

Collaborative stimulation of memory retrieval in design

J. Sauder¹ and Y. Jin*

*Department of Aerospace and Mechanical Engineering, University of Southern California, 3650
McClintock Avenue, OHE430, Los Angeles, CA 90089-1453, USA*

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Collaboration has often been attributed to encouraging creativity. This assumption is explored here by investigating the influence of interactions between designers on creativity-relevant cognitive processes. It is proposed that design interactions stimulate creativity-relevant cognitive processes through collaborative stimulation. This paper specifically explores how the cognitive process of memory retrieval is stimulated through collaboration by prompting. It is hypothesized that collaboration leads to more stimulation of memory retrieval by design entities than working alone. A study using protocol analysis was conducted to evaluate this claim. It was found that the collaborative stimulation of prompting exists and that the collaborative setting leads to design entities stimulating more cases of memory retrieval. The result is explained through fixation, and recommendations are made for how these findings can be used to improve collaborative methodologies.

Keywords: collaborative creativity; creative cognition; memory; cognitive processes

1. Introduction

Modern designers face two key challenges: complexity and globalization. The increased complexity of current designs makes collaboration a vital necessity while globalization requires innovation and creativity to remain competitive in a rapidly developing world. These two issues provide motivation to investigate collaborative creativity: how one can use required collaboration to drive creativity.

Collaboration has often been assumed to encourage creativity, a concept that can be observed in workplace practices and literature. Many methods, such as brainstorming (Osborn, 1957), have been developed to enhance collaborative creativity. While many of these approaches do improve idea generation, some, like brainstorming, have questionable effects (Diehl & Stroebe, 1987). The authors believe that there is an opportunity to develop more effective collaborative design methods, if they are established on collaborative creativity research. The core question collaborative creativity research needs to consider is, “How does collaboration influence the creative process?”

Currently, there are two approaches to modeling collaborative creativity, consisting of aggregate models and process models. However, neither of these viewpoints explores how collaboration influences cognitive processes. Research in creative cognition has generated new insights to design methodologies by taking a detailed approach which

*Corresponding author. Email: yjin@usc.edu

considers the individual's cognitive cycles (e.g., Jin & Benami, 2010), but unfortunately does not consider collaboration. Thus, there is a gap between collaborative creativity and creative cognition. Research that bridges this gap may open ways to developing new collaborative methodologies by better understanding creative cognition in the context of collaboration.

A major challenge in extending creative cognition to collaborative settings is to experimentally identify cognitive processes and their interplay with collaborative interactions without greatly altering the design process. To overcome this challenge, an experiment was designed using retrospective protocol analysis. This allowed collaborators to work together naturally, while also collecting individual protocols. Both the individual protocols and conversation transcripts were then analyzed to provide a more holistic view for identifying both collaborative interactions and cognitive processes.

Using retrospective protocol analysis, this work was able to extend creative cognition to collaboration, proposing that cognitive processes are collaboratively stimulated through shared design entities. This proposal of collaborative stimulation raises the research questions, "What types of collaborative stimulation exist?" and "How influential is collaborative stimulation?" To answer these questions, a Collaborative Cognitive Stimulation (CCS) model, to be discussed, was developed, which is an extension of the creative cognition Generate–Stimulate–Produce (GSP) model (Jin & Benami, 2010).

While multiple types of collaborative stimulation are proposed in the CCS model, this paper focuses on the collaborative stimulation called *prompting*, which stimulates the cognitive process of memory retrieval. Memory retrieval is a critical part of creative design, being the primary step in concept generation as designers must build ideas on what they already know (Nijstad & Stroebe, 2006). To identify prompting in the design process, a design experiment was conducted where two designers collaborated on a problem. A control group of designers working alone were also tested to investigate how much prompting influenced the stimulation of memory retrieval. The findings from this work bring a better understanding of how collaborative stimulation works and how strong its influence is on the stimulation of memory retrieval. This knowledge can be used in the future for the development of more effective ideation techniques.

2. Related work

Creative cognition and collaborative creativity are the foundations upon which this research is built. Creative cognition is an approach that explains creativity as a cycle of convergent and divergent thought processes. The creative cognition approach has been expanded in examining both the field of design and memory retrieval in idea generation. Research in collaborative creativity can be divided into three categories: aggregate models, process models, and tools and methods to enhance collaborative creativity. Aggregate models view collaborative creativity as the summation of each team member's creativity while process models view collaborative creativity as a set of interaction processes that lead to a creative product. Finally, there are a number of tools and methods that have been developed to improve collaborative creativity.

The creative cognition approach was introduced by Finke, Ward, and Smith (1992). Their Geneplore model divides the creative cognitive process into generation and exploration, which occur in a cyclical manner, until preinventive structures become knowledge structures (complete concepts). The Geneplore model has been expanded to engineering design from multiple perspectives. Benami and Jin (2002) identified applicable creative cognitive processes: memory retrieval, transformation, association

(from generation); and problem analysis, solution analysis (from exploration) (also see Jin & Benami, 2010). Shah et al. (2003) developed an approach to align experiments occurring in cognitive research with those occurring in design. Specifically, they focused on incubation, with the hope to develop a more complete design ideation model. Chusilp and Jin (2006) identified three iteration loops, problem redefinition, idea stimulation, and concept reuse, occurring in engineering design and explored the types of cognitive processes that occurred in each loop. Applying creative cognition to design has led to new insights, particularly in the area of design fixation.

Initially, the issue of fixation was identified in cognitive psychology (Maier, 1931), and later in the field of design (Jansson & Smith, 1991). Fixation occurs when the “new” concepts a designer creates are limited because of prior observed solutions (Jansson & Smith, 1991) or premature commitment to a concept (Purcell & Gero, 1996). Fixation has been observed when providing example solutions to both novice and expert designers (Linsey et al., 2010; Viswanathan & Linsey, 2012). Additionally, physical examples have been found to be more powerful than images in facilitating fixation (Viswanathan & Linsey, 2013). However, being provided with stimulating examples is not necessarily bad, as they can foster new ideas, but there is a danger that they can promote fixation (Chan et al., 2011). Research taking a creative cognition approach has found that more ambiguous and less mature concepts provide the best stimulation (Jin & Benami, 2010). Other work in creative cognition has proposed providing the designer with examples that have a low commonality between themselves (Perttula & Sipilä, 2007) and abstract problem statements (Finke et al., 1992) reduces design fixation.

A common approach to explore cognitive processes occurring in design activity is to use protocol analysis. There are a number of design studies that use this approach in individual (e.g., Gero & Mc Neill, 1998; Jin & Benami, 2010; Suwa, Purcell, & Gero, 1998) and collaborative settings (Stempfle & Badke-Schaub, 2002). Analyzing verbal protocols can also be used to identify aspects in design such as uncertainty (Schunn, 2010) and social interactions (Cross & Clayburn Cross, 1995). To conduct protocol analysis, subjects think aloud while they are designing, and then transcripts of their thoughts are analyzed using a coding scheme (Cross, Christiaans, & Dorst, 1996; van Someren, Barnard, & Sandberg, 1994). While design researchers have cautioned of inaccuracies in the process of verbalization, it has been deemed to be helpful in identifying cognitive processes (Chiu & Shu, 2010).

A cognitive approach has often been used to explain memory retrieval. Memory retrieval is critical to innovative design as it impregnates working memory, where creative actions are carried out (Kerne & Smith, 2004). There are multiple views of cognition, two of the more popular being the production system (Anderson, 1996) and computational cognition (Sun, 2004) views. While they differ widely as to how cognition is modeled, when it comes to memory retrieval beyond semantics, the two are basically the same: information from long-term (or declarative) memory is transferred to working (or associative) memory. The similarity regardless of cognitive model is not surprising considering that much earlier work has proposed a theory for memory retrieval, where probes (or stimulants) activate different memories, which spans multiple perspectives on cognition (Ratcliff, 1978). Similarly, Nijstad and Stroebe (2006) demonstrate that a collaborator’s ideas in brainstorming can activate problem-relevant information by examining how collaboration influences the retrieval process from long-term memory to short-term memory. This activation could occur as concepts to which individuals are exposed directly influence the ideas they remember, and collaboration increases exposure to a diverse set of concepts (Satzinger, Garfield, & Nagasundaram, 1999). In addition,

a collaborative group has a larger combined set of memories than an individual, meaning that there are more memories that can be retrieved (West, 2002).

Many authors exploring collaborative creativity, the second foundation of this work, have proposed models of collaborative creativity. Models can be grouped into two categories: aggregate models and process models. Aggregate models view collaborative creativity as the aggregation of each team member's creativity (Pirola-Merlo & Mann, 2004; Shalley & Perry-Smith, 2008; Taggar, 2002). They examine various aspects of the team's environment and the unique attributes each team member brings and how this influences the creativity each member contributes to the team. Process models view collaborative creativity as a set of interaction processes that leads to a creative product (Sonnenburg, 2004; Stempfle & Badke-Schaub, 2002; West, 2002). Often, the models have many inter-relations between each of the processes.

There has also been much work in collaborative creativity focused on the development and evaluation of methods to improve creativity. Methods and tools have included the 6-3-5 method (Rohrbach, 1969), brainstorming (Osborn, 1957), collaborative notebooks (Michalko, 2001), tablets and PDAs to share information (Warr & O'Neill, 2005), tabletop screens (Terrenghi, Fritsche, & Butz, 2006), and Smart Boards (Sundholm, Artman, & Ramberg, 2004). There are others who improve creativity through an organizational approach. Amiable et al. (1996) focuses on practices management can enact to foster a creative environment. Wilde (2010) suggests putting together team members with diverse problem-solving abilities, although it should be noted that diversity without interpersonal congruence can be damaging (Polzer, Milton, & Swann, 2002).

Perhaps the most popular method and most frequently researched is brainstorming. While brainstorming was designed to encourage ideas from a group (Osborn, 1957), it was soon found that collaborative brainstorming produced a lower quantity and quality of creative ideas than working alone (Taylor, Berry, & Block, 1958). Reviews of brainstorming research have identified that this was due to social inhibitions and procedural issues (Diehl & Stroebe, 1987; Lamm & Trommsdorff, 1973; Mullen, Johnson, & Salas, 1991). Interestingly, more recent research on brainstorming shows the method has positive stimulating effects, which are dampened by the issues (Brown, Tumeo, Larey, & Paulus, 1998; Dugosh, Paulus, Roland, & Yang, 2000). It has been found when ideas are shared momentarily, to avoid procedural issues, individuals will produce more ideas (Perttula, Krause, & Sipilä, 2006). More effective methods and tools can be designed if they are based on creativity research, as can be observed in the creation of the C-sketch method (Shah, Vargas-Hernandez, Summers, & Kulkarni, 2001) that was developed by considering collaborative creativity research.

In examining the past work on creative cognition and collaborative creativity, a gap can be observed. Creative cognition explores cognitive processes of each designer (Chusilp & Jin, 2006; Finke et al., 1992; Jin & Benami, 2010), but does not explore the influence of collaborative interactions. Collaborative creativity examines team interactions, but treats individuals as "black boxes," not investigating individual cognitive processes (Pirola-Merlo & Mann, 2004; Mullen et al., 1991; West, 2002). While there have been several attempts to bridge this gap, they have not fully extended creative cognition to collaboration. Shalley and Perry-Smith (2008), who explore team creative cognition and how individual creative cognition is infused into it, treat individual creative cognition abstractly by not exploring individual cognitive processes. Similarly Stempfle and Badke-Schaub (2002), who take a cognitive approach to the engineering design process, break down thinking operations into categories but not individual cognitive processes. This work aims to bridge that gap, by extending creative cognition to collaboration.

Models extending creative cognition to design have provided the foundation for insights on methodologies (Chusilp & Jin, 2006; Hernandez, Shah, & Smith, 2010; Jin & Benami, 2010), and methods derived from research such as C-sketch (Shah et al., 2001) have been observed to be effective. Therefore, it is prudent to extend creative cognition to collaboration in design to provide the basis for creating more effective collaborative methodologies.

3. A model of collaborative stimulation in engineering design

The CCS model extends Jin and Benami's (2010) GSP model of creativity in conceptual design to collaborative creativity. Their model consists of design entities, which then stimulates cognitive processes (both generative and exploratory), which then produces design operations, which then generates new design entities, as shown in Figure 1(a). The cycle continues until preinventive design entities (undeveloped ideas) mature to knowledge entities (more completed concepts).

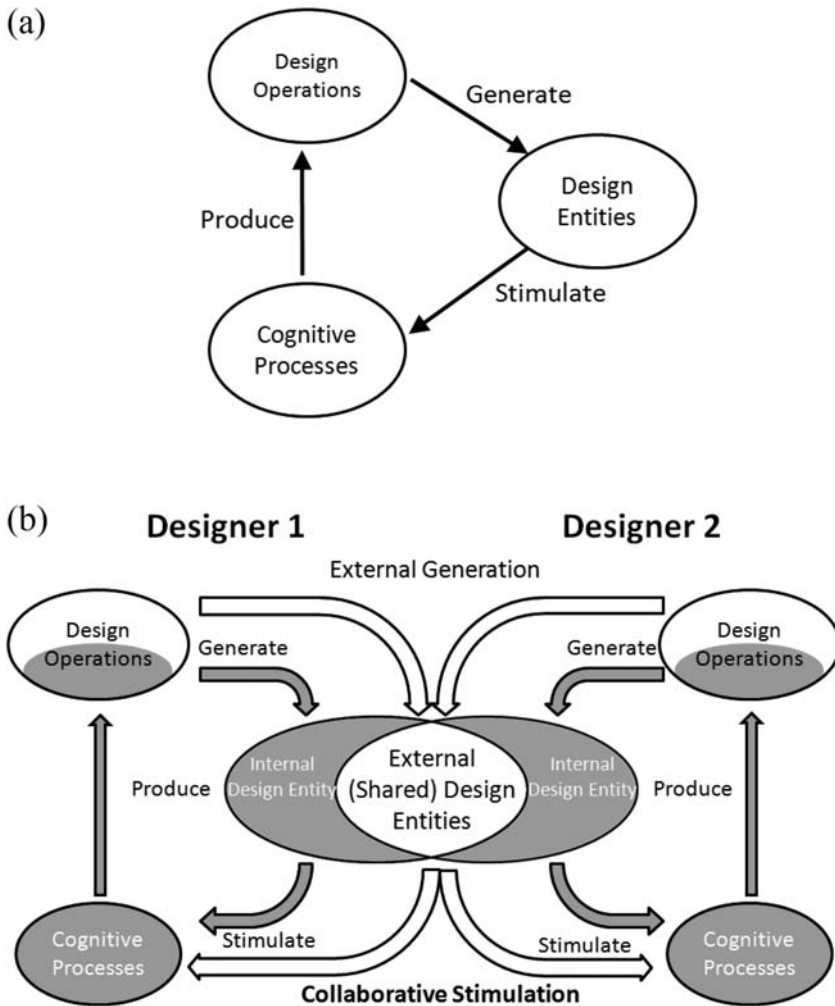


Figure 1. GSP model (a) and CCS model (b).

In the CCS model, as shown in [Figure 1\(b\)](#), each designer engages in the same individual processes (shown in gray), but there are also elements that occur externally (shown in white) and are observable by the collaborator. The CCS model extends the GSP model to collaboration by proposing that interactions between designers occur through external design entities. These interactions are hypothesized to stimulate cognitive processes through collaborative stimulation. Cognitive process stimulation now occurs both individually through internal design entities and collaboratively through external design entities.

3.1 A closer look at collaborative stimulation

There are multiple types of collaborative stimulation, which can be divided into two mechanisms through which they work: design entity initiated and questioning initiated.

Design entity initiated stimulation occurs when a design entity the collaborator developed stimulates a generative cognitive process. It takes advantage of the diversity in group knowledge and skills (West, 2002). Design entity-initiated stimulation includes *prompting*: a design entity developed by the collaborator stimulates memories in the designer (Nijstad & Stroebe, 2006). Another design entity-initiated stimulation is *seeding*: a design entity from a collaborator is infused into the designer's working memory, and the designer goes on to further develop the idea. From this seeded idea, knowledge can be applied to new domains and new ideas generated (Nijstad & Stroebe, 2006).

Questioning initiated stimulation occurs when a question (or assumed question) from the collaborator stimulates a generative cognitive process of a designer. Question-initiated stimulation consists of *correcting*: the designer is asked a question or challenged by a collaborator, and then alters the design entity to resolve the raised issue. Finding critiques and then revising the design based on those critiques is a key component of the design process (Holsapple & Joshi, 2002). Also included is *clarifying*: an individual senses that their collaborator does not understand an idea and attempts to clarify their idea by explaining it in a different way, like using an analogy, which leads to further development of the idea. Analogies have often been used to explain concepts (Glynn & Takahashi, 1998). These various types of collaborative stimulation can be summed up in [Figure 2](#).

Each type of collaborative stimulation is speculated to have a different influence on each cognitive process. The likelihood of each type of collaborative stimulation leading to the stimulation of cognitive processes is shown in [Figure 3](#). The stimulation of generative cognitive processes consisting of *memory retrieval* (remembering an idea from the past), *association* (drawing relationships between two design entities), and *transformation* (altering a design entity) (Jin & Benami, 2010), have been explored thus far.

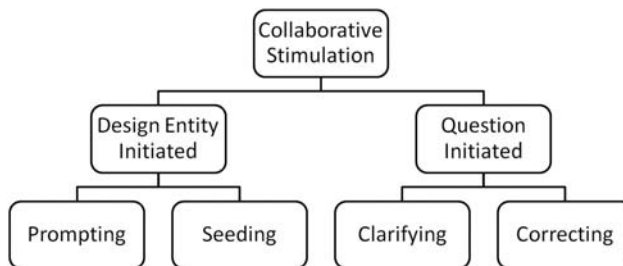


Figure 2. A breakdown of collaborative stimulation.

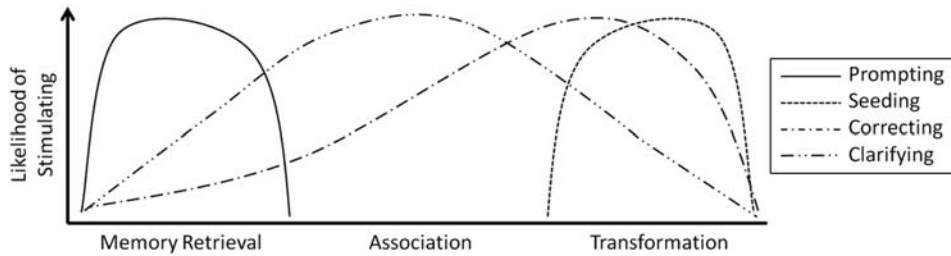


Figure 3. Relationships between collaborative stimulation and cognitive processes.

As shown in Figure 3, it is hypothesized that prompting and seeding are likely to stimulate memory retrieval and transformation, respectively, while correcting and clarifying can stimulate any of the three generative processes with a concentration on transformation and association, respectively. This paper focuses on how collaboration influences the stimulation of memory retrieval. Therefore, the collaborative stimulation type prompting will be investigated in detail.

4. Collaborative stimulation of memory retrieval

Memory retrieval occurs when a memory from the past (in long-term memory) is brought into the present (working memory). Current research, as discussed, supports that other's ideas would stimulate memory retrieval (Ratcliff, 1978; Satzinger et al., 1999; West, 2002). Memory retrieval is important for creative idea production, as all new ideas must begin with remembering an old concept, which then is changed or altered (Nijstad & Stroebe, 2006). It should be noted that memory retrieval can be stimulated by a designer's own ideas as well (defined as individual memory stimulation); however, this is not collaborative stimulation and not caused by prompting.

4.1 Hypotheses

Two hypotheses regarding the stimulation of memory retrieval are proposed.

- H1: External design entities generated by an individual's collaborators stimulate memory retrieval through the collaborative stimulation of prompting.
- H2: Design entities are more likely to stimulate memory retrieval in the collaborative setting than in the individual setting due to prompting

H1 proposes a process that occurs when a design entity from a collaborator stimulates memory retrieval. A design entity can be a form (aka structure), function, behavior, or a mix of these three elements (Benami & Jin, 2002). In the GSP model (Jin & Benami, 2010), it was shown that a design entity generated by a designer during design process can stimulate the designer's own memory retrieval process. In collaborative design, a design entity developed by a designer's collaborator and presented to the designer may have the similar stimulating effect. H1 is tested by examining whether collaborative prompting exists, and whether prompting from external design entities stimulates the cognitive process of memory retrieval.

H2 proposes that individuals collaborating are more likely to have design entities stimulate the memory retrieval process than individuals working alone. There are two proposed reasons for this. In a collaborative design situation, two or more designers are involved and there are more design entities generated that can serve as stimuli. Secondly,

design entities generated by others are likely to be more simulative as they are coming from different lines of thinking. H2 will be tested by comparing how often design entities stimulate memory retrieval in the individual and collaborative settings.

5. Experimental approach

5.1 *A retrospective and concurrent approach to protocol analysis*

To analyze collaborative activity in design, dialog transcripts have been used. Sometimes, actual protocol analysis has been used to explore cognition by applying a coding scheme to the dialog transcript (e.g., Stempfle & Badke-Schaub, 2002), while in other times the conversation is only analyzed for social interactions (e.g., Cross et al., 1996). However, these approaches usually cannot identify specific cognitive processes occurring in the mind of the individual. There are two challenges to accomplishing this: How can a subject verbalize their thoughts and not influence their collaborator (C1)? How can cognitive processes be observed when individuals are required to talk with each other and thus cannot continuously verbalize their thoughts (C2)? Two different methods were developed to address these challenges: concurrent collaborative protocol analysis and retrospective collaborative protocol analysis.

The first method, concurrent collaborative protocol analysis, used a physical barrier between subjects that allowed communication to flow but prevented verbalized thoughts from being communicated. This was accomplished by having two subjects collaborate remotely using Skype, with a screen share and push-to-talk feature installed. The screen share was used with an electronic sketchpad, allowing subjects to share images. The subjects used the push-to-talk feature whenever they wanted to communicate with their collaborator, similar to a walkie-talkie. This allowed the subjects to verbalize their thoughts as they were 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, considering that while speaking, a subject is saying what they are thinking.

The second method, retrospective protocol analysis, took a different approach to solve challenges C1 and C2. Subjects were allowed to collaborate in person in a natural environment, while being videotaped. After the session was completed, subjects watched the video and retrospectively verbalized their thoughts 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 allows the subjects to collaborate in a natural environment, and allows for continuous verbalization of their thoughts (solving C2). Also, as the verbalizations occurred after the collaboration, it was impossible for the subject's verbalizations to impact their collaborators thoughts (solving C1).

Out of the two methods, initial experiments demonstrated that the retrospective methodology worked most smoothly and provided the best data. When performing concurrent thinking aloud, individuals had a hard time verbalizing their thoughts when the other subject was talking to them, as it was too difficult to listen and verbalize their own thoughts at the same time. Thus, the verbal protocols were discontinuous. Also, it was found that using Skype and an electronic sketchpad as a collaborative tool did not allow for effective collaboration. The retrospective method gave the individuals the opportunity to work in a natural environment. It was also found the video provided adequate cues to the subjects facilitating their ability to recall their thoughts (subjects were also allowed to look

at their sketches that provided additional assistance in remembering). Therefore, it was decided to use the retrospective collaborative think aloud method.

5.2 Participants

Seven mechanical engineering students from the University of Southern California, all males, were recruited for the study on a volunteer basis. All students had either just completed a senior/graduate level course on design theory and methodology or were members of the IMPACT laboratory, and thus had exposure to design methodology and collaborative design. However, the participants were novice designers as all had less than a year of industry work experience. While the students participating in the study represented many nationalities and had grown up in different cultures, all were currently living in the Los Angeles area.

5.3 Task and materials

Before coming to the study, the students were given the Biographical Indicator of Creative Behaviours, to determine their past creative experience that was used to ensure the similarity between the control and experimental groups. The Biographical Indicator of Creative Behaviours was reviewed with other creativity tests by Silvia et al. (2012) and found to be both quick and effective. At the study, the students were presented with a design problem statement (given in full in Appendix 1) that asked to design a system or device that would reduce traffic congestion. As traffic is a prevalent problem in Los Angeles, all the students were familiar with this issue. In addition to the statement, students were given verbal instructions to go about the design task as they normally would and to come to one final solution. The students were given pens and paper to write down and sketch their ideas. The design process was documented using a video camera and a microphone, which recorded directly to a computer. Two computers with microphones were used to play back the design process video and record the retrospective think aloud.

5.4 Experiment design

In order to test the hypotheses, it was necessary to compare occurrences of prompting for those who worked individually with those who worked collaboratively. The students divided into the two groups to create the independent variable: an experimental group that collaborated (two teams of two) and a control group that worked individually (three subjects). The dependent variables of this study were the number of cases of collaborative prompting and the number of cases of individual memory stimulation. The control variables in this experiment design were the design problem and general background of the students. The same design problem was given to each student, and all students had similar mechanical engineering backgrounds with some exposure to design theory and lived in the greater Los Angeles area. [Figure 4](#) summarizes the design of the experiment.

5.5 Procedure

Before coming to the study, participants were given The Biographical Inventory of Creative Behaviours (BICB) via an internet survey to measure past creative experience. The results of the BICB were used to create control and experimental groups, such that the difference in average BICB score between both groups was within 1 standard deviation.

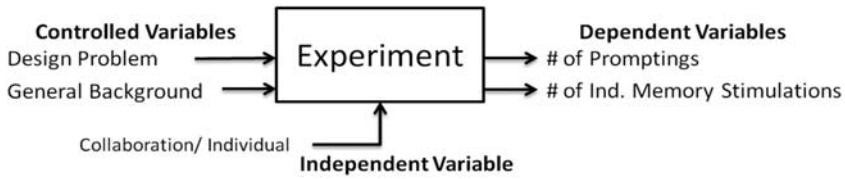


Figure 4. Experiment design.

The BICB was also used in the experimental condition to create teams with the same average BICB score.

When first arriving at the study, students were given training in verbalizing their thoughts. This training session consisted of thinking aloud while working through several problems. It started by asking the student to describe the process of coming to the study in detail, then asked them to think aloud while solving a brain teaser, and finally asked them to think aloud on a practice design task.

Then participants in the experimental group were given a design problem with their partner, while individuals in the control groups were given a design problem to solve alone. Participants were provided with a pen, paper, and the design problem statement. Both the control and experimental groups were recorded on video as they worked through the problem.

Immediately after the completion of the design problem, the subjects viewed the recorded video and were asked to retrospectively verbalize their thoughts while watching. The experimental (collaborative) groups were moved to different locations in the laboratory while retrospectively verbalizing, so they could do so in private. The retrospective verbalizations were recorded for later transcription. Although 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. The experiment procedure adopted in this research is illustrated in Figure 5.

6. Data analysis and results

6.1 Transcribing and coding

The video and audio recordings were saved, and the audio recordings of the retrospective analysis were transcribed. The transcriptions were broken into 30-second segments, which allowed the comparison of specific points in the retrospective audio between collaborators in the control condition (Figure 6).

By taking a protocol analysis approach to analyze the transcripts, how each collaborator stimulated the other in the experimental case and self-stimulations in both the

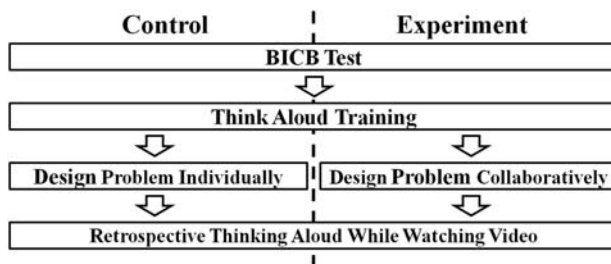


Figure 5. Experiment procedure.

Audio Time RT1	0:06:46	0:07:16	0:07:46
Retrospective Transcript 1	had to be pretty novel, just because, what we already come up with already existed. Like someone was already doing it really well. Can't really hear what he is saying, so this is...	I, Oh, at this point I think I was a little bit confused on weather we were on the same idea, because I was thinking weather we were possibly, he was thining. Oh at this point he came up with a good idea, and I was excited because I had already seen it used	In my home town, which made things difficult as I felt the ideas we were thinking of were already in use in places most often. But, Still, So at this point I was pretty much thinking directly wondering about how these boards work
Audio Time RT2	0:06:45	0:07:15	0:07:45
Retrospective Transcript 2	Yeah, smart phone is good choice, but we have to design a system, and not just a dvice. Because there are a lot of device here we can use to show traffic information. But I want to us to show, the system, not a device, that could be integrated into the vehicles or the freeway.	Well I, I have seen some board previously on the freeway or in some cities. A lot of countries or in some states they already have a board, on the side of the road can show some traffic, so I came up with the idea	yeah, and robert, some type of device already knew, and he explained some type of device already existed there. And he explain this type of device in hometown, and

Figure 6. Retrospective Transcripts for analysis.

experimental and control cases could be observed. The typical approach to protocol analysis is to segment and code the entire design episode (Gero & Mc Neill, 1998). However, as the authors were interested in only the stimulation of memory retrieval (vs. multiple cognitive process) by design entities, a hybrid three-step coding approach only identifying memory retrieval and its stimulation was taken to reduce the analysis time: identifying design entities, identifying cases of memory retrieval, and identifying cases of stimulation from prompting and individual memory stimulation.

The segments were analyzed using a coding scheme, given in Table 1. The first step in coding was to identify all design entities. A design entity was identified as an idea having a form, function, and/or behavior (Jin & Benami, 2010). Sometimes design entities were accompanied by sketches, which assisted in identification. The second step was to identify all the cases of memory retrieval in the transcript. The cognitive process of memory retrieval in design was defined along the same lines as Jin and Benami (2010): remembering an idea from the past. For the third step, the identification of the stimulation of memory retrieval, the protocol was examined for design entities followed by memory retrieval. If the design entity inspired the memory retrieval, then it was a case of prompting or individual memory stimulation. Prompting occurred when the inspiring design entity was developed by a collaborator. Individual memory stimulation occurred when the inspiring design entity was created by the student.

A similar coding scheme was used by the authors to identify more cognitive process and other types of collaborative stimulation in later experiments. When checked by an intercoder,

Table 1. Coding scheme for identifying prompting.

Type	Name	Abbr.	Coding notation	Coding example
Design entity (DE)	Function	F	F (make hole)	Makes hole in wood
	Structure	S	S (car)	Attached to a car
	Behavior	B	B (moves)	Moves up and down
Cognitive process	Memory retrieval	MR	MR (DE(X))	I think a solution would be (preexisting solution)
Stimulation	Prompting	Pr	Pr (DE(X), MR (Z))	X from collaborator reminded me of Z
	Individual memory stim.	Im	Im (DE(Y), MR(Z))	My idea Y reminded me of Z

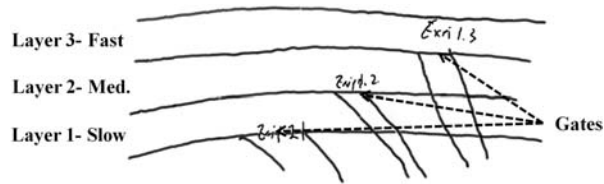


Figure 7. Sketch of multiple layers of traffic.

that coding scheme was found to have an intercoder reliability kappa of 0.85. An example of applying each step of the coding scheme follows.

6.2 Example analysis

6.2.1 Step 1: identifying design entities

Consider the protocol from a student in the control group. “I was thinking, yeah, you can have, yeah, multiple layers of traffic. High speed, medium speed, and low speed.” In this protocol, the design entity, a layered road, could be identified as having the form of multiple layers (show in Figure 7). It also had the behavior of a different speed for each layer and the implied function of reducing congestion.

6.2.2 Step 2: identifying cases of memory retrieval

In another case, two collaborators (J and M) were working on a design entity they called “Active GPS.” The active GPS, conceived by J, would direct drivers to their destination and reduce traffic by assigning cars to different routes. The concept of active GPS causes memory retrieval in participant M, found in his retrospective transcript.

So now I was just kind of thinking of having some incentives for people doing what you tell them to do. Because in my experience if you tell someone to do something and they see a solution, and think that it is better, the overall good is something they don't keep in mind.

Here, when considering how the active GPS would work, M was drawing from his memory of situations where people would not do what is in the best interest of others but seek their own best interest.

6.2.3 Step 3: identifying cases of prompting and individual memory stimulation

The “Active GPS” example just mentioned is a case of prompting. The design entity of “Active GPS” generated by J stimulated M to have a memory retrieval of his past experience interacting with individuals; specifically that “the overall good is something they don't keep in mind.”

A case of individual memory stimulation occurred immediately after the first example of “multiple traffic layers.” The subject's protocol follows:

So, at this time I was thinking some kind of gate traffic that could determine if the vehicle was exiting, or could make some sort of sound if the vehicle was exiting. Or if the vehicle was not exiting, then the gate won't open. There won't be any physical connections on this road. I realize it's almost impossible, it's like Battle Cruisers, it's like airplanes get in get out at the same time. You have to have elevators to raise and lower.

This example shows how the design entity of “gate” stimulated the memory retrieval of “Battle Cruiser.” This memory led to a solution analysis that “gates” would not work. This is a case of individual prompting, as the design entity “gate” was created by the subject.

6.3 Results

In analyzing the transcripts, it was found that memory retrieval was stimulated by design entities through both the collaborative stimulation of prompting and individual memory stimulation. The experimental condition averaged 2.25 promptings (collaborative stimulations) of memory retrieval per designer ($SD = 1.71$) and 2.50 individual stimulations per designer ($SD = 1.29$). The difference between these two is not statistically significant. The results are shown in Figure 8, with 70% confidence intervals.

In comparing the control group with the experimental group (Figure 9), it was observed that the control group had 2.0 cases of design entities stimulating memory retrieval per person ($SD = 1.00$), whereas the experimental group had 4.75 cases of design entities stimulating memory retrieval per person ($SD = 2.21$).

The results between the control and experimental groups were not found to be statistically significant, with $p = 0.15$. However, comparing just the number of memory stimulations per individual occurring during the entire design process is not the best approach, as the control group spent much more time on the design problem. They averaged 35 min on the problem (ranging from 22 to 43 min) while the experimental group

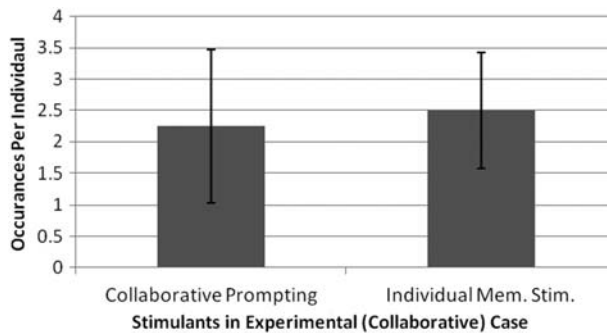


Figure 8. Experimental stimulation breakdown.

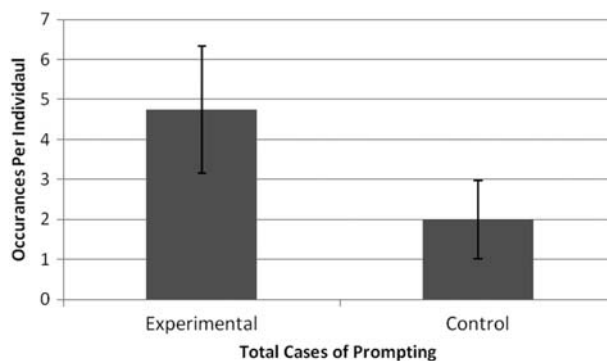


Figure 9. Experimental stimulation: control vs. experimental.

Table 2. BICB, problem time, and stimulation period.

	Experimental group	Control group
Average BICB score	7.5	11.3
Average problem time	25	35
Stimulation period	5.4	17.5

averaged 25 min on the problem (ranging from 21 to 30 min). A much better representation can be observed by exploring the frequency of memory stimulation. The experimental group had a mean of 0.187 memory stimulations per minute ($SD = 0.068$) while the control group had a mean of 0.063 memory stimulations per minute ($SD = 0.035$). Using a one-way ANOVA, these differences were found to be significant $F(1, 5) = 8.00$, $p = 0.037$.

Additional important statistical data points to consider were the average BICB scores. The experimental group had an average BICB score of 7.5 whereas the control group had an average BICB score of 11.3. Because of the small sample size, it was impossible to obtain the same average BICB score of the control and experimental groups. Therefore, it was decided to allow the BICB score to weigh in favor of the control group, as it would be undesirable to have a positive hypothesis negated by BICB scores favoring the experimental group. The results are summarized in [Table 2](#).

7. Discussion

Through protocol analysis, it was clear that external design entities developed by a designer's collaborator stimulated memory retrieval through prompting, verifying H1. This aligns with other research findings that collaboration provides creative stimulation (Brown et al., 1998; Dugosh et al., 2000) and that collaborators' ideas will prime a fellow collaborator to remember (Nijstad & Stroebe, 2006). It was also found in the experimental case that individual memory stimulation and prompting were about as equally likely to occur.

The results also substantiate H2, which claims in the collaborative setting design entities are more likely to stimulate memory retrieval than in the individual setting. When using a one-way ANOVA to compare the frequency of stimulation of memory retrieval by design entities occurring in the control and experimental cases, the difference was found to be statistically significant. The hypothesis is further supported as the control group had a higher average BICB score, which one would expect to lead to more stimulation. This consideration emphasizes the strong influence of collaboration on design entities stimulating memory retrieval.

While prompting was a key element in making the stimulation of memory retrieval more likely in the collaborative setting than the individual one, the number of individual memory stimulations was also greater. There were 2.5 individual stimulations per designer in the collaborative setting, whereas in the individual there were only 2.0 stimulations per designer. This would imply that collaboration not only has a direct effect on stimulation (through prompting), but that there is also an indirect effect on individual stimulation. Similar observations of collaboration's indirect stimulating effect were made by Dugosh et al. (2000).

Whether direct or indirect, why does collaboration seem to cause more stimulation of memory retrieval? An explanation could be that prompting reduces design fixation. When

a collaborator shares a design entity, it may stimulate an individual, pushing them away from their fixated perspective and causing them to remember new perspectives. This theory would be supported by creative cognition work that has found uncommon (Perttula & Sipilä, 2007) and immature (Jin & Benami, 2010) stimuli result in less fixation. Instead of a third party providing a stimulus as has occurred in past research (e.g., Chan et al., 2011), the collaborator provides the stimulating design entity that results in prompting. While collaborating may assist in reducing fixation on the individual level, caution must be exercised to ensure that fixation does not occur on the team level, which is also known as group think (Esser, 1998). In design experiments, groups have been observed to especially fixate when a poor example is provided (Fu, Cagan, & Kotovsky, 2010).

The results from this experiment provide several insights for collaborative methodologies encouraging creativity. First, it is important for designers to have full exposure to each other's ideas. As prompting is stimulated by external design entities, it is important for designers to ensure that any internal design entities are shared and become external. Secondly, this work found that memory retrieval is more frequently stimulated by design entities in the group setting than the individual setting. Therefore, it is important that designers generate concepts together, or at least in a way ideas can be shared. For example, methods such as electronic brainstorming can be used to reduce social inhibitions and procedural issues (Gallupe et al., 1992) or only sharing the concepts momentarily has provided positive design outcomes (Perttula et al., 2006).

It should be noted that the small number of data points (7 participants) is a definite limitation of this study, as better statistical significance for all results could be obtained by having more subjects. Due to the time-consuming nature of protocol analysis, it is challenging to have large sample sizes. However, this study's alignment with findings from collaborative creativity research outside of the field of design adds confidence to the results. The findings are also important, as memory retrieval provides the foundation on which designers build new ideas (Perttula & Liikkanen, 2006).

There are three key areas of future work remaining to be completed. First, a second experiment with more subjects should occur to verify the findings in this study, which would increase the level of significance in all areas. Second, after the stimulation of memory retrieval has been compared between groups collaborating and individual working alone, it should be explored for the rest of the generative and exploratory cognitive processes Jin and Benami (2010) identified. Thirdly, from these results, interventions need to be designed to promote more collaborative stimulation within groups.

8. Conclusion

In engineering design, there is a need to creatively collaborate. Combining collaborative creativity and creative cognition research, through a collaborative stimulation perspective, provides an opportunity to develop more effective methodologies. Specifically explored in this paper was the stimulation of memory retrieval through prompting, as proposed by the CCS model, and individual memory stimulation. Using retrospective protocol analysis, collaborative (experimental) groups were compared with individuals working alone (control group). The experiment found prompting exists and it plays an important role in stimulating memory retrieval through shared (external) design entities. Because of prompting, those in a collaborative setting had memory retrieval stimulated significantly more often than those working alone. This may occur because of reduced fixation. Collaboration also appears to have an indirect effect on individual memory stimulation. However, when considering the results, the small sample size, a key area for future work,

should be kept in mind. This study emphasized the importance of collaboration in the creative process, and while there is much future work to be done, it begins to explain the driving research question posed at the beginning of this paper “How does collaboration influence the creative process?” in an effort to provide new insights for methodologies.

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Note

1. Email: jsauder@usc.edu

References

- Amabile, T. M., Conti, R., Coon, H., Lazenby, J., & Herron, M. (1996). Assessing the work environment for creativity. *The Academy of Management Journal*, *39*, 1154–1184.
- Anderson, J. R. (1996). *The architecture of cognition* (Vol. 5). Mahwah, NJ: Psychology Press.
- Benami, O., & Jin, Y. (2002). Creative stimulation in conceptual design. *Proceedings of ASME design engineering technical conferences and computer and information in engineering conference*, Montreal, QC, Canada.
- Brown, V., Tumeo, M., Larey, T. S., & Paulus, P. B. (1998). Modeling cognitive interactions during group brainstorming. *Small Group Research*, *29*, 495–526. doi:10.1177/1046496498294005
- Chan, J., Fu, K., Schunn, C., Cagan, J., Wood, K., & Kotovsky, K. (2011). On the benefits and pitfalls of analogies for innovative design: Ideation performance based on analogical distance, commonness, and modality of examples. *Journal of Mechanical Design*, *133*, 081004–081004. doi:10.1115/1.4004396
- Chiu, I., & Shu, L. H. (2010). Potential limitations of verbal protocols in design experiments. *American Society of Mechanical Engineers*, 287–296. doi:10.1115/DETC2010-28675
- Chusilp, P., & Jin, Y. (2006). Impact of mental iteration on concept generation. *Journal of Mechanical Design*, *128*, 14–25. doi:10.1115/1.2118707
- Cross, N., Christiaans, H., & Dorst, K. (Eds.). (1996). *Analysing design activity* (Vol. 11, p. 463) Chichester: Wiley.
- Cross, N., & Clayburn Cross, A. (1995). Observations of teamwork and social processes in design. *Design Studies*, *16*, 143–170. doi:10.1016/0142-694X(94)00007-Z
- Diehl, M., & Stroebe, W. (1987). Productivity loss in brainstorming groups: Toward the solution of a riddle. *Journal of Personality and Social Psychology*, *53*, 497–509. doi:10.1037/0022-3514.53.3.497
- Dugosh, K. L., Paulus, P. B., Roland, E. J., & Yang, H. -C. (2000). Cognitive stimulation in brainstorming. *Journal of Personality and Social Psychology*, *79*, 722–735. doi:10.1037/0022-3514.79.5.722
- Esser, J. K. (1998). Alive and well after 25 years: A review of groupthink research. *Organizational Behavior and Human Decision Processes*, *73*, 116–141. doi:10.1006/obhd.1998.2758
- Finke, R. A., Ward, T. B., & Smith, S. M. (1992). *Creative cognition: Theory, research, and applications*. Cambridge, MA: The MIT Press.
- Fu, K., Cagan, J., & Kotovsky, K. (2010). Design team convergence: The influence of example solution quality. *Journal of Mechanical Design*, *132*, 111005–111005. doi:10.1115/1.4002202
- Gallupe, R. B., Dennis, A. R., Cooper, W. H., Valacich, J. S., Bastianutti, L. M., & Nunamaker, J. F. (1992). Electronic brainstorming and group size. *The Academy of Management Journal*, *35*, 350–369. doi:10.2307/256377
- Gero, J. S., & Mc Neill, T. (1998). An approach to the analysis of design protocols. *Design Studies*, *19*, 21–61. doi:10.1016/S0142-694X(97)00015-X

- Gero, J. S., & Tang, H. -H. (2001). The differences between retrospective and concurrent protocols in revealing the process-oriented aspects of the design process. *Design Studies*, 22, 283–295. doi:10.1016/S0142-694X(00)00030-2
- Glynn, S. M., & Takahashi, T. (1998). Learning form analogy-enhanced science text. *Journal of Research in Science Teaching*, 35, 1129–1149.
- Hernandez, N. V., Shah, J. J., & Smith, S. M. (2010). Understanding design ideation mechanisms through multilevel aligned empirical studies. *Design Studies*, 31, 382–410. doi:10.1016/j.destud.2010.04.001
- Holsapple, C. W., & Joshi, K. D. (2002). A collaborative approach to ontology design. *Communications of the ACM*, 45, 42–47. doi:10.1145/503124.503147
- Jansson, D. G., & Smith, S. M. (1991). Design fixation. *Design Studies*, 12, 3–11. doi:10.1016/0142-694X(91)90003-F
- Jin, Y., & Benami, O. (2010). Creative patterns and stimulation in conceptual design. *AI EDAM*, 24, 191–209. doi:10.1017/S0890060410000053 (Special Issue 02).
- Kerne, A., & Smith, S. M. (2004). The information discovery framework. In *Proceedings of the 5th conference on Designing interactive systems: processes, practices, methods, and techniques* (pp. 357–360). New York, NY: ACM.
- Lamm, H., & Trommsdorff, G. (1973). Group versus individual performance on tasks requiring ideational proficiency (brainstorming): A review. *European Journal of Social Psychology*, 3, 361–388. doi:10.1002/ejsp.2420030402
- Linsey, J. S., Tseng, I., Fu, K., Cagan, J., Wood, K. L., & Schunn, C. (2010). A study of design fixation, its mitigation and perception in engineering design faculty. *Journal of Mechanical Design*, 132, 041003–041003. doi:10.1115/1.4001110
- Maier, N. R. F. (1931). Reasoning in humans. II. The solution of a problem and its appearance in consciousness. *Journal of Comparative Psychology*, 12, 181–194. doi:10.1037/h0071361
- Michalko, M. (2001). *Cracking creativity: The secrets of creative genius*. New York, NY: Random House Digital.
- Mullen, B., Johnson, C., & Salas, E. (1991). Productivity loss in brainstorming groups: A meta-analytic integration. *Basic and Applied Social Psychology*, 12(1), 3–23. doi:10.1207/s15324834basps1201_1
- Nijstad, B. A., & Stroebe, W. (2006). How the group affects the mind: A cognitive model of idea generation in groups. *Personality and Social Psychology Review*, 10, 186–213. doi:10.1207/s15327957pspr1003_1
- Osborn, A. F. (1957). *Applied imagination: Principles and procedures of creative problemsolving*. New York, NY: Charles Scribner's Sons.
- Perttula, M. K., Krause, C. M., & Sipilä, P. (2006). Does idea exchange promote productivity in design idea generation? *CoDesign*, 2, 125–138. doi:10.1080/15710880600797942
- Perttula, M. K., & Liikkanen, L. A. (2006). Structural tendencies and exposure effects in design idea generation. *American Society of Mechanical Engineers, 2006*, 199–102. doi:10.1115/DETC2006-99123
- Perttula, M., & Sipilä, P. (2007). The idea exposure paradigm in design idea generation. *Journal of Engineering Design*, 18, 93–102. doi:10.1080/09544820600679679
- Pirola-Merlo, A., & Mann, L. (2004). The relationship between individual creativity and team creativity: Aggregating across people and time. *Journal of Organizational Behavior*, 25, 235–257. doi:10.1002/job.240
- Polzer, J. T., Milton, L. P., & Swann, W. B. (2002). Capitalizing on diversity: Interpersonal congruence in small work groups. *Administrative Science Quarterly*, 47, 296–324. doi:10.2307/3094807
- Purcell, A. T., & Gero, J. S. (1996). Design and other types of fixation. *Design Studies*, 17, 363–383. doi:10.1016/S0142-694X(96)00023-3
- Ratcliff, R. (1978). A theory of memory retrieval. *Psychological Review*, 85, 59–108. doi:10.1037/0033-295X.85.2.59
- Rohrbach, B. (1969). Creative by rules—Method 635, a new technique for solving problems. *Absatzwirtschaft*, 12, 73–75.
- Satzinger, J. W., Garfield, M. J., & Nagasundaram, M. (1999). The creative process: The effects of group memory on individual idea generation. *Journal of Management Information Systems*, 15, 143–160.

- Schunn, C. D. (2010). Chapter 6 – From uncertainly exact to certainly vague: Epistemic uncertainty and approximation in science and engineering problem solving. In Brian H. Ross (Ed.), *Psychology of learning and motivation* (Vol. 53, pp. 227–252): Academic Press. Retrieved from <http://www.sciencedirect.com/science/article/pii/S0079742110530068>
- Shah, J., Smith, S., Vargas-Hernandez, N., Gerkens, D., & Wulan, M. (2003). *Empirical studies of design ideation: Alignment of design experiments with lab experiments*. Presented at the 15th international conference on design theory and methodology. Retrieved from <http://asmedl.org.libproxy.usc.edu/getabs/servlet/GetabsServlet?prog=normal&id=ASMECP00200337017b000847000001&idtype=cvips&gifs=yes>
- Shah, J., Vargas-Hernandez, N., Summers, J., & Kulkarni, S. (2001). Collaborative sketching (C-Sketch) – An idea generation technique for engineering design. *The Journal of Creative Behavior*, 35, 168–198.
- Shalley, C. E., & Perry-Smith, J. E. (2008). The emergence of team creative cognition: The role of diverse outside ties, sociocognitive network centrality, and team evolution. *Strategic Entrepreneurship Journal*, 2, 23–41. doi:10.1002/sej.40
- Silvia, P. J., Wigert, B., Reiter-Palmon, R., & Kaufman, J. C. (2012). Assessing creativity with self-report scales: A review and empirical evaluation. *Psychology of Aesthetics, Creativity, and the Arts*, 6(1), 19–34. doi:http://dx.doi.org.libproxy.usc.edu/10.1037/a0024071
- Sonnenburg, S. (2004). Creativity in communication: A theoretical framework for collaborative product creation. *Creativity and Innovation Management*, 13, 254–262.
- Stempfle, J., & Badke-Schaub, P. (2002). Thinking in design teams – An analysis of team communication. *Design Studies*, 23, 473–496. doi:10.1016/S0142-694X(02)00004-2
- Sun, R. (2004). *Cognition and multi-agent interaction: From cognitive modeling to social simulation*. Cambridge: Cambridge University Press.
- Sundholm, H., Artman, H., & Ramberg, R. (2004). *Backdoor creativity: Collaborative creativity in technology supported teams*. In COOP (pp. 99–114). Amsterdam, The Netherlands: IOS Press. Retrieved from <http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.96.4679>
- Suwa, M., Purcell, T., & Gero, J. (1998). Macroscopic analysis of design processes based on a scheme for coding designers' cognitive actions. *Design Studies*, 19, 455–483. doi:10.1016/S0142-694X(98)00016-7
- Taggar, S. (2002). Individual creativity and group ability to utilize individual creative resources: A multilevel model. *The Academy of Management Journal*, 45, 315–330. doi:10.2307/3069349
- Taylor, D. W., Berry, P. C., & Block, C. H. (1958). Does group participation when using brainstorming facilitate or inhibit creative thinking? *Administrative Science Quarterly*, 3, 23–47. doi:10.2307/2390603
- Terrenghi, L., Fritsche, T., & Butz, A. (2006). The EnLighTable: Design of affordances to support collaborative creativity. In A. Butz, B. Fisher, A. Krüger, & P. Olivier (Eds.), *Smart graphics* (Vol. 4073, pp. 206–217). Berlin, Heidelberg: Springer. Retrieved from <http://www.springerlink.com.libproxy.usc.edu/content/43387012441622p8/>
- van Someren, M. W., Barnard, Y., & Sandberg, J. (1994). *The think aloud method: A practical guide to modelling cognitive processes*. San Diego, CA: Academic Press. (\$48). Retrieved from <http://www.eric.ed.gov/ERICWebPortal/detail?accno=ED399532>
- Viswanathan, V., & Linsey, J. (2012). A study on the role of expertise in design fixation and its mitigation. *ASME 2012 international design engineering technical conferences & computers and information in engineering conference*. Chicago, IL: ASME.
- Viswanathan, V., & Linsey, J. (2013). Examining design fixation in engineering idea generation: The role of example modality. *International Journal of Design Creativity and Innovation*, 1, 109–129. doi:10.1080/21650349.2013.774689
- Warr, A., & O'Neill, E. (2005). Understanding design as a social creative process. In *Proceedings of the 5th conference on creativity & cognition* (pp. 118–127). New York, NY: ACM.
- West, M. A. (2002). Sparkling fountains or stagnant ponds: An integrative model of creativity and innovation implementation in work groups. *Applied Psychology*, 51, 355–387. doi:10.1111/1464-0597.00951
- Wilde, D. (2010). *Personalities into teams*. Mechanical Engineering, Retrieved from http://memagazine.asme.org/Articles/2010/february/Personalities_Into_Teams.cfm

Appendix 1. Design problem statement

In Los Angeles, the freeway system is way too crowded during rush hour. Unfortunately, the sprawling nature of Los Angeles is not friendly for public transit systems, so people need cars. Design some type of system that can be integrated into either vehicles or the freeway (or both) which will reduce rush hour traffic. If you choose to integrate it into vehicles, it must work even if not all vehicles have this system.