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THE EFFECT OF COLLABORATIVE STIMULATION ON DESIGN NOVELTY

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ABSTRACT

Many times when working together, designers feel they are inspired by each other. This effect can be explained by collaborative stimulation, occurring when the design entities or questions stimulate generative cognitive processes. To this point, four types of collaborative stimulation have been identified: prompting, seeding, clarifying and correcting, through observations in collaborative design settings by retrospective protocol analysis. Consistent relationships between collaborative stimulation and the cognitive processes they stimulate have also been identified. However, impact of collaborative stimulation on the "quality" of design entities, or the ideas produced, remains unknown. This paper identifies the novelty of design entities in the collaborative setting, and compares those which resulted directly from collaborative stimulation to those which were created by individuals working alone. It was found the collaborative stimulation types of seeding and correcting resulted in the greatest increases in novelty of design entities. This finding indicates that these types of collaborative stimulation tend to stimulate novelty. Interventions are suggested to encourage seeding and correcting in the design process.

Keywords: Creativity; collaborative stimulation; novelty

1. INTRODUCTION

Collaboration in design has an impact on creativity. There are aspects which negatively influence creativity, such as social inhibitions and procedural issues [1,2] and there are aspects which stimulate collaborators [3,4]. In the past many methods like brainstorming [5], the 6-3-5 method [6], and support tools [7,8] have been developed to encourage creativity through collaboration. These methods produce mixed results as some, like brainstorming, have been found to not be effective in idea generation [1]. However, methods based on research, such as C-sketch, have been found to be effective [9].

Research in creative cognition, established through the Genplore model by Finke, Ward and Smith [10] has provided valuable insights when applied to design methodologies. For example, it has found more ambiguous and less mature concepts tend to provide the best stimulation [11]. These findings were based on the Generate-Stimulate-Produce (GSP) model, which provides an explanation of how the individual designer's mind works in the design process [11,12]. However, as of yet, creative cognition does not account for the influence of collaboration.

Research modeling collaborative creativity 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 [13–15]. They examine various aspects of the team's environment, the unique attributes each team member brings, and how this influences the creativity each member is able to contribute. Process models view collaborative creativity as a set of interaction processes which lead to a creative product [16–18]. Often, the models have many inter-relations between each of the processes. However, these models do not consider the individual cognitive processes.

In an examination of the past work on creative cognition and collaborative creativity, a gap is observed. Creative cognition explores cognitive processes of each designer [10,12], 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 [14,17,19]. While there have been several attempts to bridge this gap, they have not fully extended creative cognition to collaboration. Shalley and Perry-Smith [15], who explore how individual creative cognition is infused into team cognition, treat individual creative cognition abstractly by not exploring individual cognitive processes. Similarly Stempfle and Badke-Schaub [16], who take a cognitive approach to the engineering design process, breakdown thinking operations into categories but not individual cognitive processes.

The goal of this research is to extend creative cognition to collaboration, to find the background knowledge necessary to develop more effective methods. As taking a cognitive approach to design creativity has provided unique insights [11], it is expected taking a cognitive approach to collaborative creative design will produce similar insights.

2. COLLABORATIVE STIMULATION

2.1 Modeling Collaborative Stimulation

To explore collaboration, this work proposes a Collaborative Cognitive Stimulation (CCS) model, based on Jin and Benami's [11] Generate-Stimulate-Produce (GSP) model of creative cognition in conceptual design. Their model consists of design entities, which stimulate cognitive processes, which produce design operations, which generate new design entities (figure 1). The cycle continues until pre-inventive design entities (undeveloped concepts) mature to knowledge entities (the completed design).

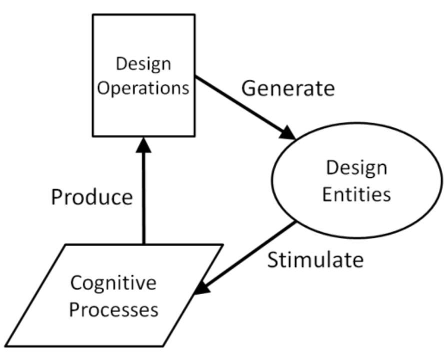

Figure 1: GSP Model

The CCS model (figure 2) extends the GSP model to collaboration by proposing each designer's cognition interacts through external design entities, by sharing or questioning concepts. Each designer engages in the same individual processes occurring in the GSP model (shown in grey), but the external interactions with the other designers are also accounted for in the CCS model (shown in white in figure 2).

The CCS model hypothesizes that external design entities and questions regarding them stimulate cognitive processes through collaborative stimulation (bottom of figure 2). Of specific interest are generative cognitive processes, or those that create ideas, consisting of memory retrieval (remembering an idea from the past), association (drawing relationships between two design entities), and transformation (altering a design entity) [11].

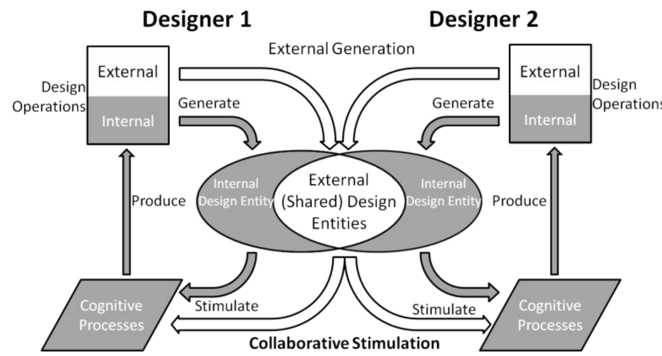

Figure 2: CCS Model

2.2 Types of Collaborative Stimulation

Collaborative stimulation influences generative cognitive processes through two mechanisms: design entity initiated or question initiated. Underneath each mechanism there are multiple specific types of stimulation that have been identified from literature review, personal industry experience, and qualitative pilot experiment observations.

Design entity initiated stimulation occurs when a design entity generated by a collaborator stimulates a generative cognitive process. The specific types of design entity initiated stimulation are:

- Prompting: An external design entity developed by the collaborator stimulates specific memories in the designer. Memory research has shown that ideas from another individual will often stimulate one's memory [20].
- Seeding: A collaborator's external design entity is internalized by the subject and modified. Building on each other's ideas is a key element in aggregate models of collaborative creativity [13,14].

Question initiated stimulation occurs when a question (or assumed question) from the collaborator stimulates a generative cognitive process. The specific types of question initiated stimulation are:

- Correcting: A subject corrects their idea because of a partner's question or challenge, to make it acceptable. Finding critiques and then revising the design based on those critiques is a key component of the design process [21].
- Clarifying: A subject feel their collaborator does not understand an idea, so they further clarify it. The process of clarification leads to further development. Elaboration is an important practice which supports creativity, opening opportunities for additional insights [22].

The types of collaborative stimulation can be summarized by Figure 3.

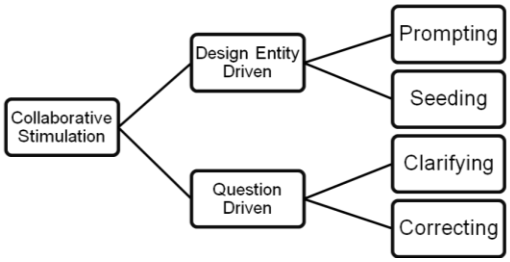

Figure 3: A breakdown of collaborative stimulation.

After identifying the various types of collaborative stimulation, it should be asked how impactful collaborative stimulation is. There are two ways this question could be approached. One is to explore the impact of collaborative stimulation on cognitive processes, and the second is to go one step further and explore the impact on design entities, or the concepts generated by the cognitive processes which were collaboratively stimulated. Prior papers by the authors have focused on the former, where as this paper focuses on the latter. This generates the research questions: *"What is the impact of collaborative stimulation on design entities?"* and *"Are certain types of collaborative stimulation more impactful than others?"* The answers to these questions would reveal what types of collaborative stimulation new methods and interventions should target.

3. EXPERIMENTAL APPROACH

3.1 Hypotheses

In general, how creative an idea is, can be measured through novelty, variety, quantity and quality [23,24]. While these are well established metrics, in order to measure the impact of collaborative stimulation, it was decided to focus on novelty. Variety and quantity were not selected as they focus on sets of ideas, rather than rating individual ideas [24]. Therefore, while they could be useful to measure creativity in the overall process, it would be hard to observe what impact collaborative stimulation had on specific ideas. In measures of novelty and quality, it was decided to measure the impact of collaborative stimulation through novelty as it is quantitative, whereas quality is qualitative [24].

To answer the research questions two hypotheses were formed.

H1: Ideas developed through the direct influence of collaborative stimulation will have greater novelty than ideas individuals develop alone.

H2: The collaborative stimulations working through the mechanism of questioning have the greatest impact on novelty.

The basis of H1 is that ideas created with a collaborator come from a greater, combined basis of knowledge. One of the advantages of a group is the diversity in knowledge and skill sets, and therefore the ability to be stimulated in new ways where these areas overlap [17]. However, it should be noted that diversity in places where interpersonal congruence (how well group members relate to each other) is low, too much diversity will have a negative effect on creativity [25].

The basis for H2 is formed from prior findings regarding the impact of collaborative stimulation on cognitive processes. Question related stimulation, while less common, was discovered to be strongly related to the cognitive processes of transformation and association [26]. As novelty is defined as how unexpected or unusual a concept is compared to the others [24], it is expected that it will be most correlated with occurrences of transformation and association, which modify concepts (versus remembering something that already exists) [11].

3.2 Past Approaches to Analyzing Collaboration

Dialog transcripts are often used to analyze collaborative activity. Sometimes the conversation is simply analyzed for social interactions [27,28] while other times protocol analysis is done, applying a coding scheme to a dialog transcript [16,29]. Stempfle and Badke-Schaub [16] specifically applied protocol analysis to a team's dialog transcript in order to identify underlying thought operations. Their validation for applying protocol analysis to conversation in order to observe thought operations came through work by Goldschmidtt [30], which states the intimate nature of sharing occurring in design team conversations is close to the internal speech individual verbalizations produce.

However, none of the past collaborative approaches obtain individual protocols over the length of the design process. In order to identify specific cognitive processes and types of collaborative stimulation occurring in the CCS model, it is necessary to obtain protocols from each designer, in addition to the group dialog. Goldschmidtt's [30] and Stempfle and Badke-Schaub's [16] approach of only analyzing the conversation transcript does not serve the CCS model well, as it explores both external (shared) and internal (private) thoughts. Therefore a modified protocol analysis approach is required.

3.3 Retrospective Protocol Analysis

Two different methods, concurrent and retrospective were developed from current protocol analysis techniques to reveal internal thoughts in the collaborative setting. However, tests on both methods revealed the retrospective approach was most effective, as concurrently thinking aloud and interacting with a team proved to be too much for one designer to process. Retrospective protocols have also been found to produce similar results to concurrent protocols [31]. In collaborative retrospective protocol analysis designers collaborated on the problem while being videotaped. After the experiment they were separated and performed retrospective thinking aloud while watching the video. If the video moved too fast for the subject to provide a complete verbalization, the subject could pause the video and complete their thought. This allowed for the observation of both private and shared thoughts.

It was found the video provided adequate cues for the designers triggering their memory as to what they had been thinking. Subjects reported that they were able to remember 90% or greater of their thoughts in a design processes lasting under thirty minutes. But, as there is no certain way to determine exactly how much information is missing, it is hard to quantify how large an issue memory recall may be. In general, protocol analysis also presents the issue that not all thoughts may be verbalized [32]. However, this method is the best the design available to researchers to explore cognitive interactions.

3.4 CCS Model Evaluation- A Collaborative Retrospective Protocol Analysis Approach

3.4.1 Subjects

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

3.4.2 Procedure

Prior to coming to the study, participants were given the Biographical Inventory of Creative Behaviors (BICB), to determine their past creative experience (this test was reviewed with other creativity tests and found to be both quick and effective [33]). The results of the BICB will be used in future research if it is desired to compare the groups to each other.

When first arriving at the study, participants were given individual training in verbalizing their thoughts. The training started with verbalizing a simple process, and continued to become more difficult until the subject was verbalizing their performance during a practice design problem.

After training, the designers were put in a group and provided with pencil, paper, and the design problem statement (given in the appendix) which asked them to develop a device that would securely store skateboards to prevent students from stacking them up against classroom walls. The designers were then videoed as they collaboratively worked through the design problem.

Immediately after the subjects completed the design problem, they were asked to retrospectively verbalize their thoughts from the design process. This was done while watching a video of the design problem, providing verbal and visual cues. The retrospective verbalizations were recorded in an audio file for later transcription.

Each step of the experimental procedure is summarized in figure 4.

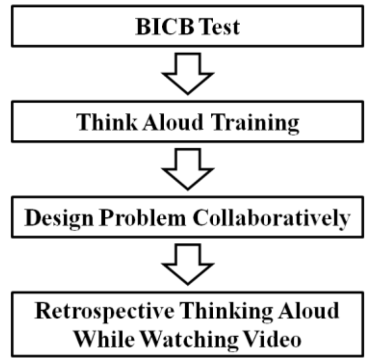

Figure 4: Step-by-step experimental process

4. ANALYSIS

4.1 Protocol Analysis

To explore the relationship between collaborative stimulation and design entity novelty, the design entities, cognitive processes and collaborative stimulation first had to be identified. The data from each experiment consisted of two audio files and a video file. A coding scheme was employed (table 1) to analyze the data, identifying design entities, cognitive processes, and collaborative stimulation.

A design entity was identified as a potential or partial solution having a form, function, and/or behavior. Any time a form, function, or behavior was mentioned in the transcript, it was classified as a design entity. Sometimes, sketches accompanied design entities, making them easier to identify.

After the design entities were identified, the generative cognitive processes occurring in the transcript were identified. Generative cognitive processes consisted of *Memory Retrieval:* when an experience or design entity which existed in the past is remembered; *Association:* when connections are drawn between two design entities; *Transformation:* when a design entity is altered or changed.

Finally the collaborative stimulation processes were identified by examining how cognitive processes came about, and if they could be attributed to a collaborative stimulation. Collaborative stimulation consisted of *Prompting:* an external design entity leads to a new memory retrieval; *Seeding:* a collaborator's external design entity is internalized by the subject and modified; *Correcting:* a subject corrects their idea because of a partner's question or challenge; *Clarifying:* a subject senses their collaborator does not understand an idea, so they further clarify it, leading to additional concept development.

Name	Coding Notation	Coding Example
Design Entities (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 Processes (CP)		
Memory Retrieval (MR)	MR(DE(X))	I think a solution would be X
Transformation (TF)	TF(DE(X), expanded)	If X was expanded
Association (AS)	AS(DE(X), DE(Y))	Idea X is like Idea Y
Collaborative Stimulation		
Prompting (Pr)	Pr(DE(X),MR(Y))	X reminded me of Y
Seeding (Se)	Se(DE(X),CP(DE(X));DE(X*))	X, your idea can be altered to create X*
Correcting (Co)	Co(DE(X), CP(S(X), DE(X*)))	X can be modified to X*, which solves the issue you brought up
Clarifying (Cl)	Cl(DE(X), CP(X);DE(X*))	this is how X works but it can be changed to X*

Table 1 Coding scheme for the CCS model

The coding scheme was checked by conducting intercoder reliability which gave a proportional coefficient of 0.86 for collaborative stimulation, and a proportional coefficient of 0.87 for generative cognitive processes.

4.2 Novelty Analysis

Novelty was the metric used to measure the creativity of each concept, as it is both quantitative and can measure each concept individually, not only the entire set of concepts produced. To quantify novelty, Shah, Smith and Vargas-Hernandez's approach was used [24]. But, before the novelty of each concept could be evaluated, first each new concept had to be identified.

A new concept was identified by examining the design entities found through the coding scheme and determining when each design entity was created. These design entities were put into a list with a time stamp of their occurrence. In the list, it was also noted if the concept was created by a collaboratively stimulated cognitive process and the number of times other groups had identified the same concept.

After each concept was identified, they were then categorized into a series of hierarchy levels: functions, physical principles, working principles, embodiment, and details. Functions are extracted from the problem statement and are the concept requirements. All the possible functions from the problem statement were first identified, and the rest of the hierarchy was then grouped under each function. Physical principles are verbs which fulfill a function. Working principles are nouns which are able to implement the physical principle, usually through structures. Embodiment is how the structure is constructed. Details consist of many minute aspects, such as materials or aesthetics.

The total novelty of a concept, N, is measured by comparing the maximum number of times a concept can be repeated to the number of times it was invented by each team (equation 1).

$$N = S \times \frac{Cases_{max}}{\#\ of\ Cases}$$

Equation 1: Novelty equation (change to cases)

In the equation, S is the weighting factor for each level of the hierarchy. A weighting factor was necessary as novelty in broad working principles is more influential than novelty in small details [24]. Physical principles have a weight of 10, working principles a weight of 6, embodiments a weight of 3, and details a weight of 1. Next in the equation, the maximum number of cases (equivalent to the number of groups in the experiment) is divided by the total number of times the concept occurred (the total number of groups who produced the same concept).

4.3 Example Analysis

Using collaborative retrospective protocol analysis provided the ability to identify both internal (private) and external (shared) thoughts. Consider the example dialog and verbalized transcript/coding below, discussing a wall mounted skateboard rack. The numbers in front of the text represents which collaborator was speaking.

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

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

Individual 1 Retrospective Protocol Transcript: One of the things that I was thinking about when we were talking about the locking mechanism is how, in convention center back in Chicago I saw… almost like people lockup their coats in individual lock boxes and they all had ID cards that were based, it was in a convention center located in a hotel and that's part of where the ID card idea came from.

Coding 1: Pr(f(locking mechanism), MR(convention, f(people, b(lock, f(coats), f(lock boxes, f(ID cards, F(access f(lock boxes)))))))

Images of the way the skateboard is locked are shown in figure 5. The locking mechanism (ID card or padlock) would be located at the front of the arm where the arrow points.

Figure 5: Locking arm side and front views

In the transcript, two concepts, both at the working principles level in the hierarchy, were identified. The first was “padlock” and was a concept which was repeated by all the teams. The second concept, “ID card swipeable”, was repeated by only one team. To compute novelty scores for both concepts, the weighting factor (6 for working principles) was multiplied by the number of maximum possible repetitions (5 as there were 5 teams) divided by the number of repetitions. For the “padlock” concept, this resulted in 6*5/5 (as the concept was repeated by all 5 teams) producing a novelty score of 6. For the “ID card swipeable” concept, the novelty was computed by 6*5/2 (as the concept was repeated by 2 teams), giving a total novelty score of 15.

In the example given above, it can be observed how the individual verbalization brings additional information the collaborative dialog does not reveal. The dialog only allows for the observation of specific design entities being discussed. However, the retrospective verbalization reveals the cognitive process (memory retrieval) creating the new entities, the design entity which stimulated the cognitive process (locking mechanism/padlock), and the type of collaborative stimulation involved (prompting).

5. RESULTS & DISCUSSION

5.1 Novelty Analysis

The five experimental cases of collaborative design had an average duration of 22 minutes, lasting from around 10 minutes to 40 minutes. There were 92 occurrences of collaborative stimulation, which resulted in the stimulation of 161 generative cognitive processes. Table 2 gives specific numbers for each cognitive process that was collaboratively stimulated and each occurrence of collaborative stimulation.

Cognitive Processes	Number	Collaborative Stimulation	Number
Memory Retrieval	58	Prompting	30
Association	24	Seeding	25
Transformation	77	Correcting	20
		Clarifying	17

Table 2: Collaborative stimulation results

In analyzing the concepts each team generated, a total of 295 concepts were accounted for. The number of concepts generated at each level of the hierarchy and their average novelty is charted below.

Hierarchy Level	Number of Concepts	Average Novelty
Physical Principal	44	26.6
Working Principal	98	17.0
Embodiment	93	13.6
Detail	60	4.9

Table 3: Novelty experimental results

From the data, patterns could be drawn between the concept novelty and collaborative stimulation, by comparing the average novelty of ideas resulting from collaboratively stimulated cognitive processes, and those not involving collaborative stimulation (shown as none in figure 6).

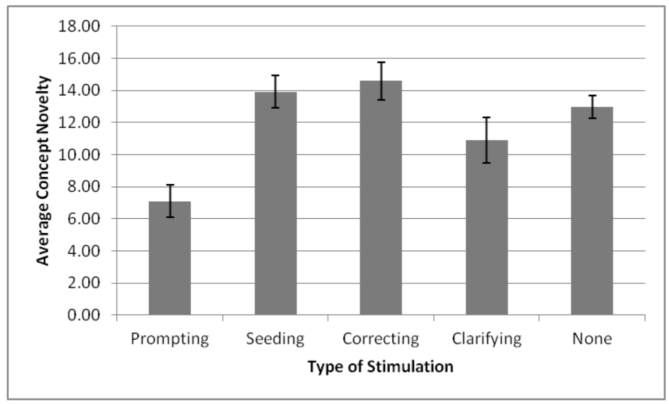

Figure 6: Stimulation and average novelty

The error bars in figure 6 represent 90% confidence intervals. The concepts produced by collaboratively stimulated cognitive processes could be broken down by hierarchy levels to observe its influence at each level (figure 7).

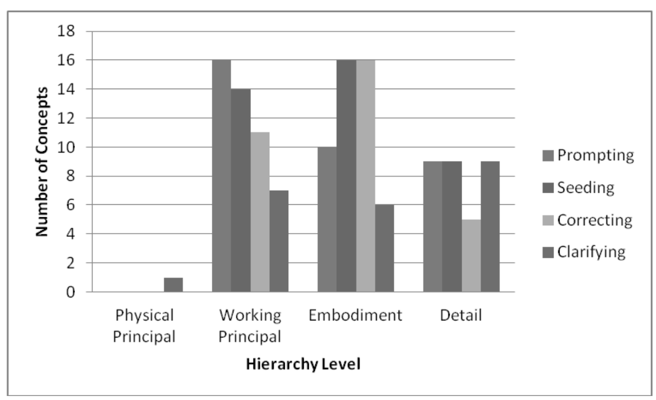

Figure 7: Collaobrative stimulation and hierarchy levels

Combining the number of concepts influenced by collaborative stimulation at each hierarchy level and the novelty of each concept, a graph could be developed which compares the average novelty of concepts influenced by each type of collaborative stimulation (and no stimulation) at each hierarchy level (figure 8).

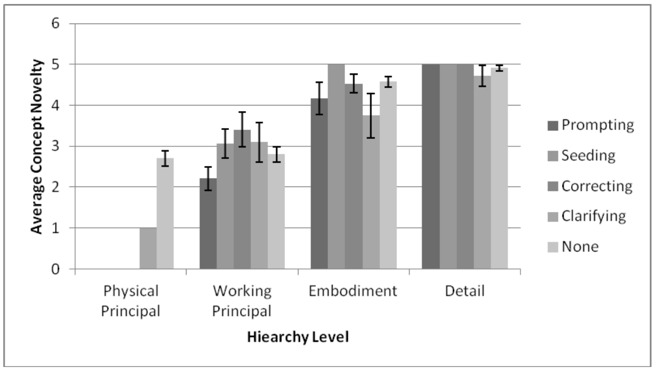

Figure 8: Average concept novelty per hiearchy level

Once again, the error bars in figure 8 represent 90% confidence intervals. It should be noted in this graph, as it compares novelty at each hierarchy level, the weighting factor has been removed. This makes 5 the maximum possible novelty score.

5.2 Discussion

The experimental results regarding novelty partially validate hypotheses 1 and 2. Hypothesis 1 was partially correct as the collaborative stimulation types of both seeding and correcting influenced ideas with higher novelty than concepts created without the direct influence of collaborative stimulation (figure 6). However, the results from prompting and clarifying were found to be less novel. Therefore, the type of collaborative stimulation was important in determining if ideas were more or less novel than those developed without collaborative stimulation.

Other evidence supporting hypothesis 1 can be found in figure 8, where it also depends on which concept hierarchy level collaborative stimulation influences. Both seeding and correcting performed well in all cases, and clarifying does well at the working principal level. The data at the detail level all maintained the maximum level of novelty (as details are rarely repeated in a group of 5), and therefore while ideas influenced by collaborative stimulation were more novel than ideas without influence, this information is not very meaningful.

Hypothesis 2 was found to be partially correct, as the collaborative stimulation of correcting generated the most novel concepts (figures 6 and 8). However, clarifying performed quite poorly, except for at the working principal level (figure 8). This would suggest that it is not question inspired or design entity inspired which determines collaborative stimulation's impact on novelty, but something else.

Question inspired collaborative stimulation was proposed to have a greater impact on novelty because the connections found in the author's earlier work to transformation and association [26] and the definition of novelty leads to an expectation that it will mostly be influenced by transformation [24]. The author's same prior work [26] proposed specific relationships between collaborative stimulation and cognitive processes given in Table 4, the dots show the strength of the relationship (three being strong, two being moderate, and one being weak).

Collaborative Stimulation		MR	AS	TF
Design Entity Inspired	Prompting	●●●	●	
	Seeding		●	●●●
Question Inspired	Correcting	●	●	●●●
	Clarifying	●●●	●●	●●

Table 4: Collaborative stimulation and cognitive process relationships

As can be seen in the table, question inspired stimulation has a greater combined relationship to transformation than design entity inspired. However, if one was just to examine which types of collaborative stimulation which have the strongest relationship with transformation, it can be seen it is seeding and correcting. It would then be expected that seeding and correcting would have the strongest influence on concept novelty. This aligns with the results of the experiment, as mentioned earlier. Furthermore, a comparison of the rest of the transformation column in table 4 directly relates to the results for novelty found in figure 6, with prompting having the lowest novelty and clarifying having moderate novelty. The results from this experiment, then align both with the expectations of others, that transformation leads to greater novelty [11], and with the findings of the author's previous work, that certain types of collaborative stimulation lead to greater transformation [26].

From the results, seeding and correcting are the most influential collaborative stimulations increasing idea novelty. But, from examining figure 7, it can be observed that in the natural design process they occur more often at lower hierarchy levels, with much of those types of stimulation occurring during embodiment. It would be beneficial to introduce methods and interventions to encourage seeding and correcting at higher hierarchy levels, where they have the opportunity to have greater impact on novelty.

One possible method could consist of teaching better questioning techniques (to encourage correcting). While there has been a lot of work in developing interventions to encourage stimulation from design entities, for example shared design notebooks [34] or providing stimuli to designers [20], there is a lack of focus on developing good questioning techniques [26]. Perhaps one of the reasons for the lack of development of questioning techniques to encourage creativity, is because brainstorming literature emphasizes that judgment should be deferred [5]. However, as was observed in this experiment, questioning and constructive criticism can be highly beneficial.

Another opportunity is for a creativity method encouraging collaborators to build on each other's ideas (to encourage seeding). In fact, Shah's method, mentioned earlier, heavily uses this type of collaborative stimulation with great success [9]. But, there are still opportunities to build additional interventions which would encourage building on ideas verbally or physically with prototypes.

SUMMARY & FUTURE WORK

In summary, it is believed that better methods for creative collaboration can be developed. To provide new insights into method development, a collaborative stimulation approach is used, which extends creative cognition to collaborative creativity. The CCS model, based on creative cognition, proposes interactions take place through design entities by the concepts themselves and questions about the concepts. These interactions lead to collaborative stimulation: the question inspired *clarifying* and *correcting*, and the design entity inspired *prompting* and *seeding*. An experiment using retrospective protocol analysis was conducted to identify occurrences of collaborative stimulation and discover their influence on concept novelty. Novelty was chosen as the creativity metric explored, as it is quantitative and can be measured for each concept individually.

The experiment found concepts created by cognitive processes collaboratively stimulated by seeding and correcting had higher novelty than those created without stimulation. Seeding and correcting both have a strong relationship with stimulating the cognitive process of transformation. However, it was found these two types of collaborative stimulation tend to occur naturally at lower hierarchy levels. Therefore, an opportunity exists to develop interventions which encourage seeding and correcting at higher hierarchy levels leading to further increases in novelty.

While these results are insightful, there is future work remaining to be completed. First, at extremely low levels of the hierarchy, the results for novelty reached a ceiling, as details were rarely repeated with just 5 groups. Running another study with increased sample size would be beneficial, as it is more likely ideas would be repeated. These increased sample sizes would also make the confidence interval tighter. A second area of future work is the development of interventions which encourage correcting and seeding. After an intervention has been created, its influence needs to be verified by comparing a control and experimental group. Increasing the number of groups, fulfilling the first area of future work, could be done when testing interventions.

Extending creative cognition to collaborative creativity through collaborative stimulation has provided a new level of understanding. Collaborative stimulation has revealed what behaviors should be encouraged by methods in order to raise novelty.

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REFERENCES

[1] Diehl M., and Stroebe W., 1987, "Productivity loss in brainstorming groups: Toward the solution of a riddle.," Journal of Personality and Social Psychology, **53**(3), pp. 497–509.

[2] Mullen B., Johnson C., and Salas E., 1991, "Productivity Loss in Brainstorming Groups: A Meta-Analytic Integration," Basic and Applied Social Psychology, **12**(1), p. 3.

[3] Brown V., Tumeo M., Larey T. S., and Paulus P. B., 1998, "Modeling Cognitive Interactions During Group Brainstorming," Small Group Research, **29**(4), pp. 495 – 526.

[4] Dugosh K. L., Paulus P. B., Roland E. J., and Yang H.-C., 2000, "Cognitive stimulation in brainstorming.," Journal of Personality and Social Psychology, **79**(5), pp. 722–735.

[5] Osborn A. F., 1963, Applied imagination; principles and procedures of creative problem-solving, Scribner.

[6] Rohrbach B., 1969, "Creative by rules—method 635, a new technique for solving problems.," Absatzwirtschaft, **12**, pp. 73–75.

[7] Warr A., and O'Neill E., 2005, "Tools to Support Collaborative Creativity."

[8] Terrenghi L., Fritsche T., and Butz A., 2006, "The EnLighTable: Design of Affordances to Support Collaborative Creativity," Smart Graphics, A. Butz, B. Fisher, A. Krüger, and P. Olivier, eds., Springer Berlin Heidelberg, Berlin, Heidelberg, pp. 206–217.

[9] Shah J., Vargas-Hernandez N., Summers J., and Kulkarni S., 2001, "Collaborative Sketching (C-Sketch) - An Idea Generation Technique for Engineering Design," The Journal of Creative Behavior, **35**(3), pp. 168–198.

[10] Finke R. A., Ward T. B., and Smith S. M., 1996, Creative Cognition: Theory, Research, and Applications, The MIT Press.

[11] Jin Y., and Benami O., 2010, "Creative patterns and stimulation in conceptual design," AI EDAM, **24**(Special Issue 02), pp. 191–209.

[12] Benami O., and Jin Y., 2002, "Creative Stimulation in Conceptual Design," Proc. ASME Design Engineering Technical Conferences and Computer and Information in Engineering Conference, pp. 1–13.

[13] Taggar S., 2002, "Individual Creativity and Group Ability to Utilize Individual Creative Resources: A Multilevel Model," The Academy of Management Journal, **45**(2), pp. 315–330.

[14] Pirola-Merlo A., and Mann L., 2004, "The relationship between individual creativity and team creativity: aggregating across people and time," Journal of Organizational Behavior, **25**(2), pp. 235–257.

[15] Perry-Smith J. E., and Shalley C. E., 2003, "The Social Side of Creativity: A Static and Dynamic Social Network Perspective," The Academy of Management Review, **28**(1), pp. 89–106.

[16] Stempfle J., and Badke-Schaub P., 2002, "Thinking in design teams - an analysis of team communication," Design Studies, **23**(5), pp. 473–496.
[17] West M. A., 2002, "Sparkling Fountains or Stagnant Ponds: An Integrative Model of Creativity and Innovation Implementation in Work Groups," Applied Psychology, **51**(3), pp. 355–387.
[18] Sonnenburg S., 2004, "Creativity in Communication: A Theoretical Framework for Collaborative Product Creation," Creativity and Innovation Management, **13**(4), pp. 254–262.
[19] Sarmiento J. W., and Stahl G., 2008, "Group Creativity in Interaction: Collaborative Referencing, Remembering, and Bridging," International Journal of Human-Computer Interaction, **24**(5), p. 492.
[20] Nijstad B. A., and Stroebe W., 2006, "How the Group Affects the Mind: A Cognitive Model of Idea Generation in Groups," Pers Soc Psychol Rev, **10**(3), pp. 186–213.
[21] Holsapple C. W., and Joshi K. D., 2002, "A collaborative approach to ontology design," Commun. ACM, **45**(2), pp. 42–47.
[22] Vyas D., and Nijholt A., 2009, "Collaborative Practices That Support Creativity in Design."
[23] Oman S. K., Tumer I. Y., Wood K., and Seepersad C., 2013, "A comparison of creativity and innovation metrics and sample validation through in-class design projects," Res Eng Design, **24**(1), pp. 65–92.
[24] Shah J. J., Smith S. M., and Vargas-Hernandez N., 2003, "Metrics for measuring ideation effectiveness," Design Studies, **24**(2), pp. 111–134.
[25] Polzer J. T., Milton L. P., and Swann W. B., 2002, "Capitalizing on Diversity: Interpersonal Congruence in Small Work Groups," Administrative Science Quarterly, **47**(2), pp. 296–324.
[26] Sauder J., and Jin Y., Pre-submission, "A Study of Collaborative Simulation in Conceptual Design," Design Studies.
[27] Brereton M., Cannon D., Mabogunje A., and Leifer L. J., 1997, "Collaboration in Design Teams: How Social Interaction Shapes the Product," Analysing Design Activity, N. Cross, H. Christiaans, and K. Dorst, eds., Wiley.
[28] Cross N., and Clayburn Cross A., 1995, "Observations of teamwork and social processes in design," Design Studies, **16**(2), pp. 143–170.
[29] Artzt A. F., and Armour-Thomas E., 1992, "Development of a Cognitive-Metacognitive Framework for Protocol Analysis of Mathematical Problem Solving in Small Groups," Cognition and Instruction, **9**(2), pp. 137–175.
[30] Goldschmidt G., 1997, "The Designer as a Team of One," Analysing Design Activity, N. Cross, H. Christiaans, and K. Dorst, eds., Wiley.
[31] Gero J. S., and Tang H.-H., 2001, "The differences between retrospective and concurrent protocols in revealing the process-oriented aspects of the design process," Design Studies, **22**(3), pp. 283–295.
[32] Chiu I., and Shu L. H., 2010, "Potential Limitations of Verbal Protocols in Design Experiments," ASME, pp. 287–296.
[33] Silvia P. J., Wigert B., Reiter-Palmon R., and Kaufman J. C., 2012, "Assessing creativity with self-report scales: A review and empirical evaluation," Psychology of Aesthetics, Creativity, and the Arts, **6**(1), pp. 19–34.
[34] Michalko M., 2001, Cracking Creativity: The Secrets of Creative Genius, Random House Digital, Inc.

APPENDIX

Design problem statement: Skateboards are one of the most popular forms of transportation at USC. Unfortunately though, when students come to class, the only current method for skateboard storage is to line them up against the wall. However, this has the potential to mark up the wall and skateboards can fall over in a domino effect if one is accidently bumped. A larger problem is that in large lecture halls, where there are often 2-3 rows of skateboards stacked up against the back wall. With so many boards, it can be hard to find yours, or even worse, it provides the opportunity for someone to steal one unnoticed. Design a device which will safely and securely hold skateboards while students are in class. This device could either be located in the hallway or outside the building, but not in the class room due to space constraints.

BICB Test: 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

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

11. Published article
12. Made sculpture
13. Criticized scientific theory
14. Made recipes
15. Produced short film
16. Made webpage
17. Created a theory
27. Acted
28. Gave speech
29. Mentored others
30. Designed experiment
31. Wrote jokes
32. Served as leader
33. Composed music
34. Made collage