external design entity is internalized by the subject and modified. Collaborative Completion: This occurs when an individual can’t make an association or transformation on an idea. Their collaborator then assists them to make the required cognitive process they were unable to make.
- Clarifying: This occurs when a subject feel their collaborator does not understand an idea, so they further clarify it. The process of clarification leads to further development.

- Accommodating: When a subject mixes their own idea with a collaborators idea, to either out of courtesy/negotiation or they see desirable properties in their collaborators idea.

Table 1 Coding scheme for the CCS model

Name	Abbr.	Coding Notation	Coding Example
Design Entities	**DE**		
Function Form Behaviour	F f b	F(hole) f(car) b(moves)	Makes hole in wood attached to a car which moves
Cognitive Processes	**CP**		
Memory Retrieval Transformation Association Problem Analysis Solution Analysis	MR TF AS PA SA	MR(X) TF(f(X), expanded) AS(f(x), f(y)) PA(X) SA(X)	I remember when ____ If X was expanded Idea X is like Idea Y Do we really need to accommodate X I don't think X would fit
Collaborative Stimulants	**CS**		
Memory Stimulation Seeding Collaborative Completion Clarifying Accommodating	Ms Se Cc Cl Ac	Ms(F(X),MR(f(y))) Se(F(X),TF(X);F(X*)) Cc(AS(F(X), F(Y));F(X*))) Cl(f(X), TF(X);F(X*)) Ac(AS(f(X), f(Y)), f(Z))	X reminded me of Y X was modified to create X* X and Y can be associated in this way, producing X* X works like this, but wait! it can be changed to X* We can combine X and Y to make Z

5. Discussion of Analysis

Using collaborative retrospective protocol analysis provided the ability to identify both internal (private) and external (shared) thoughts. Consider the example dialog and verbalized transcript/coding below, discussing a wall mounted skateboard rack.

Collaborative Dialog Transcript and Coding:

(1)you can just use like a pad lock…(2)Well, who with a skateboard carry around a padlock? What if it was like ID card swipeable? Every USD student is going to have an ID card…

Coding:(1)f(padlock),(2)f(IDcard, b(swipeable)) f(student, b(has,f(IDcard)))

Individual Retrospective protocol Transcript and Coding:

One of the things that I was thinking about when we were talking about the locking mechanism is how, in convention center back in Chicago I saw… almost like people lockup their coats in individual lock boxes and they all had ID cards that were based, it was in a convention center located in a hotel and that's part of where the ID card idea came from.

Coding: Ms(f(locking mechanism), MR(convention, f(people, b(lock, f(coats), f(lock boxes, f(ID cards, F(access f(lock boxes)))))))

In the example given above, it can be observed how the individual verbalization brings additional information the collaborative dialog does not show. The dialog only specifies specific design entities, where as the retrospective verbalization reveals the cognitive process (memory retrieval) creating the new entities, the design entity which stimulated the cognitive process (locking mechanism/padlock), and the type of collaborative stimulation involved (memory stimulation). It can also be observed how this retrospective verbalization goes into detail about the memory which was retrieved. Using collaborative retrospective protocol analysis method internal thoughts can be observed that conversation analysis would ignore. However, while subjects reported being able to remember 90% or greater of their thoughts while using this method, there is no way to be certain how much information is missing. In addition to the fact that not all thoughts may be verbalized, (Chiu & Shu, 2010) retrospective protocol analysis has the issue of memory accuracy. It is hard to quantify how large an issue memory may be.

6. Conclusion

The collaborative retrospective protocol analysis allows for the collection of both group dialogs and individual verbalizations, providing a new way to more fully analyse the individual's thought processes in the collaborative setting. The method allows for the observation of processes that are external (shared) and of those that are internal (private). It provides data that cannot be obtained by conversation analysis. While the authors are not cognitive scientists nor have formal training in this field, they would like to humbly propose that collaborative retrospective protocol analysis extends beyond evaluating the CCS model. They offer this method stands to be valuable for others analysing cognitive processes in the collaborative setting.

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