Creative Stimulation in Collaborative Design

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Creative collaboration in engineering conceptual design is a subject which is not studied enough. Particularly, there is a lack of research on this subject which takes a cognitive approach. Current research tends to either just look at the team from a social perspective (treating the individual as a "black box") or just look at the individuals themselves (ignoring collaborative interactions). Our research takes a novel approach of combining interactions, communication, and cognitive processes on both the individual and group level. This gives a more holistic and deeper understanding of the collaborative creative process in engineering design. In this paper, we focus on how collaboration influences analogies through cognitive process stimulation. We propose that collaboration will increase the number of analogies under certain conditions. To help establish our claim and examine the conditions, we have developed a theoretical model and carried out an empirical pilot study using protocol analysis.

Introduction

Many studies in the past have looked into collaborative creativity. Much of the relevant work for collaborative creativity in conceptual engineering design comes from brainstorming research. Contrary to popular belief, much of this research concludes that collaboration actually hurts the quality and quantity of creative ideas. This work investigated collaborative activity by comparing real groups and nominal groups (same number of individuals who all worked independently). According to the research, the reason why nominal groups have better performance than real groups can be attributed to categories of barriers; *social inhibitions* and *procedural Issues* (Deihl & Stroebe 1987, Mullen et. al. 1991, Paulus 2000). More specifically, social inhibitions consist of *social anxiety* (being afraid to share an idea due to personal judgment that may be produced), *social loafing/free riding* (where other team members do not work as hard, as it appears others are there to do the work), *illusion of productivity* (because many people are working, and ideas are being produced, a person feels they are doing work even though they are minimally contributing), *matching* (an individual feels they only have to contribute as much as the average group member, which isn't that much), and *downward comparison* (an individual generally maintains a more positive view of themselves, feeling they are better than the average where in reality they are not). The procedural issues generally consist of *production blocking* (an individual can't share their idea due to others speaking, and eventually forgets this idea. Also only so many ideas can be discussed at a time), *task-irrelevant behaviors* (groups tend to take time with social groom behaviors, etc., which do not contribute to production), and *cognitive load* (there is so much to think about, a person's generative abilities are hurt). (Paulus 2000, Warr & O'Neil 2005). These same issues also apply to creative behavior in engineering design. However, does it have significant effects which impede creativity?

It has been proposed that collaboration does have positive aspects which encourage creativity. Individuals who work collaboratively feel more positive about the work they do are doing, and working together is a morale booster. (Sutton & Hargadon 1996). Idea retention also improves by collaboration, through the effect of group remembering (Sarmiento & Stahl 2008). This means that team members will revisit old ideas which the team has created, meaning it is less likely for these ideas to be left by the wayside. It has been observed that many times when individuals are working on a design problem, they will ignore the most innovative initial solutions they come up with, and purse less innovative ideas to completion (Jin and Benami 2010). Group remembering, or retention, means that it is more likely this will not occur and creative ideas will be retained and pursed to completion.

Brainstorming research has also found there are positive results from people working together through stimulation (Brown et. al. 1998, Dugosh et. al. 2000). In non-brainstorming research, this stimulation has also been referred to as bridging (Sarmiento & Stahl 2008), or purposeful action to overcome an obstacle. Analogy, merging/blending and prior pool of solutions are all types of stimulation that occur from collaboration. Analogies occur when a solution to a different problem is used to find a solution to the current one. They can often bridge large gaps and create entirely novel solutions as the different problem can be seemingly unrelated (Novick 1988). Merging/blending occurs when two or more ideas are combined to create a new solution (Turner & Fauconnier 1995). The ideas that are merged and blended can either occur entirely in one designers mind, or occur more publically through discussion. Finally, prior pool of solutions is the occurrence that when multiple designers are working together they have access to a larger pool of experience. This is because each designer brings a unique set of abilities and experience of prior problems solved, which means the overall pool of solutions to past problems is larger (West 2002). Many times these solutions can be modified to solve the current design problem.

In taking a cognitive approach to understanding the creative process, one of the most relevant pieces of research is Finke and Ward's Geneplore model (1996). Their model divides the creative cognitive thought process into two key components, a generation process and an exploration phases. The generation and exploration phases occur in a cyclical manner. Benami (2002) took the phases and identified which specific cognitive processes apply to conceptual design. In the generation phase, the cognitive processes of memory retrieval, transformation, and association where specifically identified as relevant. In the exploration phase, the processes of problem analysis and solution analysis were identified.

Our proposed research takes a new approach when compared to previous studies. While some past studies have broken down the cognitive process in the mind of each designer (Finke and Ward 1996, Benami 2002), they fail to look at what happens to this process when interactions with other designers occur. Others, who look at the creative collaborative process, treat the individuals as "black boxes", not looking into the cognitive process of each participant (Pirola-Merlo 2004, West 2002, Sarmiento and Stahl 2008). Even Shalley and Perry-Smith (2008), who look into team creative cognition, and how individual creative cognition is infused into it, unfortunately treat individual creative cognition rather abstractly, not breaking into the individual cognitive processes of each person. Our research approach looks at both the external interactions of engineering designers and the internal thought processes occurring in the designer's mind. This is a deeper approach than most current research takes, allowing us to observe collaboration's influence on specific cognitive processes.

Signal and Noise Framework of Collaborative Interaction

As mentioned above, there are many who say collaboration hurts creative idea generation (Deihl & Stroebe 1987, Mullen et. al. 1991, Paulus 2000, Warr & O'Neil 2005). However, others state collaboration can be positive and will stimulate new ideas (Brown et. al. (1998), Dugosh et. al. (2000), Sarmiento & Stahl 2008, West 2002). With these differing views the only statement that can be made is that there is no clear answer as to whether collaboration is beneficial or not. There is not cut and dried “Yes” or “No”. This raises the key question we are attempting to address in our research.

Q1: When is collaboration beneficial to creative idea generation?

From our literature review, there are numerous factors in collaboration which disrupt creativity. These disruptions can be identified as “Noise”, a name which comes from a control systems analogy, as noise makes information less identifiable. The noise can be divided into the two categories Social Inhibitions and Procedural Issues (Deihl & Stroebe 1987, Mullen et. al. 1991, Paulus 2000). In engineering design, Procedural Issues are the dominant source of noise. Social Inhibitions are secondary due to the analytic nature of engineering design. Specifically with regards to procedural issues, in our research we expect to see Production Blocking as being the main issue, with Task Irrelevant Behaviors Being a secondary one. As this research will only be looking at small teams with a couple individuals, Cognitive Load will be negligible. As for Social Inhibitions, while they are secondary to Procedural Issues, they are definitely still relevant. In our research, Social Anxiety, Social Loafing/Free Riding, and Illusion of Productivity are expected to play a role. Due to the small group size, Matching and Downward Comparison will also be negligible.

However, from the literature review, there are also a number of interactions which positively influence creativity. Once again using a control systems analogy, we have decided to call these positive interactions “Signal”. The key positive effects of collaboration which have been suggested are Stimulation (Brown et. al. 1998, Dugosh et. al. 2000,Sarmiento & Stahl 2008) and Retention (Sarmiento & Stahl 2008). Three key areas stimulation from the literature have been identified, which are Analogy (Benami 2002), Merging/Blending (Turner & Fauconnier 1995) and Prior Pool of Solutions (West 2002).

Each Stimulation interaction and Retention can be tied to specific cognitive processes. Analogies are generated by the cognitive processes of Memory Retrieval, Association, and Transformation (Benami 2002). Merging/Blending (Turner & Fauconnier 1995) occurs when past solutions are remembered through the cognitive process of Memory Retrieval and then related parts of the ideas are combined together to create a new idea through the cognitive process of Association. Finally, there is a larger Prior Pool of Solutions in the team setting (West 2002) which can be potentially used to solve the problem. This Prior Pool of Solutions is accessed by the cognitive process of Memory Retrieval. Finally, Retention of ideas in teams is improved as designers participate in Group Remembering (Sarmiento & Stahl 2008), which also occurs through the cognitive process of Memory Retrieval. However, unlike the Prior Pool of Solutions, the memories that are retrieved occur from earlier in the design process

There are other factors which don't fall neatly into the Signal or Noise categories. For example, team diversity has been noted to both hurt and improve creative idea generation. Polzer et. al. (2002) states determining factor in the effect of diversity is interpersonal congruence, which is how much a group members view of another member lines up with their view of self. If interpersonal congruence is high, diversity will improve creative idea generation, and vice versa. However, it is not necessary to account for diversity in our factors of Signal and Noise, as interpersonal congruence and its effect of diversity is already accounted for. Why diversity hurts when interpersonal congruence is low, is that Social Inhibitions are more likely to be an issue (individuals with different views of each other are more likely to have Social Anxiety). If interpersonal congruence is high, the Social Inhibitions are avoided and the collaborators have a larger pool of ideas to draw from. Thus, diversity and interpersonal congruence are already accounted for in the current factors that make up signal and noise.

Our fundamental theory for answering Q1 is: For collaboration to be positive, signal must be greater than noise. This means the stimulation and retention collaboration generates must be greater than disruption it generates. This is shown in Figure 1, which also summarizes what Signal and Noise consist of.

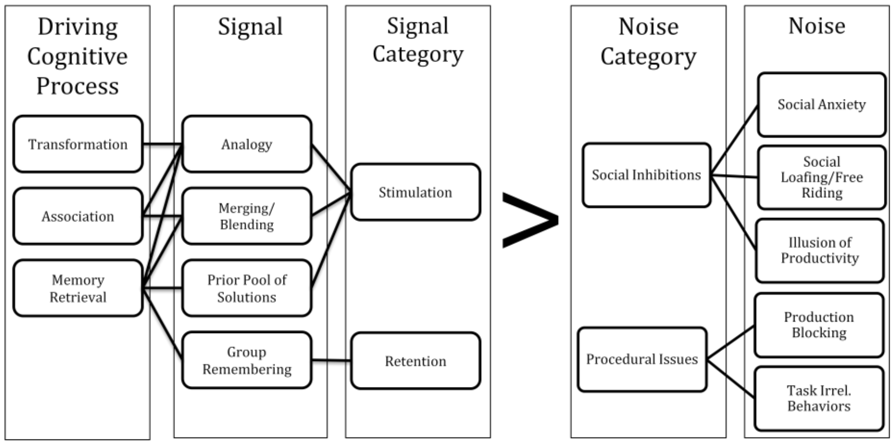

Figure 1: Framework of Signal and Noise

A step by step approach will be taken in exploring the framework. First the different types of Signal (Stimulation and Retention) will be explored by examining if collaboration increases the occurrence of the Signal categories. In the area of Stimulation, the specific interactions of Analogy, Merging/Blending, and Prior Pool of Solutions will be explored. In the area of Retention, Group Remembering will be explored, and it will be observed if retention is increased by collaboration. If the specific interactions of Signal increase with collaboration, it means that collaboration improve Signal, which is necessary for the inequality to work out.

Secondly, the types of Noise, Procedural Issues and Social Inhibitions, will be explored. Of specific interest here, are how the specific types of noise in each category (Social Anxiety, Social Loafing/Free Riding, Illusion of Productivity for Social Inhibitions and Production Blocking and Task Irrelevant Behaviors for Procedural Issues) influence cognitive processes. In the exploration, it will also be observed how collaboration gives rise to these issues.

The third step will be to identify the conditions in which Signal is greater than Noise, or where collaboration is positive for creative idea generation. This can only be done after fully ascertaining the elements of Signal and Noise, and how these elements are influenced by cognitive thought processes.

In this particular paper, we focus on exploring the analogy portion of the model, and how collaboration influences the number of analogies which are made. Specifically, we will be exploring if collaboration influences the cognitive thought processes that create analogies in a way that increases the number of analogies made (which would increase Signal).

Hypothesis

Our hypothesis for this paper is as follows:

> "Collaboration increases the number of analogies made due to stimulation of the following generative cognitive processes: Memory Retrieval, Association, and Transformation"

An analogy is made up of several base level cognitive processes. They are Memory Retrieval, Association, and Transformation (Benami 2002). The process by which an analogy occurs starts with retrieval cues from the problem which leads to Memory Retrieval of past problems and solutions. The designer then attempts to map the retrieved elements of past problems to the current problem (the cognitive process of Association). If the mapping is successful, then the solution to the retrieved problem is then adapted to fit the current problem (the cognitive process of Transformation) (Novick 1988). We hypothesize collaboration will increase the number of analogies made for three reasons:

1. *Increased Memory Retrieval*: Memory Retrieval is the first step in making an analogy (Novick 1998). If there is a better chance of memory retrieval occurring, more analogies should be made. Stimulation of Memory Retrieval should increase due to a larger amount of background information being available. When collaborators bring different backgrounds of experience to the table, they are bringing a much larger pool of ideas to draw from (West 2002). This larger pool of ideas increases the probability that a relevant idea can be retrieved from memory. It also increases the likelihood that one memory will lead to another memory which would begin an analogy.
2. *Forced Analogies*: In order to understand the idea a collaborator is sharing, either the person hearing the idea or the individual sharing the idea is "forced" to make an analogy for the idea to be communicated. Analogies are commonly used in education in this manner to help explain difficult concepts (Glynn and Takahashi 1998, Duit 1991). As for specific cognitive components (association and transformation), association is "forced" to identify the new idea that is trying to be understood, where as mental transformation is "forced" to bring the idea into the individual's reality.
3. *Collaborative Analogies*: Collaborative analogies occur when the analogy is started by one team member, but then completed by others. The three base cognitive processes of Memory Retrieval, Association, and Transformation (Benami 2002) still occur in that order, but instead they are completed by different team members. For example, one individual may retrieve a memory and share it with the team, and then another team member will make an association and transformation, thus completing the analogy.

Experimental Approach and Results

Studying cognitive processes in design activity has been a common procedure, and been done in multiple studies (e.g., Benami 2002). The general approach is to have the subjects think aloud while they are designing, and then analyze transcripts of their thoughts. This is known as protocol analysis (Cross et. al. 1997). However, few have attempted to look at design cognitive processes in collaborative settings, as it is quite challenging. There are two key challenges which exist:

> 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 Methods for Studying Cognitive Processes in Collaboration

Concurrent Collaborative Think Aloud

Two different methods were developed observe creative cognitive processes in a collaborative setting. The first method 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 subject used the push to talk feature 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, as when a subject was talking, what they were saying is what they would be talking about. The interface is shown in Figure 2.

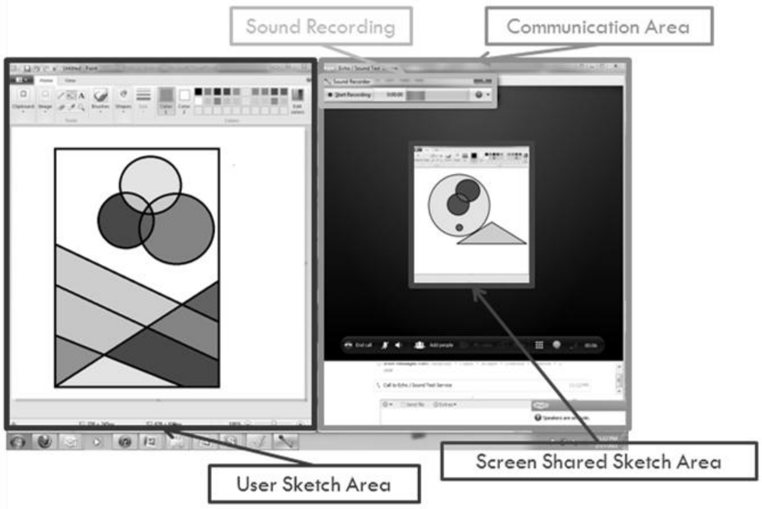

Figure 2: Experiment Interface

While protocols were successfully recorded and the subjects were not influenced by each other's protocols, there were several issues with this attempt. First, individuals had a hard time verbalizing their thoughts when the other subject was talking to them. This was because it was too difficult to listen to what the other subject was saying while also trying to verbalize their own thoughts. Thus, the verbal protocols were discontinuous. Secondly, and more importantly, working remotely with each other did not provide the full collaborative experience that working in the same room would have. Trying to work together via Skype and an electronic sketchpad made the situation complicated and reduced efficiency.

Retrospective Collaborative Think Aloud Method

The second methodology took a different approach to solve challenges C1 and C2. Subjects 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 subjects were working together. After the session was complete, subjects 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 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 collaborating on the design problem, there was no way for the subject's verbalizations to impact their collaborators thoughts (solving C1). The collaboration environment for the second methodology is shown in Figure 3.

Figure 3: Collaboration Environment

Using the second methodology subjects were able to collaborate naturally. Also, in doing the retrospective analysis, the video provided adequate cues to the subjects so they would not forget where they were at (subjects were also allowed to look at their sketches which provided additional assistance in remembering). One of the challenges with this methodology though, was that occasionally while subjects were doing the retrospective protocol, they would slip into just describing the task they were doing, instead of describing their thoughts. At this point, the experimenter would have to ask the subject to verbalize their thoughts, not just their actions.

Out of the two methodologies, our initial experiments demonstrated that the retrospective methodology worked the most smoothly, and provided the best data. Therefore, it was decided to use Retrospective Collaborative Think Aloud Method in this experiment.

Experiment Design

In order to test our hypothesis, it was necessary to compare those who worked individually to those who worked collaboratively. This was done by conducting a pilot experiment on seven subjects, who were divided into the two groups, one that collaborated and one that did not. The experiment design is represented in Figure 4 below.

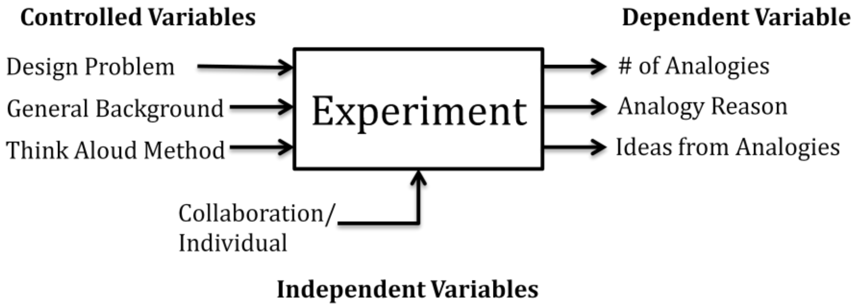

Figure 4: Experiment Design

Our Independent Variable in this experiment was whether the subjects were collaborating (the experimental group) or if they were working by themselves (the control group). The experimental group collaborated with each other in teams of two on the design problem, where as the control group worked on the design problem alone. In this pilot study, the experimental group and control group were made up of four and three subjects, respectively.

The Controlled Variables in this experiment design was the Design Problem, General Background of the subjects, and Think Aloud Method/Training. The Design Problem given was to develop a system or device that would reduce traffic congestion (the full problem statement is given in the appendix). All subjects were given the same problem, printed on a slip of paper.

The General Background of the subjects was similar as well. All subjects were Mechanical Engineering majors with some exposure to design theory and methodology. Also, the subjects all lived in the greater Los Angeles area, so they were aware and familiar with traffic congestion. Finally, to ensure similarity in creative ability between the experimental and control groups, before coming to the study, participants were given the Biographical Inventory of Creative Behaviors (BICB, included in the appendix), to determine their individual creative potential (this test was reviewed with other creativity tests by (Silvia et. al. 2011) and found to be both quick and effective). The results of the BICB were used to create control and experimental groups with similar creative potential and to set up teams in the experimental group (those with high BICB scores were paired to those with low BICB scores). The average score of those working on teams was 7.5, where as those working by themselves was 11.3 (BICB has a maximum score of 34).

Finally, all subjects used the same Think Aloud Method/Training. Each subject went through the same training for thinking aloud, and were given the same problems to practice on. Then both the control and experimental subjects participated in retrospective thinking aloud after the experiment. 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 groups thought process being altered when thinking aloud.

The Dependent Variables were the number of analogies each subject produced, the reasons the analogies were produced (mentioned in Hypothesis Details), and the percent of potential design solutions generated from analogies. These were found by using protocol analysis the subjects think aloud transcripts, and are detailed in the Data Analysis section.

Procedure

When first arriving at the study, participants were given training in verbalizing their thoughts. This training session consisted of working through several simple problems, while verbalizing their thoughts. Then, participants in the experimental group were given a design problem with their partner; where as individuals in the control group were given a design problem to work through by themselves. Participants were provided with pencil, 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 subjects completed the design problem, they were asked retrospectively verbalize their thoughts from the design process. However, retrospective analysis presents the challenge "How can subjects be prevented from forgetting their thoughts between the design process and the retrospective verbalization?" this was minimized by having subjects watch a video of themselves working through the design problem, and giving them sketches they had created during the design process. The subject's actions and talking in the video provided cues for the subjects to remember what they were thinking at that point. The video assisted in providing both verbal and visual cues, to help the individuals remember what they were thinking at that moment. Also, the subjects were given the paper they had used to take any notes, to assist their memory. The audio of retrospective verbalization of their thoughts was recorded for later transcription. Each step of the experimental method is summarized in Figure 5.

Control	Experimental
BICB Test	
Think Aloud Training	
Design Problem Individually	Design Problem Collaboratively
Retrospective Thinking Aloud While Watching Video	

Figure 5: Step by Step Experimental Process

Data Analysis

The video and audio recordings were saved, and the audio recordings of the retrospective analysis were transcribed. This was done by breaking up the audio transcripts into thirty second sections, and typing out each section. Dividing the transcripts into sections allowed the comparison of specific points in the retrospective audio to specific points in the video, which was particularly valuable in the collaborative setting. A protocol analysis approach was taken to analyze the transcripts. The typical approach to protocol analysis is to protocol analysis is to take the entire episode and segment it (Gero and McNeill 1998). However, as we were specifically interested in only analogies and the solutions generated, a hybrid approach was taken to reduce analysis time. A three step approach was taken to analyze the data. First the transcripts were examined to find all the design solutions the subjects created and how the solutions came into existence were documented (to see which came from analogies). Second, the transcripts were examined to identify all the cases of Memory Retrieval (as Memory Retrieval is the first step in an analogy). The third step was to take the analogies from the experimental (collaborative) group identified in the first two steps, and identify the reason this collaborative analogy existed

Identifying Design Solutions

A design solution was identified as a potential solution having a form, function, and behavior (Benami 2002). Sometimes, design solutions were accompanied by sketches, which made them easier to identify. For example, consider the protocol below where a subject in the control group describes a design solution he had just come up with.

> "I just remember the project we do in 410. And it's a conveyor belt based system moving some components and I just thought it, maybe it works just to use a conveyer belt to accelerate cars. And the capacity of the freeway will be increased sharply."

In this protocol, we can observe the form (conveyor belt based system), function (increased freeway capacity), and behavior (accelerates cars). This protocol was also accompanied by a sketch, Figure 6, which better shows the behavior where multiple conveyor belts are used to accelerate cars to different speeds.

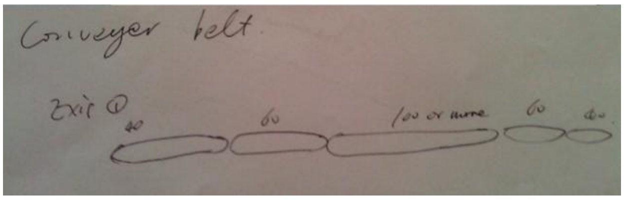

Figure 6: Conveyor Belt Analogy

When a design solution was identified, it was named, a description was written for it, and the time where it occurred in the protocol was identified. After identifying all the potential design solutions in the transcript, and eliminating redundant ones (solutions individuals mentioned multiple times), the protocol before the design solution was examined to see how the solution came into existence. In particular, it was observed if there were instances of a Memory Retrieval, followed by an Association and a Transformation which generated the idea. An Association was identified drawing similarities between two concepts. A Transformation was identified as taking an existing idea and morphing it (Finke 1992). If the design solution was due to these three cognitive processes, then the solution originated from an analogy (Benami 2002). The example discussed earlier was identified as an analogy. The analogy started with Memory Retrieval "remember the project". After this, the subject made an Association by likening "components" to "cars". The subject then completed the analogy by Transformation "use a conveyer belt to accelerate". The analogy is diagramed in Figure 7.

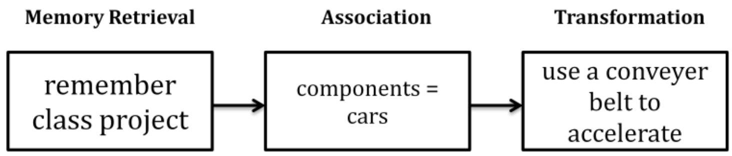

Figure 7: Example Control Group Analogy

The origin of the idea was noted along with the name, description, and time of occurrence. The example we have been using was recorded as:

Idea Title	Audio Time	Origin	Description
Conveyor Belt	12:34	Analogy	Conveyor belts used to slow down and speed up cars

Identifying Memory Retrieval

The second step was to examine the retrospective protocol transcript for cases of cognitive process of Memory Retrieval. Memory Retrieval is defined as when an individual recalls a past idea (Finke 1992). All the cases of memory retrieval were identified, as it is required to have memory retrieval for an analogy to be made. For an example, a portion of one subject's transcript from the experimental group is included below:

> "J: At this point I wasn't thinking that it really wasn't a new invention, but rather an old invention that would be more prevalent in more cars, but we would add a few new tweaks. As I was talking I realized we would add a little bit to it. And now I'm picturing an air traffic controller in my mind, even though I don't know how an air traffic control system works."

In this transcript, the subject has a Memory Retrieval of "air traffic controller", as this was a memory which came to his mind. This portion of the text was highlighted for later reference. After cases of Memory Retrieval were identified, the surrounding protocol and accompanying video of conversations (for the experimental group) was examined for Associations and Transformations, as these are the three cognitive processes which make up an analogy (Benami 2002). If it was found that a memory was retrieved, which was then associated with the current problem or idea, and then a transformation occurred to solve the current problem or modify an idea in the same way the memory did, an analogy occurred (Novick 1998). While the case we have identified may not initially appear to be an analogy, it was determined to be one after examining the video transcript, included below:

> J: We might as well use the GPS then. Well that's now different, pretty much no different than the existing GPS. Except this would be like active, active management, rather than just warning, warning people…
> M: So it will have some type of history to it.
> J: Yeah.
> M: So it's not just this place is busy, it's this place is gonna to be busy.
> J: Right
> M: Which is more useful than this place is busy, oh that place isn't busy, oh yea it is.
> J: Right, Right. And it could take into account where everyone else is going, kind of like an air traffic controller.
> M: Ok
> J: And just make sure you aren't going to get any congestion at any certain nodes on the grid.

The Association is made by comparing "air traffic controller guidance" was to "active GPS guidance". Finally, a Transformation occurs "you aren't going to get any congestion at any certain nodes on the grid." This analogy is diagramed in Figure 8.

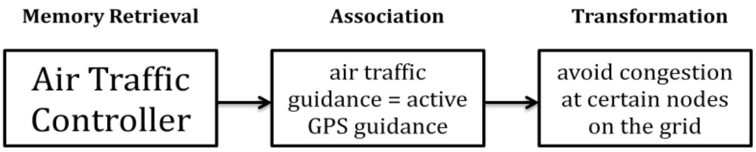

Figure 8: Example Experiment Group Analogy

Categorizing Analogies

Finally, all the analogies which were recorded from the experimental (collaborative) groups were then examined to observe the reason they came being (Increased Memory Retrieval, Forced Analogies, and Collaborative Analogy). Analogies were attributed to Increased Memory Retrieval if what the collaborator had said, or an idea the collaborator had, stimulated the subject to retrieve memories which lead to the analogy. Forced

Analogies were identified in occurring if the analogy occurred when the subject was explaining the idea to a collaborator, or if the subject was using the analogy to understand the collaborator. Finally, Collaborative Analogies were identified if one subject performed several of the cognitive processes making up an analogy (Memory Retrieval, Association, and Transformation (Benami 2002)), but then their collaborator completed the cognitive processes to complete the analogy. The reason each analogy occurred in the experimental group was recorded along with the analogy. In the collaborative example we have been exploring, the analogy was found to be a forced analogy. That is because subject J used made the analogy to explain and clarify how the active GPS would work to subject M.

> M: Which is more useful than this place is busy, oh that place isn't busy, oh yea it is.
> J: Right, Right. And it could take into account where everyone else is going, kind of like an air traffic controller.
> M: Ok
> J: And just make sure you aren't going to get any congestion at any certain nodes on the grid.

From the transcript, it can be observed the subject M is starting to get the concept, and subject J wants to clarify further, to make sure M gets his point. But by using this analogy in the explanation, it also brought up a new concept of avoiding congestion at specific nodes by using prior planning. This analogy was recorded as a forced analogy.

Initial Results

After analyzing the data, it was found that the experimental subjects tended to produce 1 analogy per member, where as the control groups produced .67 analogies per member. Analogies were observed from all the reasons stated earlier (Increased Memory Retrieval, Forced Analogies, and Collaborative Analogies). Additionally, analogies also occurred naturally, meaning that the collaborative process did not necessarily affect this analogy. The distribution in the number of analogies made were the same for Memory Retrieval, Forced Analogies, Collaborative Analogies, and Natural Analogies.

Another key observed result is that individuals tended to follow a specific, or very step wise process. Groups on the other hand tended to be more stochastic in their discussions. In total production of ideas individuals produced a larger quantity if ideas than groups working together (average number of ideas generated per individual was 11.3 for individuals but only 2.25 for groups). But analogies were more prevalent in the teams. This means that of the total ideas produced, those produced by groups were more likely to have occurred by analogy. Twenty-two percent of the ideas teams produced came from analogies, where as in individuals, six percent of the ideas resulted from analogies. These results are shown in Figure 9.

	Individual	**Collaborative**
BICB Average Score	11.3/34	7.5/34
Analogies per Designer	0.67	1.0
Ideas per Designer	11.3	2.25
% Ideas from Analogies	6%	22%

Figure 9: Experimental Results

Discussion and Conclusion

NOTE: THIS PAPER WILL BE UPDATED WITH RESULTS FROM A FULL SCALE EXPERIMENT WITH A LARGER SAMPLE SIZE. THIS WILL PROVIDE MORE STATISTICALLY SIGNIFICANT DATA, AND ALLOW FOR MORE DEFINITIVE CONCLUSIONS TO BE REACHED

From the results of the pilot experiment, it is not conclusive whether our hypothesis is valid. With the difference in the number of analogies produced per individual in both the control and experimental group, and the small size of the experimental group (seven individuals), the results were not statistically significant. However, it does provide an initial indicator that we are on the right track. What was specifically helpful, was that analogies were generated due to all the reasons stated earlier (Increased Memory Retrieval, Forced Analogies, and Collaborative Analogies), which seems to imply that the general theory is correct. Further research is required, and experiments on larger sample sizes will be run to determine if this hypothesis is correct.

Our other finding, which is that ideas generated by groups are more likely to result from analogies, is more significant. It was found that an idea generated by a group is almost four times more likely to be created because of an analogy than an idea generated by an individual. Groups tend to produce less ideas then individuals, as they spend time understanding each other and communicating (research suggests up to fifty-three percent of time is spent towards clarification and management (Olson et. al. 1992)). But, even though fewer ideas are produced, the same or greater number of analogies is created. This means that analogy is a more typical method of idea generation in groups. A possible reason for this is that it was observed when individuals work alone they tend to follow a specific thought process and way of thinking. This leads to a very structured and deductive design methodology. However, collaboration breaks these normal routines, making individuals use a less deductive and process based problem solving techniques, leading to a higher percentage of ideas being generated by analogies. This is most likely stimulated by the stochastic nature of group interactions. Stochasticity has been proposed as a primary driver of creativity in individuals by Simonton (2003). This, however, is a subject needing more exploration.

In conclusion, we have found initial data trends towards the fact that analogies are more likely to occur in creative conceptual design when collaboration takes place. Also, it was found that ideas are more likely to be generated by analogies if individuals are collaborating. Beyond obtaining further data beyond the pilot study, there are four key areas in need of future research. First, there is a need for a more detailed analysis of interaction areas of merging/blending and prior pool of solutions. Specifically, exploration is needed into how exactly these are affected by cognitive thought processes. A second place for exploration is looking at the disruption, and drawing connections between each type of disruption and how they impact specific cognitive processes. The third area to investigate is the stochasticity of collaborative idea generation in engineering conceptual design. Specifically, our point of interest is how this stochasticity influences cognitive processes. The final area of investigation is to look in which cases is collaboration positive for idea generation, or where Signal is greater than Noise.

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Appendix 1: BICB

Please type a "yes" by the following items that you have participated in the past 12 months.

1. Wrote short story
2. Wrote novel
3. Organized Event
4. Produced script
5. Designed textile
6. Decorated room
7. Invented product
8. Drew cartoon
9. Started Club
10. Made Picture
11. Published article
12. Made sculpture
13. Criticized scientific theory
14. Made recipes
15. Produced short film
16. Made webpage
17. Created a theory
18. Invented game
19. Chosen to lead
20. Made a present
21. Wrote poem
22. Adapted object
23. Published research
24. Choreographed dance
25. Designed garden
26. Made photography portfolio
27. Acted
28. Gave speech
29. Mentored others
30. Designed experiment
31. Wrote jokes
32. Served as leader
33. Composed music
34. Made collage

Appendix 2: 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.