## Title
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# The Influence of Group Interaction on Creativity in Engineering Design

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**Abstract**

Group work is frequently part of idea generation, despite evidence that group interaction may reduce productivity during brainstorming sessions. Idea quantity is one aspect of creativity, but the originality of ideas generated is also important. In this paper, we examine how different aspects of group interaction, such as who makes the most contributions to an idea and the number of group members contribute to an idea, impact the originality of concepts generated by engineering students. We found that the most original concepts were produced when the concept originator was the top contributor to the design, and when the majority of group members contributed to the concept, particularly among senior students. These results are discussed in relation to previous work and suggestions are made for future research that assesses the interaction between design fixation and group processes.

**Keywords:** creativity; group processes; engineering

Brainstorming (Osborn, 1957) has long been a popular method of idea generation, despite pervasive evidence that individuals produce more ideas than groups (Diehl & Stroebe, 1987, 1991; Mullen, Johnson, & Salas, 1991; Paulus & Brown, 2003). Research about group dynamics during group idea generation sessions suggests that fewer ideas are developed due to production blocking (Diehl & Stroebe, 1987). While group members may be able to generate many ideas, a delay between generating ideas and expressing them, such as when waiting for someone else to finish speaking, leads to fewer ideas being produced by groups compared to individuals (Diehl & Stroebe, 1991).

While there is much research on the negative aspects of brainstorming, there can also be benefits to the technique. For example, Nijstad and Stroebe (2006) found that exposure to group members' ideas led to generation of related ideas, thus suggesting that the other ideas were serving as retrieval cues for related semantic information in long-term memory. Brainstorming is also a popular technique because of higher levels of satisfaction of working in a group rather than working alone (Paulus, Dzindolet, Poletes, & Camacho, 1993). Nijstad, Diehl, and Stroebe (2003) suggest that the experience of fellow group members generating similar ideas reduces an individual's performance anxiety.

Because traditional brainstorming has a mix of positive and negative aspects, several alterations have been proposed to improve the process. One method is brainwriting, in which group members write out their ideas rather than speaking them (VanGundy, 1983). Brainwriting can reduce production blocking because group members do not have to wait to express their ideas. Another suggestion is to have individuals generate ideas alone, and then share them with the group (Diehl & Strobe, 1987). Baruah and Paulus (2008) found that participants who generated ideas alone, then in a group, had a higher quantity of ideas than participants who followed the opposite sequence.

Suggestions such as writing out ideas and working alone before interacting in a group are part of an idea generation technique that is frequently used in engineering research, the 6-3-5 method (Rohrbach, 1969). The 6-3-5 method involves a group of 6 individuals who each write out 3 ideas. The ideas are then circulated through the group so that each group member can comment on and modify the ideas of the other 5 group members. We use a modified version of the 6-3-5 procedure, designed by Otto and Wood (2001), in which group sizes can range from 4-6 participants, ideas are expressed as annotated sketches instead of as words, and the ideas only make three circulations through the group. The modified version of the 6-3-5 method not only involves the suggestions of written instead of oral production of ideas and individual work prior to group interaction, but the groups are *together nominal* groups, in which group members sit together but do not speak to each other. In the modified 6-3-5 method, both the initial individual ideation and subsequent idea circulation periods are performed in silence, rather than with spoken interaction between group members. Mullen et al. (1991) found that together nominal groups had less loss of productivity than traditional brainstorming groups. Further, idea generation techniques that use a combination of annotated sketches plus rotational sharing of others' ideas led to a greater quantity of ideas than idea generation techniques that used words only, sketches only, or gallery sharing of others' ideas, in which generated ideas are all viewed at once (Linsey et al., 2011).

Thus far, our discussion has focused on the quantity of ideas generated, which is only one aspect of creativity. The quality of ideas is also important. In engineering, there is a strong need for the creation of innovative products that can compete in the global marketplace (Duderstadt, 2008). In recent work, we have focused on the development of creativity in undergraduate engineering students (Kershaw et al., 2014, 2015). We have measured the originality of concepts that students produce as solutions to engineering problems that involve designing next-generation products such as alarm clocks or litter collection systems. Thus far, our work has shown that senior students produce more original concepts than freshmen, in line with other similar studies (e.g., Atman, Chimka, Bursic, & Nachtmann, 1999) and well-established theories of skill acquisition (e.g., Fitts & Posner, 1967), which suggest that higher levels of engineering skill and knowledge are associated with greater levels of creativity (cf. Ericsson, 1999).

Our work thus far, however, has not examined the role of group factors in creativity. While we have used the 6-3-5 idea generation method, which involves together nominal groups, we have only examined differences between groups, such as curriculum level (freshman vs. senior), and have not examined processes that are occurring within the groups that may influence the originality of generated ideas. In the following study, we examine two aspects of group interaction: which group members have the most creative inputs for a concept, and the number of group members that contribute to the overall originality of a concept.

In the 6-3-5 method, multiple group members view each concept and have an opportunity to modify it, but it is possible that some group members may contribute more to the final design than others. Blair and Hölttä-Otto (2012) found that final designs, once they had been circulated through the 6-3-5 group, received higher originality scores than the initial versions of the same concepts. This suggests that the contributions of the concept originator may not be as influential on the originality of the design as the contributions of other group members. Likewise, the cohesiveness of the group may affect overall creativity. Groups that value high standards for performance (Paulus & Brown, 2003) or have experience working together (Milliken, Bartel, & Kurtzberg, 2003) tend to produce more creative ideas.

Based on previous literature, we predicted that groups in which multiple individuals contributed to the originality of a concept would produce the most creative solutions to engineering problems. Based on our previous research, we expected that group factors would interact with students' curriculum level: freshman or senior. Participants who were seniors were enrolled in a year-long capstone design course that required extensive group work. As they were more accustomed to working in groups, and were familiar with the high technical standards expected in engineering, we expected that interactive senior groups would produce the most original concepts.

## Method

### Participants

Participants were 180 undergraduate students enrolled in freshman and senior undergraduate engineering courses at the University of Massachusetts Dartmouth (UMD). The freshmen (n = 100) were enrolled in an introduction to engineering course that included students in all engineering majors, including mechanical, electrical and computer, and bioengineering. The seniors (n = 80) were enrolled in a senior mechanical engineering design course, which is the capstone course of their curriculum. All students completed the concept generation procedure as part of an in-class exercise about creativity. No demographic data were collected about the participants.

### Materials and Procedure

Participants were separated into groups of 4-6 students and provided with a consent letter. They also received blank paper and a colored marker for drawing their concepts. Each group received a sample product for the redesign exercise. For this experiment, the sample product was a simple litter collection device (see Figure 1). After receiving the materials, the experimenters explained the concept generation exercise to the students.

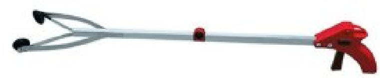

Figure 1: Simple Litter Collection Device

All participants followed the modified 6-3-5 concept generation method (Otto & Wood, 2001). Each participant had 10 minutes to individually sketch 3 concepts of a next generation litter collection system, annotating his/her designs as necessary. After the individual ideation period, participants circulated their concepts clockwise to the next student in the group. Students were instructed that they had 5 minutes to modify the concepts they received, make suggestions or other comments, or sketch a new concept on the same page. Concept sketches continued to be circulated until they returned to the original owner, or at least were passed to 3 different participants within the group. This procedure is the same as was reported in Kershaw et al. (2015).

### Analysis

**Originality Coding: Concept Level.** The originality metric (Table 1) was derived from the CEDA instrument developed by Charyton, Jagacinski, and Merrill (2008). Several modifications were made: first, we only used the originality scale, and not the other items. Second, we modified the 11-point originality scale to a standard 5-point Likert scale, based on higher inter-rater agreement findings by Genco, Johnson, Hölttä-Otto, and Seepersad (2011). Third, we developed a decision tree to assess the originality of the concept as a whole (c.f. Kershaw et al., 2015; Figure 2).

Table 1: Originality Metric

| Originality Metric | |
|---|---|
| 0 | Common |
| 2.5 | Somewhat interesting |
| 5 | Interesting |
| 7.5 | Very Interesting |
| 10 | Exceptional |

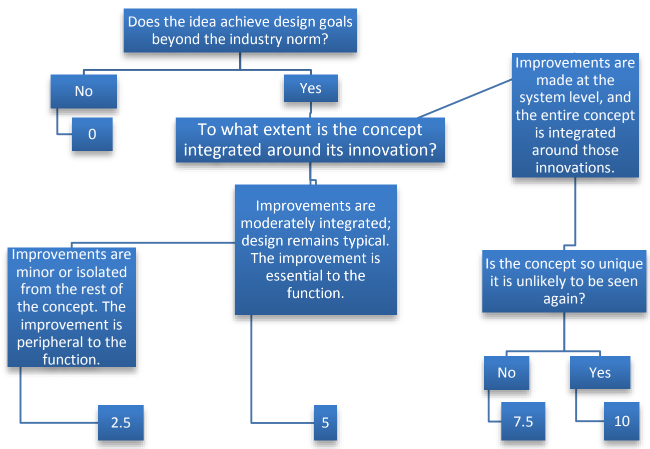


Figure 2: Originality Coding Decision Tree

Of the 465 concepts produced by the participants, a subset of 90 concepts was coded by the first and second authors and a research assistant. The agreement between raters was evaluated using Cohen's (1968) weighted kappa. After the training round of 90 concepts, inter-rater agreement between the three raters exceeded 0.7. The raters discussed any remaining differences and identified a mutually agreeable final rating for the subset of concepts. After the training round, the remaining concepts were coded by the second author or a research assistant.

**Originality Coding: Individual Contributions to Concepts.** In the following analysis, we assessed the contribution of each individual to each concept produced by the group using the decision tree shown in Figure 2. This analysis was not the improvement that each group member made to the overall concept beyond the originator, but instead, the unique contribution of each individual. We were able to track each individual's contribution because each group member was assigned a different color marker. As was done for the concept-level coding, a subset of the individual contributions were coded by the authors to determine inter-rater agreement. After review of the contributions of 35 individuals to 90 concepts, inter-rater agreement (kappa) between the three authors was .85. The second author then coded the remaining individual contributions to the concepts.

**Top Contributor Analysis.** Once individual contributions were coded, we examined the weight of each group member's contribution to the originality of the concept. Did the originator of a concept create its most creative aspect? Or was the originality of a concept more due to the contributions of other group members? Or were there equal contributions among group members?

The top contributor scores were derived from examination of the individual-level coding. The designation of the top contributor was scored as follows: if the concept's originator had the highest originality score, a 0 was scored. If a different group member had the highest score, a 1 was scored. If multiple group members had the same top score (e.g., two group members had individual-level originality scores of 2.5), then a 2 was scored. The authors scored a subset of the concepts together but the majority of the scoring was completed by the third author.

**Group Contribution Coding.** Each of the concepts was coded for the degree to which group members contributed to it. For each concept, the total number of group members, number of group members who had an originality score for a concept, and number of group members who contributed to the concept were tracked. It is important to note the difference between having a score for a concept and actually contributing to it. For example, a group member could have written "good idea" or drawn a smiley face on a concept. This person would have a score, but would not have contributed to the overall originality. Level of group contribution was coded dichotomously: a concept either showed evidence of group members working together (1) or was the product of one group member (0), with the other members simply commenting on the design. A group contribution score was calculated by dividing the number of contributors to the concept by the total number of group members. The second author completed the group contribution coding under the direction of the first author.

**Coding Demonstration.** A demonstration of the concept-level originality coding, individual-contribution originality coding, top contributor analysis, and group contribution coding is applied to the concepts shown in Figures 3 and 4. The concept shown in Figure 3 received an overall originality score of 5. It is an improvement to the function of a standard litter picker. This design received an originality score of 5 because, according to the decision tree (Figure 2), it shows moderate improvements over a standard litter picker, and these improvements are somewhat integrated. For example, the modified ends are expandable and include sensors that detect particular types of materials. At the same time, much of the design remains typical. It is clear from Figure 3 that the originator of the design, green, has copied his/her drawing from the design of the provided sample litter picker.

At the individual level, green is the originator of the concept, and modifies the basic litter picker by suggesting that different ends are needed to collect more litter. Purple suggests that these different ends should be expandable. Green and purple's ideas were both minor, isolated improvements to the basic litter picker and thus both were given an individual originality score of 2.5. Teal suggests that sensors could be incorporated into these larger, expandable ends to detect particular types of material, such as gold. Teal's contribution suggests a more system-level than isolated change, yet most of the design remains standard. Thus, teal was given an individual originality score of 5, and is also the top contributor to this design. Because red only commented without making any modifications, he/she received an originality score of 0.

In terms of degree of group contribution, this concept showed a high level of interaction between most of the group members, and thus received a group contribution value of 1. Three of the four members of the group contributed to the concept. Thus, it received a group contribution score of .75 (3 contributors/4 total group members).

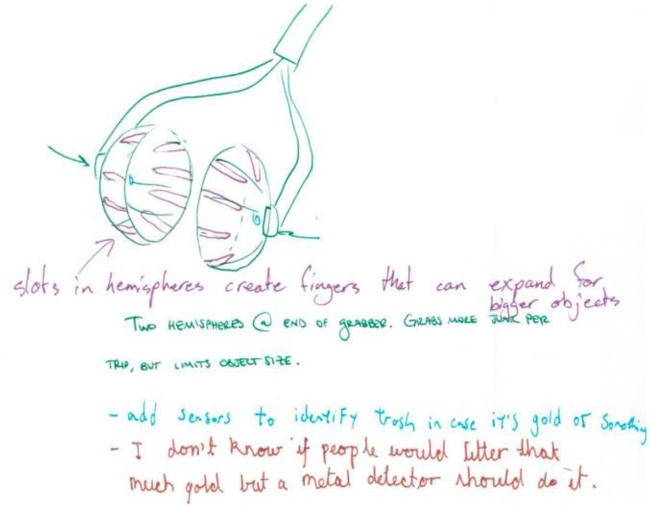


Figure 3: Sample Concept

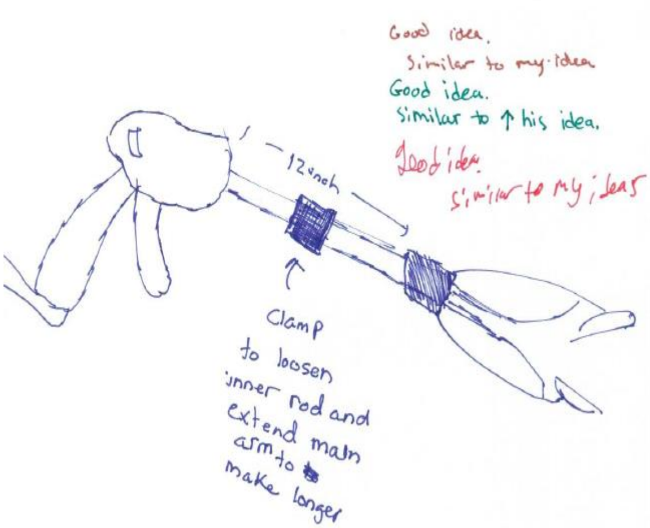


Figure 4: Sample Concept

As a second example, the concept shown in Figure 4 received an overall originality score of 2.5. This design is a standard litter picker that is very similar to the sample that was provided to students, but has a minor addition of telescoping. According to the decision tree (Figure 2), minor or isolated improvements such as telescoping features should receive an overall originality score of 2.5. Because this concept design has only one minor addition to a standard litter picker it received an originality score of 2.5.

At the individual level, this design is an example of one group member, in this case the originator, being responsible for the overall originality while the other members are supportive of the design choices. Blue is the originator and contributed the telescoping feature to the standard picker design and received the individual score of 2.5 for a basic and minor addition to the litter picker. Blue is the top (and only) contributor to the concept. Brown, green, and red each received individual scores of 0 because they did not contribute to the design by drawing in improvements; they only commented in agreement with the design blue made. Because only one group member contributed to the originality of the concept, it received a group contribution value of 0, and a group contribution score of .25 (1 contributor/4 group members).

## Results

Participants produced 465 litter collection system concepts. Thirty-eight concepts were removed from final analysis, 11 generated by freshmen and 17 by seniors, because they were not engineering solutions (ex. train a vulture to eat trash), leaving 427 concepts for analysis.

Results regarding the effects of curriculum level on concept-level and individual-level originality scores were discussed in Kershaw et al. (2015). In summary, there was not a significant difference in overall originality between freshmen and seniors. As noted earlier in the paper, however, the goal of the current set of analyses was to examine how interactions between group members affected originality, which was not examined in previous work.

### Top Contributors to Originality

For the following analyses, only concepts with originality scores of 2.5 or above were used. If a concept received a score of 0, meaning that it did not achieve design goals beyond industry standards, then there could not be a top contributor. We removed 137 concepts that received originality scores of 0, thus leaving 290 concepts in the analysis. Descriptive statistics for the top contributor analyses are in Table 2.

Table 2: Summary of Top Contributor Originality Scores

| | *M* | *SD* | n Concepts |
|---|---|---|---|
| Freshmen | | | |
| • Concept Originator | 3.78 | 1.78 | 111 |
| • Other Group Member | 2.86 | 1.20 | 21 |
| • Multiple Group Members | 3.08 | 1.50 | 13 |
| Seniors | | | |
| • Concept Originator | 3.71 | 1.75 | 101 |
| • Other Group Member | 3.10 | 1.09 | 21 |
| • Multiple Group Members | 3.15 | 1.55 | 23 |

First, we examined the distribution of top contributors within each curriculum level. A chi square test of independence indicated that there was no difference in the distribution of top contributor types (original, other group member, or multiple group members) between freshmen and seniors, $\chi^2$ (2, N = 290) = 3.25, *p* = .20. A second chi square test showed that having the design originator as the top contributor to originality was more common than having another group member or multiple group members, $\chi^2$ (2, N = 290) = 206.59, *p* = .0001.

Second, we examined the relationship between curriculum level (freshmen vs. seniors), contributor type (originator, other group member, or multiple group members), and concept-level originality. A two-way between-subjects analysis of variance (ANOVA) was conducted. There was no main effect of curriculum level and no interaction between curriculum level and contributor type, *F*s < 1. There was a significant main effect of contributor type, $F$ (2, 284) = 5.12, $p$ = .01, $\eta_p^2$ = .04. Post-hoc Tukey tests indicated that groups in which the concept originator was the top contributor had higher originality scores than groups in which a different group member was the top contributor, $p$ = .02, 95% CI = .11-1.44. There were no other significant differences between the contributor types.

## Level of Group Contribution

To test the effects of the level of group contribution on originality, all 427 concepts were included. A one-way ANOVA conducted to compare freshmen and seniors indicated that freshmen had higher group contribution scores ($M$ = .87, $SD$ = .24, 95% CI = .81-.88) than seniors ($M$ = .78, $SD$ = .25, 95% CI = .74-.81), $F$ (1, 425) = 8.89, $p$ = .003, $\eta_p^2$ = .02, indicating a higher degree of group interaction on the concepts produced by freshmen. A correlation analysis with all students showed a non-significant relationship between group contribution scores and originality, $r$ (427) = .07, $p$ = .16. Because other analyses had shown cohort differences, we also examined this relationship within the freshman and senior groups. Within the freshmen, the level of group contribution was not correlated with originality, $r$ (220) = .01, $p$ = .89. In contrast, within the seniors, the level of group contribution was significantly correlated with originality, $r$ (207) = .14, $p$ = .05.

# Discussion

The results indicate that it was most common for the originator of a concept to be the top contributor to a concept than a different member of the group or several group members. This pattern was shown in both freshmen and seniors. We also found that higher originality scores were achieved in groups in which the concept originator was the top contributor. The dominance of the originator as the top contributor, and higher originality scores in concepts with originators as top contributors, indicates that individuals may generate the most original ideas, in contrast to groups. This finding is in contrast with our predictions and with previous data obtained at UMD using similar samples and design problems, in which group members' contributions were found to raise the originality scores of concepts above what was generated by the concept originators (Blair & Hölttä-Otto, 2012). This finding, however, is in line with previous findings that show fewer ideas produced by groups rather than individuals (e.g. Mullen et al., 1991).

One of the chief differences between the current research and that reviewed by Mullen et al. (1991) is that our focus was on originality, not quantity. Further, there are some key differences between our work and that reported by Blair and Hölttä-Otto (2012). First, Blair and Hölttä-Otto only analyzed a set of 15 litter collection system concepts, compared to the 427 concepts that were analyzed for this paper. Second, Blair and Hölttä-Otto applied a feature-level analysis of originality to the concepts instead of using the decision tree we used. Thus, their determination of originality was based on how a given design satisfied different features, such as trash removal or storage, while our determination was based on how well the ideas in a particular design were integrated. One can make the argument that group design may enhance feature-level improvement but not an overall improvement in creativity. Clearly the metrics of the coding were different and one needs to carefully compare the two to ascertain whether there are actually fundamental differences in our results versus those of Blair and Hölttä-Otto (2012).

Another explanation of the top contributor results is related to design fixation. While results indicate that the originator was the predominant contributor in design creativity, it is important to point out that there may have been multiple members in the group who contributed to originality points. However, they were unable to contribute at a higher level of creativity compared to the originator. It may have been difficult for students to improve on an existing design and earn creativity points as opposed to earning points by designing from scratch. So, the lack of contribution could be because students were led into a particular line of thinking based on an existing design. This would be related to design fixation, a common problem in engineering design that can occur because of exposure to group members' ideas. For example, Kohn and Smith (2011) found that more exposure to typical design solutions produced by group members led to lower novelty, yet had no effect of quantity of ideas produced. Further analysis is necessary to assess the role of design fixation in group interactions within our current data set.

In contrast to the findings regarding the top contributor in each group, the level of group contribution was related to originality, but only among the seniors. Senior groups who had higher levels of interaction produced more original concepts. This finding is in line with previous findings that groups with high performance standards and experience working together will produce more creative ideas (Milliken et al., 2003; Paulus & Brown, 2003). Our previous research had shown that seniors had higher originality scores compared to freshmen (Kershaw et al., 2014). Although we did not replicate that finding here, the group contribution results suggest that something different is happening within the senior groups than the freshman groups. Our seniors completed the litter collection system exercise within the project groups within their capstone course. Group dynamics that were already established could have played a role, in that some project groups could be more egalitarian in design decisions while others may have had a clear leader who dominated group decisions. Alternatively, individual ability differences could affect group outcomes, with higher levels of intelligence, need for cognition, or flexibility affecting the originality of designs that groups produced. Further research is needed to explore these factors.

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