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Idea Generation Mechanisms: Comparing the influence of classification, combination, building on others, and stimulation mechanisms on ideation effectiveness.

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ABSTRACT

Ideation methods have been extensively studied, and several ideation methods can be beneficial in different contexts, but it is not understood what makes a specific method work. Previous work has shown that all the ideation methods comprise of 25 fundamental ideation mechanisms in two categories: idea implementation and idea promoting mechanisms. In this study, we try to understand how individual

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mechanisms affect idea generation outcomes. We chose four idea promoting mechanisms: two from the process category (Classification & Combination) and two from the idea sources category (Building on Others and Stimulation). These mechanisms were selected as they are examples of comparable mechanisms that could easily be integrated into any other ideation method. We conducted four experiments and assessed idea quantity, novelty, and originality. Our study showed that the chosen mechanism increased ideation performance. For the most part, the mechanisms are statistically equivalent, but we found evidence that classification outperforms combination in a simple ideation exercise. We also found the building on others can be more useful than the type of stimulation used in engineering concept generation, but the difference was not found in a simple ideation exercise. Overall, we find evidence that all mechanisms improve ideation effectiveness and could be incorporated into any ideation method, but further studies are needed to build more comprehensive understanding.

1. INTRODUCTION

Idea generation is a standard part of any design project. Accordingly, several tools and methods have been developed to support this phase. Generally, such tools or methods help to inspire or remove mental blocks in order to help designers to create several diverse ideas [1]. This has been shown to lead to higher overall quality ideas for further development [2, 3].

There is significant research on idea generation methods. For example, Daly et al. [4] found that the use of morphological analysis [5] and design heuristics [6, 7] in idea generation produced more elaborated and practical ideas than the use of individual brainstorming. Another study compares TRIZ [8] and SCAMPER [9] to team brainstorming, and no method is used at all. The study finds that TRIZ and SCAMPER produce more useful ideas, whereas Brainstorming and TRIZ result in more novel ideas when compared to the other methods. While we learn from these studies, the results are not easily generalizable or comparable due to chosen sets of methods and experimental setup. Morphological analysis and TRIZ are considered logical methods [10], whereas SCAMPER and Heuristics fall into the intuitive method category. On the other hand, the TRIZ principles, SCAMPER words, and Heuristics are all forms of stimulus, whereas individual brainstorming has no stimulus, and team brainstorming relies on being inspired by the other team members. The studies also differ in whether the idea generation was done alone or in teams.

The above research compares creativity methods against one another. However, these methods consist of components, elements, or strategies that help in idea generation. Kirjavainen and Hölttä-Otto [11] call these "mechanisms" and present 25 mechanisms that form all idea generation methods (Fig. 1). The mechanisms are divided into two categories: 1) Idea promoting mechanisms that help inspire or trigger ideas, and 2) the implementation mechanisms that guide the practical organization and format of the idea generation session.

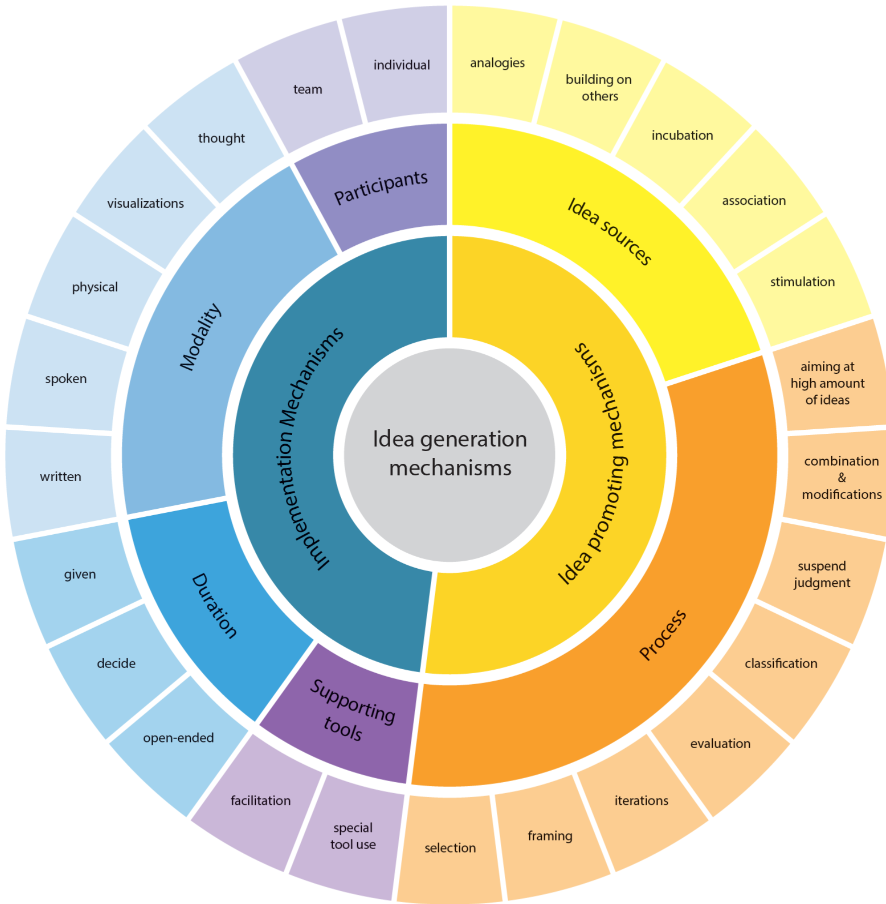

Fig. 1 Ideation Mechanisms [11]

The mechanisms provide an opportunity to study them independent of the creativity method they are used with. In this paper, we take the initial step towards understanding each of the mechanisms by studying two mechanisms from two idea promoting mechanism categories. Specifically, we aim to investigate two mechanisms from the process category: Combination and Classification, and two from the Idea Sources category: Stimulation and Building on others (BoO). Table 1 shows the definition of these chosen mechanisms.

Table 1 Definition of the Selected Idea Generation Mechanisms [11]

	Chosen Mechanism	Definition
Process	Classification	A phase in an idea generation method where ideas are classified or grouped as a part of using the method.
	Combination & Modifications	Combining, synthesizing, or modifying ideas as a part of the idea generation session creates new ideas and meanings. Modified ideas can be either idea created during the session or existing products, things, ideas, or meanings.
	Building on others	Participants are encouraged to build on others' ideas, while the ideas are created or stated. Also, rotating ideas or thoughts to other participants and building on those ideas.
	Stimulation	Using stimuli to prompt ideas. For example, using stimulating pictures, questions, or words or adapting a role to tease out ideas. The method might include collecting and using inspirational material or influencing the subconscious by exposing the participant(s) to pictures, sounds, words, or other ways to influence idea generation and activate thinking to help in accessing already existing knowledge.

2. BACKGROUND

2.1. IDEA GENERATION MECHANISMS

The ideation mechanisms build on past work, including past idea generation mechanism classifications and identification of some mechanisms [28-30]. On the implementation mechanisms side, Kirjavainen and Hölttä-Otto [11] find that team ideation is most common. It has also been studied. For example, Linsey et al. [24] and Blair et al. [26] study the role of an individual in 6-3-5/C-Sketch ideation where individual and team ideation are both used. Edelman et al. [27] and Heininger et al. [31], on the other hand, show how individual characteristics influence team ideation. Also, nominal teams vs. actual teams during concept development have been studied [32-34]. Modality has also been researched [16, 22, 23]. For example, sketching is found to be more useful than writing in engineering design [23, 35]. The other implementation mechanisms are less studied. However, past work can be found on, e.g., use of a facilitator [36] and specific special tools that have been developed such as electronic tools for group brainstorming [37-39] or several specific cards or other analog tools [40] for inspiration [41, 42].

The use of Stimulation at the beginning of idea generation is the most common idea promoting mechanism [11]. Different stimuli have also been well studied. The cards mentioned above is a special tool but also function as stimuli, and they have been shown to aid in ideation [17, 42]. Others have compared, e.g., different stimuli such as verbal vs. pictorial stimuli [16], and other specific stimuli such as personas [20] or embodied experiential stimuli [18, 19, 21]. Often these stimuli are meant to prime the designer toward specific outcomes [21]. Also, other idea source mechanisms in the idea promoting mechanisms have been researched. The use of analogies has been found useful. The effect of analogy types [43-46] or their distance [47] has been studied. Incubation is found to be useful [48, 49]. Also, some of the process related idea source mechanisms have been explored. For example, many studies show a correlation between the high amount of ideas and ideation success [2, 3, 15]. Suspending judgment and reframing were studied alongside with other cognitive creativity mechanisms [28]. In team ideation, it is often encouraged to build on other people's ideas. This has been shown to have a positive effect on both nominal and actual teams [24, 32, 34].

Overall, we find that many mechanisms have been studied, although some more than others. Very few works exist that compare the mechanisms. The work by Vargas

Hernandez [28] is a notable exception. They compared Stimuli, Suspending Judgment, Representation (Modality), Frame of Reference Shifting (Reframing), Incubation, and Example Exposure in a single study. They analyzed each mechanism individually as well as their interactions in a laboratory task of coming up with ways to move a ping-pong ball. They found that there are mechanisms that are stronger than others and that the interactions between mechanisms are not simple. Further, a recent study [50] explored design problem framing, using design heuristics (Stimulus) or teaming based on students' cognitive styles and how they affected students' idea generation. They found that especially teaming had a significant effect. We continue the mechanism level analysis in this paper. Here, our focus is on comparable or potentially interchangeable mechanism pairs.

Let us first explore two process related idea source mechanisms: classify and combine & modify. Kirjavainen and Hölttä-Otto [11] found that combining ideas during idea generation is present in 38% of the ideation methods they studied, whereas a potentially equivalent mechanism of classifying ideas was present only in 11% of the methods. In SCAMPER, the C stands explicitly for combining and M for modifying ideas. In Morphological analysis, the designer is asked first to decompose the problem into functions or other attributes and then list ideas for each attribute. They are then asked to combine the sub-ideas in many different combinations into potential solutions. Heuristic Ideation Technique (HIT) [51] is similar, but it is based on combining all potentially "relevant" concepts, not necessarily a problem decomposition. Classifying ideas is not present in as many idea generation methods, but for example, Forward

Steps [52] method advises the designer to pursue many paths and support finding these different paths but using classifying criteria. We can, however, not find studies where these have been explicitly compared.

Similarly, different idea source mechanisms could potentially be interchanged in an idea generation method. We take two different ones as an example: Stimulation and Building on Others. Stimulation is well studied, and since team ideation is common, at least some building on others is typical even if not always explicitly stated in a method. Kirjavainen and Hölttä-Otto [11] found that Stimulation is present in 57% and Building on others in 28% of the idea generation methods. For example, in Empathic Experience Design [19], wearing simulation gear is intended to stimulate innovation. Word Tree design by analogy method [44], on the hand, mentions explicitly how certain types of verbs are better stimuli than others for creativity. 6-3-5- method [53] and various extensions of it rely on building on others. Designlibs, [54] a method mimicked after the game Mad Lips, is also based on building on others. Different stimuli have been compared against no stimulus and occasionally against other types of stimuli, and the roles of an individual in a team have been studied as previously discussed, but we are not aware of studies comparing the use of a stimulus to building on others. While these two mechanisms can also appear simultaneously in a single idea generation method, it is interesting to begin to understand how each work compared to the other.

2.2 CREATIVITY EVALUATION

Divergent thinking is a good indicator of creative potential [55]. As we study divergent thinking or creativity through idea generation, we focus on the ideas produced. This is an outcome-based approach, where methods for idea generation are considered effective if they produce good ideas [10]. In previous studies, multiple different metrics have been used to evaluate the results of idea generation [18, 29, 55]. These metrics have been summarized by, e.g., Dean et al. [56] and Kudrowitz & Wallace [57].

In this study, we used three metrics to evaluate the creativity. Fluency can be used as a creativity measure, as it depicts how easily one can create a mass of ideas. The more ideas there are, the better the chance of good ideas exists [10, 55, 58, 59]. In addition to counting the ideas for the two rounds, unique ideas were also counted [15, 18]. The newness of an idea could be judged with its commonness in the mind of the rater, relative to existing products, or with how common it is in the whole population of ideas [10, 56]. The choice of metric partially depends on the type of problem. We chose to use two different measures to capture: Novelty for measuring how common or uncommon an idea is compared to other generated ideas in the set [10], and the Decision Tree for Originality Assessment in Design (DTOAD) [60] to capture originality relative to the industry norm. Both have been used in the context of engineering design. Novelty is suitable for a standard (non-engineering) creativity tests, whereas DTOAD is designed explicitly for engineering design.

Novelty – Shah's novelty metrics calculate novelty score using Equation (1), and for that, it considers commonness or uncommonness of idea within the whole dataset. In this equation, *S* is Novelty Score, *T* is the Total number of solutions or ideas produced, i.e., total bins, and *C* is the number of ideas in that bin.

$$S = ((T-C)/T)) \times 10 \quad (1)$$

DTOAD uses a 5-point ordinal scale to represent lowest to highest originality score ranging from 0 to 10 with an incremental step of 2.5 between each level (Fig. 2). Examples of how we used each of these three metrics are given in the subsequent section.

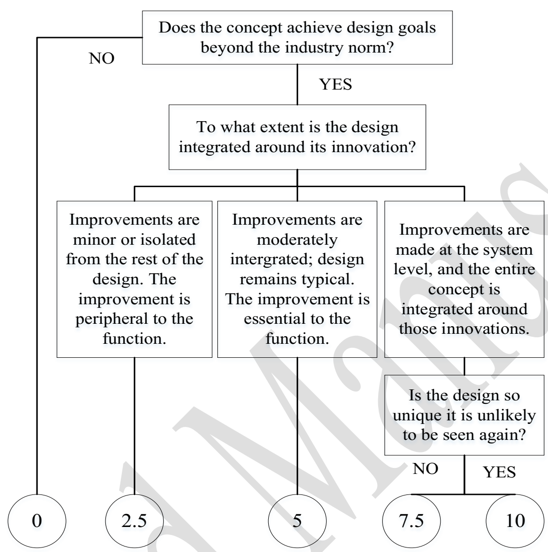

Fig. 2 The Decision Tree for Originality Assessment in Design (DTOAD) [60]

2.3 RESEARCH QUESTIONS

We aim to understand how the mechanisms affect the idea generation effectiveness. We chose to study four idea promoting mechanisms: two from the process category (Classification & Combination) and two from the idea sources category (Building on Others and Stimulation) [11]. These mechanisms are selected as they are examples of comparable mechanisms that could easily be integrated into any other ideation process. We aim to answer the following research questions:

RQ1: How does classifying or combining ideas during simple idea generation or engineering concept generation impact the number of ideas or idea novelty or originality?

RQ2: How does Building on others or Stimulation during simple idea generation or engineering concept generation impact the number of ideas or idea novelty or originality?

3. METHODOLOGY

To answer these two research questions, we conducted four different experiments. Fig. 3 shows the experimental approach. The research methodology for each experiment is described separately below.

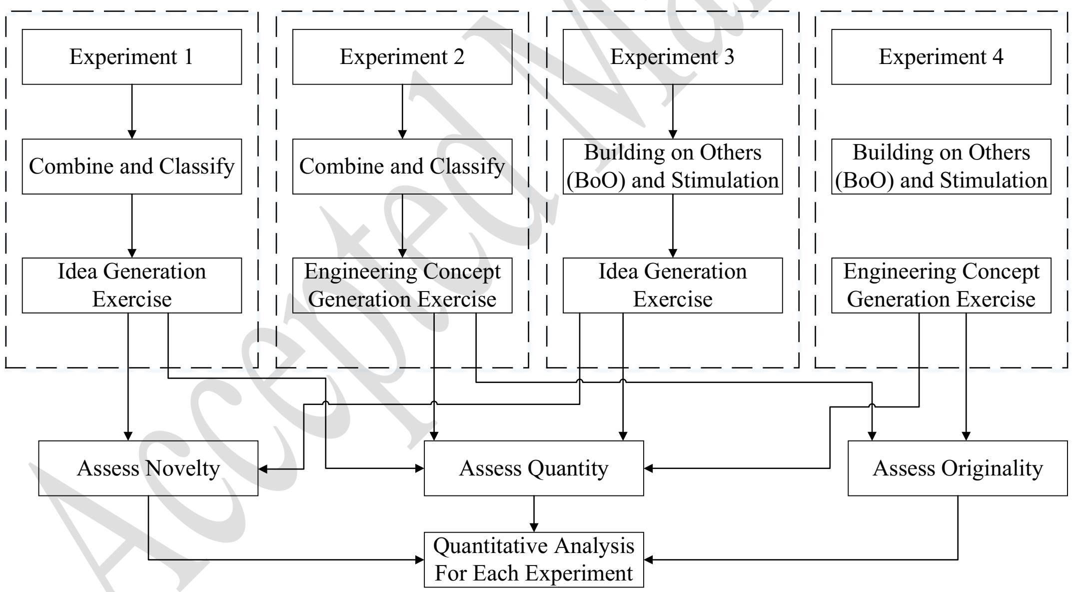

Fig. 3 Methodology Adopted to Answer Research Questions

4. DESIGN PROMPT AND EXPERIMENTAL DETAILS

4.1 EXPERIMENT 1:

The first experiment tested Classify and Combine mechanisms in a simple ideation task. The data were collected using alternate uses tests [61, 62]. The participants were asked to list as many ways of using a paperclip as they possibly can. The modified test included two rounds of idea generation and implementing one of two alternative idea-promoting mechanisms as a task in the middle (Fig 4).. The participants were given the design challenge and a 3-page ideation template with instructions about round 1, intervention, and round 2. A similar appraoch was deployed for the other three experiments. Participation was voluntary. In the end, we received 579 individual ideas. Some entries were also translated from Finnish or Spanish to English by a native speaker fluent in English.

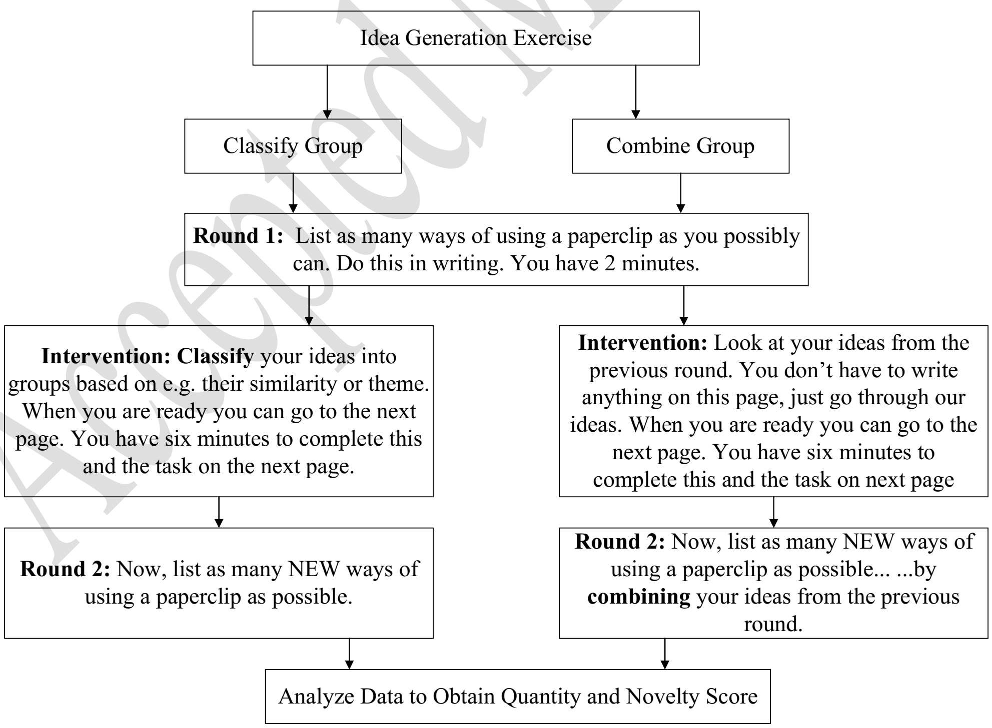

Fig. 4 Design of Experiment 1

4.2 EXPERIMENT 2:

This experiment tested classify and combine mechanisms in an engineering-related task. The participants were asked to propose concepts for a "next-generation garbage picker." The experimental approach adopted for this research is in Fig. 5. We followed the procedure similar to Kershaw et al. [63]. The design challenge did not have any further design requirements. As done in previous studies [63], no reference example; physical or in any other form of communication was presented to reduce unintentional fixation [64].

The experiment was conducted in the pre-post form for three groups: control, combine, and classify. The general-purpose of the research was conveyed to the participants, but no information about the experimental set up was revealed. Participation was voluntary, and after obtaining the consent, they were randomly assigned to the three groups.

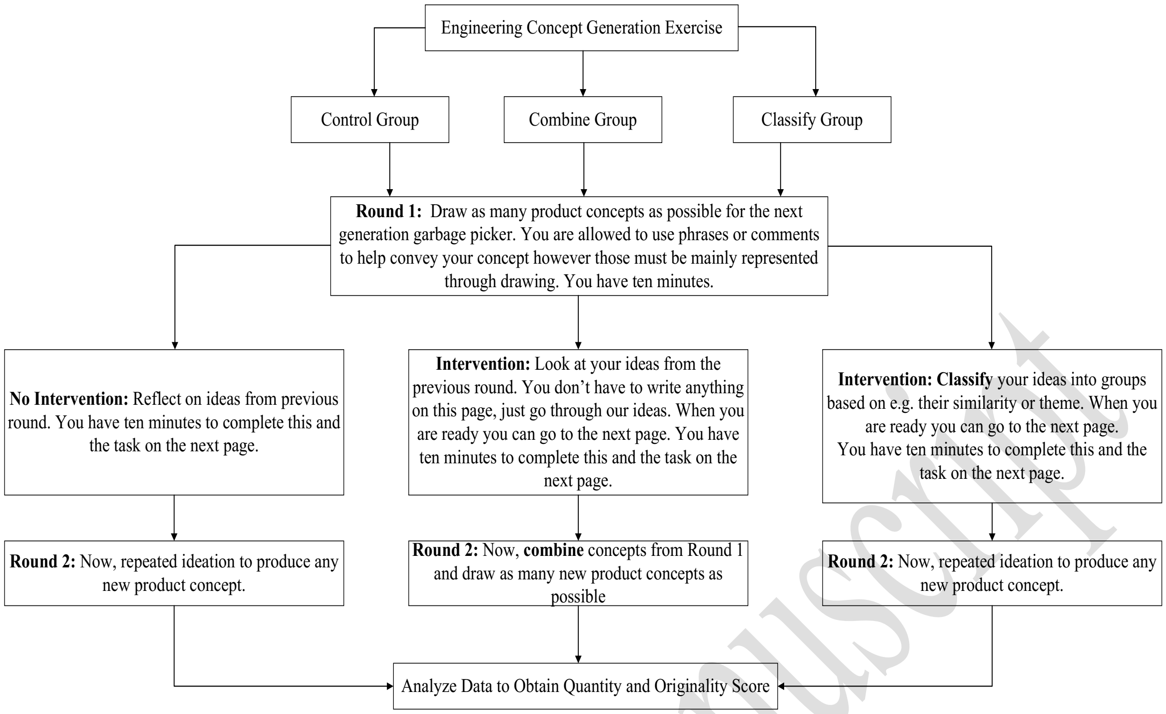

Fig. 5 Design of Experiment 2

4.3 EXPERIMENT 3:

This experiment investigated the effects of two mechanisms, Building on others (BoO) and Stimulation. Here, we followed a procedure similar to the first experiments. The experiment follows a pre-post format with intervention in between the rounds (Fig 6). There was no control group in this experiment. The participants were given an alternate uses test [61] [62]. The test asked the participants to generate as many ways as possible of using a paperclip, and no examples were provided.

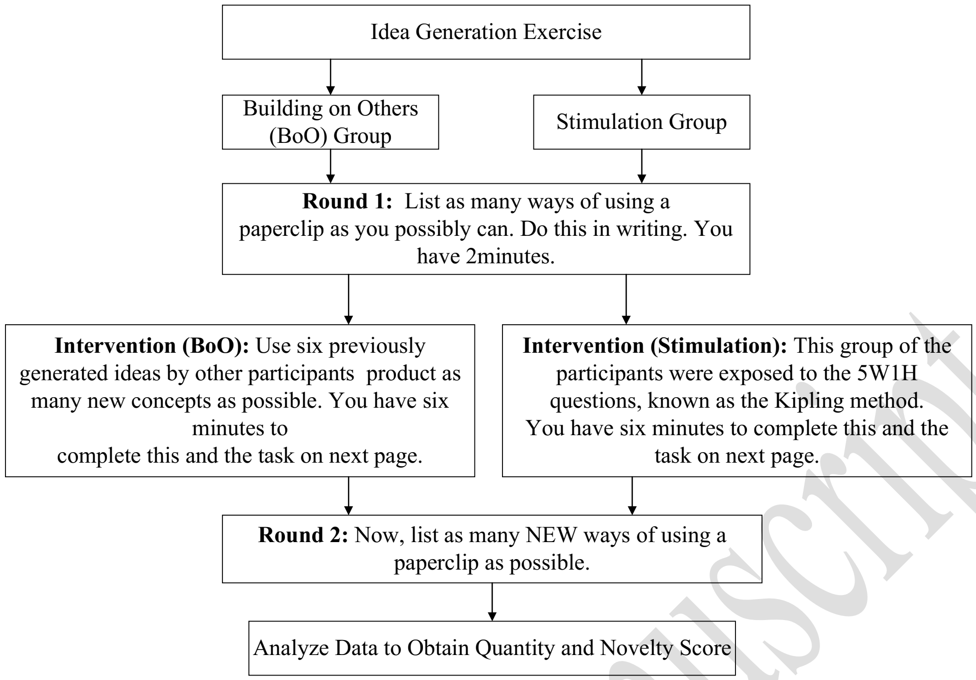

Fig. 6 Design of Experiment 3

4.4 EXPERIMENT 4:

This experiment investigated the effects of two mechanisms, Building on others (BoO) and Stimulation, but for engineering concept generation, 'Next generation garbage picker' was used as a design prompt similar to Experiment 2. The method of delivery and instructions were similar to the previous three experiments (Fig. 7).

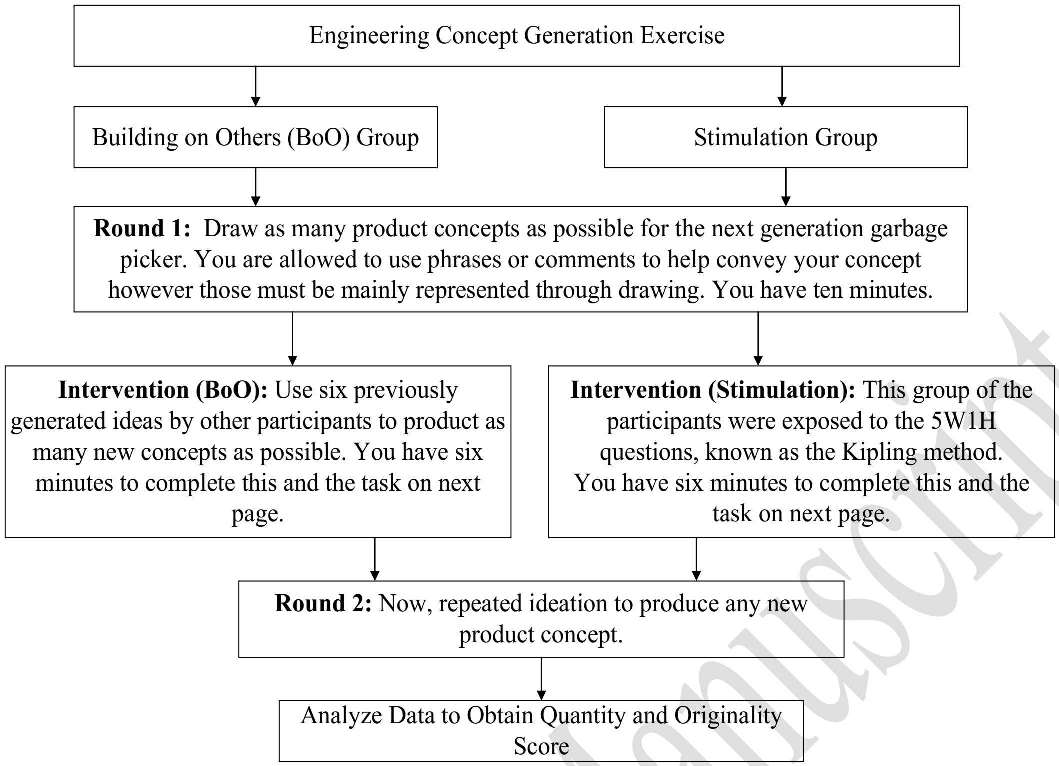

Fig. 7 Design of Experiment 4

5. PARTICIPANTS

Participants are in Table 2. For three experiments, we collected participant details such as major, age demography, etc. For one experiment, we did not collect that information. Since we did not use that information for any further analysis or assessment in this study, those details are not included here.

Table 2 Participant for Each Experiment

Exp.	Participants' Background	Total Number	University/College	Course	Academic Year	Average Age (Yrs)
1	Graduate-Level Students	61	Aalto University, Finland	Product Development	2016-17 and 2017-18	25.4
2	Freshman-Engineering Students	57	Maharashtra Academy of Engineering (MIT	Design Thinking	2018-19	N/A

			AoE), India			
3	Master's Level	35	Aalto University, Finland	Methods in Early Product Development	2019-20	24.3
4	Master's Level	41	Aalto University, Finland	Product Development Project	2019-20	N/A

6. ASSESSMENT

To find answers to our research questions, we assessed the quantity, novelty, and originality of the concepts produced. Here, we explain methods to calculate quantity, novelty, and originality with one example for each.

6.1 QUANTITY

Quantity stands for the number of ideas, i.e., alternate uses, generated by the participants during the given task. All ideas generated by each participant in both round 1 and 2 were counted. In addition, each unique idea by the participants mentioned in round 2 was also counted separately. This was done by coding the ideas from round 1 to the idea bins. If a participant contributed to the same bin on both rounds, the recurring idea on round 2 was not considered unique. A similar principle was applied to calculate quantity for all other experiments.

6.2 NOVELTY

The ideas were binned based on the similarity of the intended use, i.e., according to their meaning to a potential user to rate the novelty of ideas. For this, a set of coding guidelines was generated. The 579 ideas were rated in binned into 113 bins for experiment 1, each representing a recurring idea (see Table 3 for a binning example).

Most idea mentions were in a bin representing "clipping paper," the original use of a paperclip. The ideas mentioned only once in the whole population of ideas formed their bins of one mention. For example, the uses involving cleaning were divided into bins of a) Personal hygiene; nails, ears, eyes, and so forth b) Toothpicks and cleaning teeth c) Cleaning other things such as small gaps, drains, holes, earplugs, etc. d) Cleaning gum, stickers' glue marks, etc.

Table 3 Example of Binned Ideas

Ideas # in bin	Bin # 4: Fork	Bin # 85: Magnetic Uses	Bin # 18: Belt Buckle	Bin # 113: Tablecloth Holder
1	As a fork	Sticking paper to fridge	Part of the belt buckle	For holding Tablecloth on an Outdoor table
2	Make a heart pick fork	As a magnet	Belt buckle part	
3	Pick food	Testing a magnet		
4	Cocktail pick	Magnetic		
5	Punching: cocktail sticks			
6	Fork			
7	Food dip			

Novelty was calculated for each bin or idea using Equation (1). For example, bin number 4 in Table 3. Gets a novelty value of: ((113-7) / 113) x 10 ≈ 9.38, since a fork-type idea appeared seven times, forming one bin out of the total 113 bins.

6.3 ORIGINALITY ASSESSMENT

This assessment was used an engineering concept generation task. A few sample concepts are shown in Fig. 8. The concepts varied from a simple broom stick and dustpan to more complex system-level designs. Two representative cases are chosen to demonstrate the originality assessment. One concept was rated 2.5 and the other 7.5. These two originality scores cover the second-lowest to the second-highest scores in our entire dataset. None of the concepts were rated ten on the DTOAD scale (Fig. 2) in our experiments.

In Fig. 9, a participant proposed a type of dustbin (trashcan) with a filtering machine in the middle. This dustbin might sort and store the garbage as plastic and degradable separately, unlike done manually in most cases. Referring to the DTOAD (Fig. 2), the first level check was whether the concept achieved design goals beyond the industry norm.

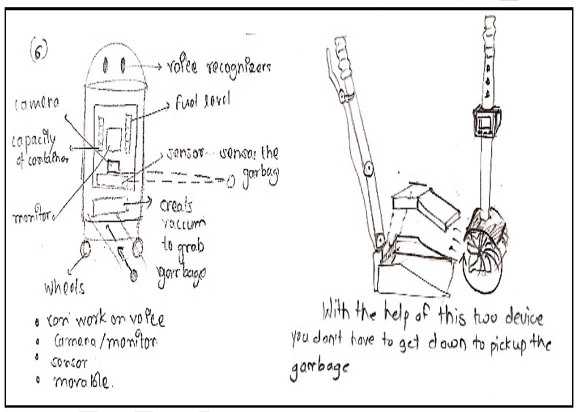

Fig. 8 Exemplary Concepts

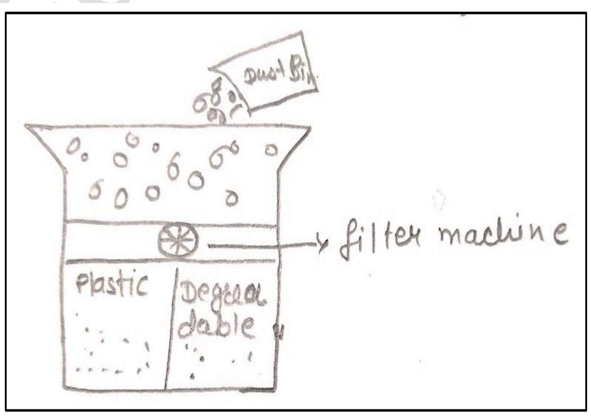

Fig. 9 Sample with Score 2.5 on DTOAD Scale

At the time of writing this paper, our research did not show any similar product being widely used. The 'filter machine' feature is additional functionality to the dustbin, and it is beyond the current industrial practice of using two separate dustbins. Therefore, this concept satisfied the condition to reach level 2 on the DTOAD scale. At this level, we tried to understand if the design is well integrated around innovation. This concept does add a feature, which is not an industry norm. However, this feature is a minor and just one addition to the existing products. Trash bins with an inbuilt partition for different garbage types are commonly available. Therefore, coders concluded that this improvement is isolated from the rest of the design. The product concept was not an industrial norm and embodied minor improvement; hence, it was rated 2.5.

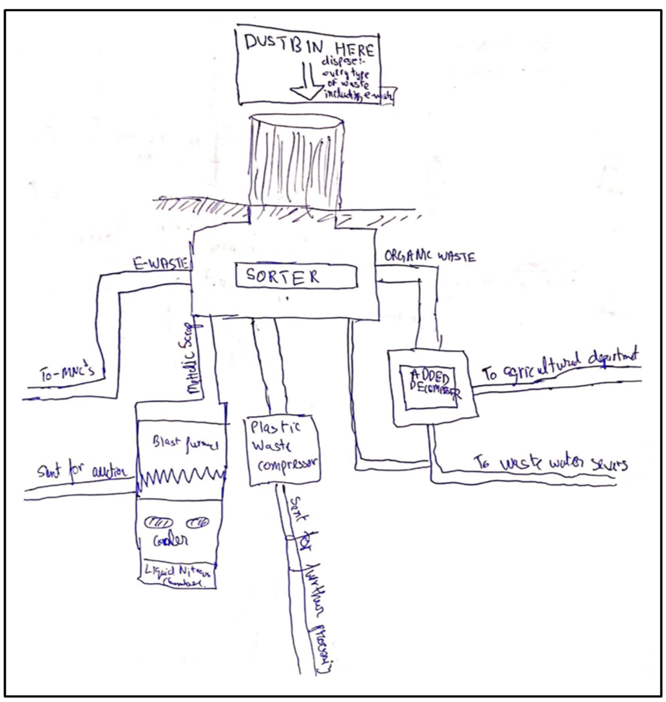

Fig. 10 Sample with Score 7.5 on DTOAD Scale

Fig. 10 shows a design with multiple features and functionalities incorporated in it, such as sorting waste into the organic, metallic, plastic, and the e-waste. Garbage is further processed appropriately. It involved burning, compressing, decomposing, or simply transferring to waste sewers. Currently, transferring trash to landfills through an underground piping system does exist, but that systems do not automatically process the garbage to the extent shown in this concept. To design a system consisting of these features requires considerable system-level infrastructure improvement, integration of the processes for garbage collection and transport. In all the concepts we have rated, this concept was not repeated, but some other underground transport systems were found. It is highly unlikely that this concept will never be seen again. Therefore it was 7.5. A similar approach was deployed for coding of all the concepts.

7. INTER-RATER RELIABILITY

We used two raters to reach an agreement for each experiment. We rated 20 concepts per round to assess reliability. In between two rounds, raters discussed rules of agreement and repeated the binning, coding until a final agreement was reached. For experiments 2 and 4, Weighted Cohen's Kappa was used because of the incremental DTOAD scale. Details of inter-rater reliability are in Table 4.

Table 4 Inter-Rater Reliability for Each Experiment

Experiment	Number of Raters	Number of Rounds	Agreement Method	Agreement Reached	Total Concepts Coded
1	2	2	Cohen’s Kappa	0.82	579
2	2	3	Weighted Cohen’s Kappa	0.70	381
3	2	1	Cohen’s Kappa	0.76	337
4	2	3	Weighted Cohen’s Kappa	0.74	245

8. ANALYSIS AND RESULTS

For all the experiments, we followed a systematic assessment approach, as shown in Fig. 11. The finding from each experiment is described individually.

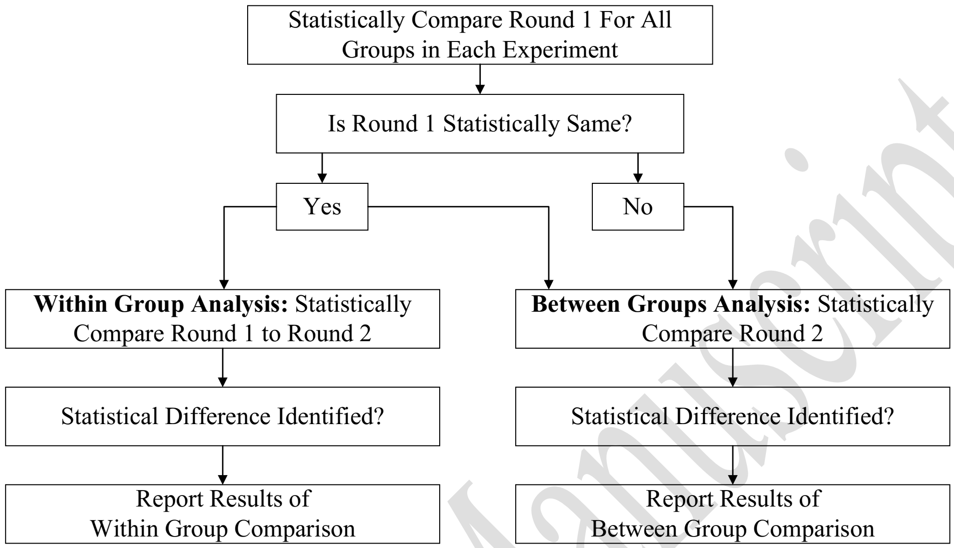

Fig. 11 Systematic Analysis Approach Adopted for All Four Experiments

8.1 EXPERIMENT 1: IDEA GENERATION EXERCISE

8.1.1 QUANTITY OF IDEAS

To test which mechanism, classify, or combine, produced more ideas, we first ensured that the two groups are comparable. We compared the quantity of ideas in round 1 using the Mann-Whitney test and found that they produced a statistically equivalent quantity of ideas (p-value = 0.609). We then compared round 2 of both groups. We did both within-group and between-group analysis. The within-group analysis helped us understand how well the mechanism works on its own, and the between-group analysis allows us to compare two mechanisms.

8.1.1.1 WITHIN GROUP ANALYSIS:

The quantity data failed all tests for normality; thus, a non-parametric Wilcoxon Signed Rank test was used. The overall quantity decreased significantly from round 1 to round 2 in both groups (for classify group p-value = 0.001 and for combine group p-value= 0.000). The same decrease is present when comparing the quantity of ideas from round 1 to the quantity of unique ideas from round 2 (in both cases, p-value = 0.000).

Table 5 Idea Generation (Exp. 1) Quantity Analysis Results

Group	Round	Total Concepts	Mean Quantity	Std. Dev.	Std. Error	P-Value
Classify	1	161	5.75	2.50	0.47	0.001**
	2	112	4.00	1.49	0.28	
	2 Unique Only	89	3.18	1.28	0.24	
Combine	1	199	6.03	2.69	0.47	0.000**
	2	121	3.67	2.25	0.39	
	2 Unique Only	59	1.79	1.97	0.34	

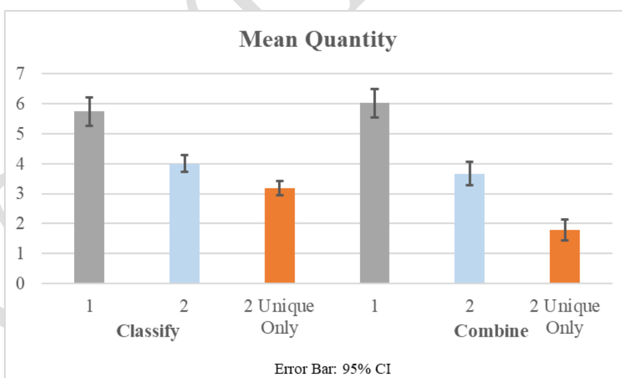

Fig. 12 Mean Quantity of Ideas and Unique Ideas Per Round with Standard Error Bar (95% CI) For Both Mechanisms

8.1.1.2. BETWEEN GROUP ANALYSIS:

The analysis confirmed no statistical difference between the groups when comparing all ideas in round 2 (p-value= 0.256). However, there was a significant difference in the number of unique ideas produced in round 2 (p-value= 0.000). Looking at Table 5 and Fig. 12, we can see that the classify mechanism produced a significantly higher number of ideas than the combine group, having an average just above three unique ideas, while for the combine group, the average amount of unique ideas was under two.

8.1.2 NOVELTY OF IDEAS

The novelty data failed tests for normality; thus, a non-parametric Mann-Whitney U test was chosen. We found no statistical difference between the two groups in idea novelty in round 1 (p-value= 0.150); thus, the groups are comparable.

8.1.2.1 WITHIN GROUP ANALYSIS:

Firstly, the data were analyzed to see if the mechanism, classifying, or combining affected novelty score from round 1 to round 2. For both groups, the novelty of ideas between the two rounds increased statistically significantly (in both cases, p-value= 0.000). We also tested if the mechanisms influenced the novelty of unique ideas between rounds 1 and 2. We found, for both groups, there was a significant increase in the novelty of unique ideas from round 1 to 2. (in both cases, p-value= 0.000).

8.1.2.2 BETWEEN GROUP ANALYSIS:

The difference in idea novelty between the groups classifying and combining was compared using the Mann-Whitney U test and was found to be statistically significantly higher in round two (p-value= 0.014). The classify group scored significantly higher than the combine group when testing all ideas (Table 6 and Fig 13). It also means classifying ideas lead to higher novelty than combining.

Table 6 Idea Generation (Exp. 1) Novelty Analysis Results

Group	Round	Total Participants	Mean Novelty	Std. Dev.	Std. Error	P-Value
Classify	1	28	8.19	1.80	0.14	0.000**
	2	28	9.17	0.69	0.07	
	2 Only Unique		9.28	0.60	0.06	
Combine	1	33	8.12	1.66	0.12	0.000**
	2	33	8.74	1.24	0.11	
	2 Only Unique		9.24	0.67	0.09	

The tests were repeated for only unique ideas from round 2. There was no difference in the novelty of unique ideas between the two groups in round 2 (p-value= 0.907).

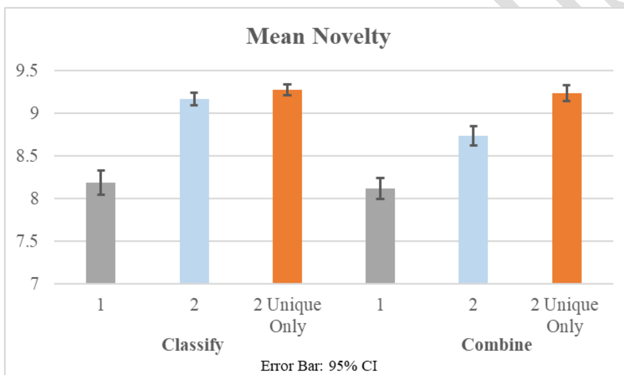

Fig. 13 Mean Novelty Per Round with Standard Error Bar (95% CI) For Both Mechanism

8.2 EXPERIMENT 2: ENGINEERING CONCEPT GENERATION EXERCISE

8.2.1 QUANTITY OF IDEAS

We first compare the quantity of concepts produced in round 1 of all three groups. A non-parametric Kruskal-Wallis, independent samples test showed that for round 1 mean rank was statistically significantly different (p-value= 0.000). Therefore, it was not possible to conduct the between-group analysis to determine which mechanism produced a higher quantity of engineering concepts in round 2. Therefore, we only did the within-group analysis.

8.2.1.1 WITHIN GROUP ANALYSIS:

The normality test showed that the data were non-parametric. Since each group underwent a pre-post test format, we did two related samples Wilcoxon Signed Rank test. Our analysis for control (p-value =0.039), combine (p-value= 0.003), and classify (p-value= 0.000) group showed that there was a statistically significant decrease in the quantity of concepts produced in round 2 (Table 7).

Table 7 Engineering Concept Generation (Exp. 2) Quantity Analysis Results

Group	Round	Total Quantity	Mean Quantity	Std. Dev.	Std. Error	P-Value
Control	1	45	2.25	1.070	0.23	0.039*
	2	35	1.75	0.910	0.20	
Combine	1	70	3.68	1.600	0.36	0.003**
	2	50	2.63	1.422	0.32	
Classify	1	115	6.38	2.033	0.47	0.000**
	2	66	3.72	2.052	0.46	

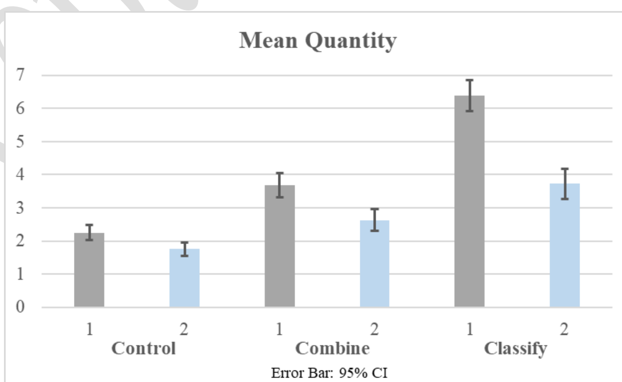

Fig. 14 Mean Quantity of Concept Per Round for All Three Mechanisms with Standard Error Bar (95% CI)

8.2.1.2 RADICALLY DIFFERENT CONCEPT GENERATION:

We also measured whether the quantity of 'radically different concepts' increased from round 1 to 2. Kershaw et al. [60] defined the product concept as 'radically different' if it scored 7.5 or 10 on the DTOAD scale.

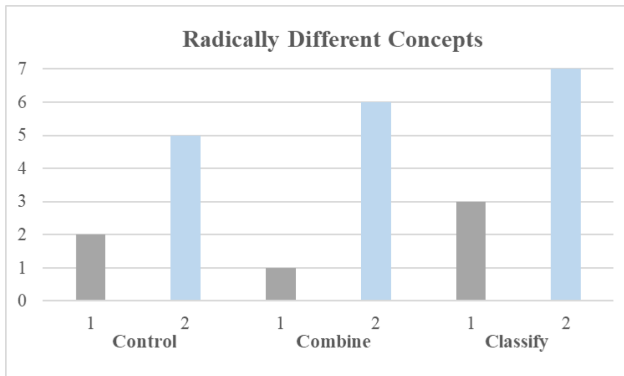

Fig. 15 Quantity of Radically Different Concept

We observed an interesting pattern in all the groups (Fig. 15). The number of radically different concepts increased in round 2 for all three groups. Out of all three groups, the combine group showed the highest percentage increase. Surprisingly, the control group also showed an increased quantity of radically different concepts from round 1 to 2. Due to the low quantity of these concepts in round 1, we choose not to perform statistical analysis on these results.

8.2.2 ORIGINALITY OF IDEAS

The originality scores of round 1 for control, combine and classify groups were compared against each other using the Kruskal-Wallis test due to the non-parametric nature of the data. A p-value= 0.180 means round 1 was comparable, and we can perform both between-group and within-group analysis.

8.2.2.1 WITHIN GROUP ANALYSIS:

We started the analysis with the control group. Round 1 and round 2 concepts were checked for normality. Data were non-parametric; thus, a non-parametric Mann Whitney U test was used. For the control group, we find no statistical difference between the rounds (p-value= 0.406) (Table 8).

Table 8 Engineering Concept Generation (Exp. 2) Originality Analysis Results

Group	Round	Total Participants	Mean Originality	Std. Dev.	Std. Error	P-Value
Control	1	20	2.333	2.223	0.33	0.406
	2	20	2.928	2.810	0.47	
Combine	1	19	1.571	1.958	0.23	0.023*
	2	19	2.650	2.595	0.36	
Classify	1	15	1.891	2.186	0.2	0.000**
	2	15	3.219	2.471	0.3	

Figure 5 shows the mean originality score with the bar chart, standard error (95% CI) for all three groups. For the combine intervention group, the normality test showed that data were non-parametric. Mann-Whitney U test showed that the difference in mean ranks between round 1 and 2 was statistically significant (p-value= 0.023). The combine mechanism resulted in concepts with higher originality in round 2 compared to round 1. Finally, we investigated the classify mechanism groups. Data were non-parametric, the

Mann-Whitney U test showed a statistically significant difference between round 1 and 2. The highest significance was found in this group with p-value= 0.000.

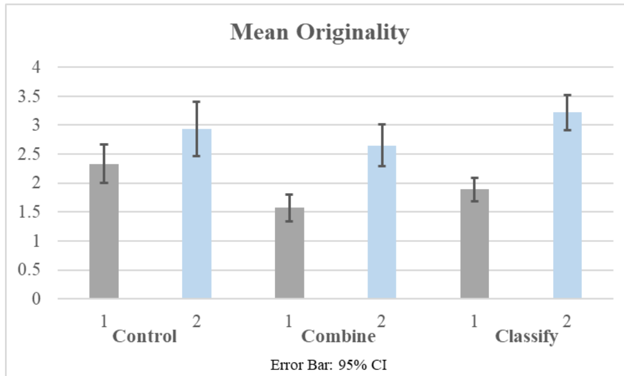

Fig. 16 Mean Originality Per Round for All Three Mechanisms with Standard Error Bar (95% CI)

8.2.2.2 BETWEEN GROUP ANALYSIS:

We further compared the originality scores of the round 2 of all three groups to identify which mechanism resulted in the highest increase in originality. The non-parametric Kruskal-Wallis test ($p= 0.445$) indicated no statistically significant difference.

8.3 EXPERIMENT 3: IDEA GENERATION EXERCISE

8.3.1 QUANTITY OF IDEAS

The quantity data failed all tests for normality; therefore, non-parametric tests were used. Mann-Whitney U test showed the quantity in round 1 was statistically equivalent (0.07) for all groups. Therefore, we performed between-group as well as within-group analysis.

8.3.1.1 WITHIN GROUP ANALYSIS:

At first, the Wilcoxon Signed Rank test was performed to analyze the effects of the mechanisms on the quantity of the ideas from round 1 to round 2. The test showed no statistically significant difference in quantity for the BoO group (p= 0.182) nor stimulation group (p= 0.475).

8.3.1.2 BETWEEN GROUP ANALYSIS:

Next, we did a between-groups analysis to assess whether BoO or stimulation mechanism leads to a higher idea quantity. We did the Mann-Whitney U test and found a statistically insignificant difference in quantity (p= 0.44).

Table 9 Idea Generation (Exp. 3) Quantity Analysis Results

Group	Round	Total Quantity	Mean Quantity	Std. Dev.	Std. Error	P-Value
Building on Others (BoO)	1	84	4.42	1.38	0.31	0.182
	2	103	5.42	3.11	0.71	
	2 Only Unique	85	4.47	2.59	0.59	
Stimulation	1	71	4.43	1.09	0.27	0.475
	2	79	4.93	2.99	0.74	
	2 Only Unique	59	3.68	3.11	0.77	

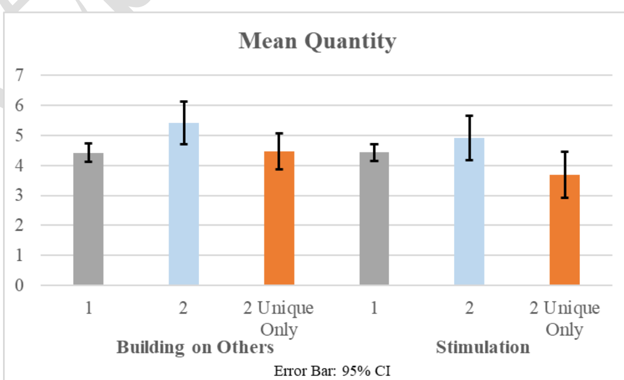

Fig. 17 Mean Quantity of Ideas and Unique Ideas Per Round with Standard Error Bar (95% CI) For Both Mechanisms

8.3.2 NOVELTY OF IDEAS

A novelty score was calculated for each of the 337 ideas generated. The data failed the tests of normality; therefore, non-parametric tests were used. Mann-Whitney U test found no different in the round 1 scores (P=0.981) (Table 10 and Figure 7).

8.3.2.1 WITHIN GROUP ANALYSIS:

Mann-Whitney U test (p= 0.001) indicated that the BoO mechanism had a statistically highly significant effect on novelty. Similarly, for the stimulation mechanisms had a statistically significant effect (p= 0.005) on novelty.

8.3.2.2 BETWEEN GROUP ANALYSIS:

To evaluate the effect of the interventions against each other, novelty scores from round 2 of each group were compared. There was no statistically significant difference between BoO and stimulation interventions (p= 0.606); therefore, it is not possible to conclude which intervention resulted in more novel ideas. Furthermore, the novelty scores of unique ideas from round 2 were compared to check which intervention resulted in more novel unique ideas, and a p-value= 0.137 implies no statistical difference between the novelty of unique ideas after both interventions.

Table 10 Idea Generation (Exp. 3) Novelty Analysis Results

Group	Round	Total Participants	Mean Novelty	Std. Dev.	Std. Error	P-Value
Building on Others (BoO)	1	19	9.47	0.40	0.04	0.001**
	2	19	9.67	0.34	0.03	
	2 Only Unique		9.80	0.12	0.01	
Stimulation	1	16	9.48	0.41	0.04	0.005**
	2	16	9.63	0.40	0.04	
	2 Only Unique		9.81	0.18	0.02	

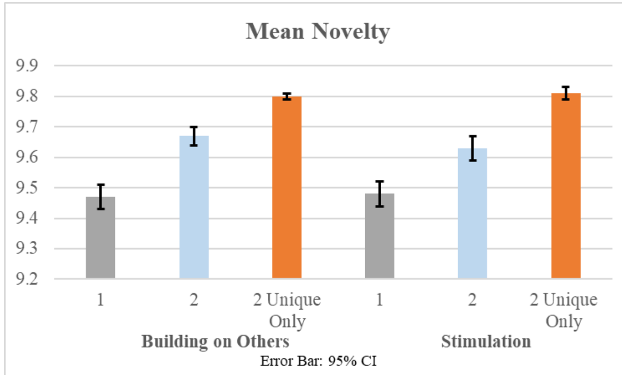

Fig. 18 Mean Novelty with Standard Error Bar (95% CI) For Both Mechanism Per Round

8.4 EXPERIMENT 4: ENGINEERING CONCEPT GENERATION EXERCISE

8.4.1 QUANTITY OF IDEAS

For both groups, the quantity of concepts decreased. The quantity data failed all tests of normality; therefore, non-parametric Mann-Whitney U test were used. The quantity of concepts generated by both BoO and stimulation groups is statistically equivalent (p=0.588). Therefore, we can compare whether BoO is better or Stimulation.

8.4.1.1 WITHIN GROUP ANALYSIS:

We find that both BoO (p=0.002) and Stimulation (P00.001) groups show significant decrease in quantity.

8.4.1.2 BETWEEN GROUP ANALYSIS:

The quantity ideas from round 2 were compared using the non-parametric Mann Whitney U test, and a p-value= 0.903 indicates the two mechanisms performed equally.

Table 11 Engineering Concept Generation (Exp. 4) Quantity Analysis Results

Group	Round	Total Quantity	Mean Quantity	Std. Dev.	Std. Error	P-Value
Building on Others (BoO)	1	71	3.55	1.79	0.40	0.002**
	2	42	2.10	0.91	0.28	
Stimulation	1	81	3.86	1.79	0.39	0.001**

2	48	2.29	1.41	0.31

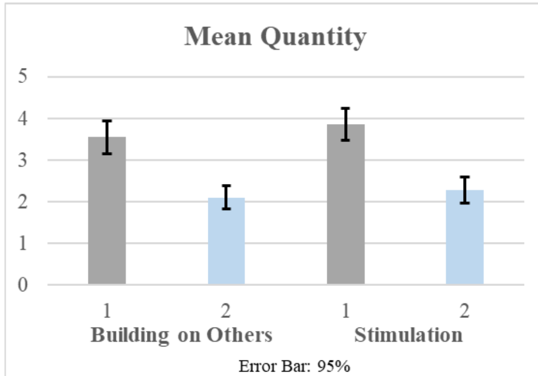

Fig. 19 Mean Quantity of Concept for Both Mechanisms Per Round with Standard Error Bar (95% CI)

8.4.1.3 RADICALLY DIFFERENT CONCEPTS:

Similar to experiment 2, here, we calculated the quantity of 'Radically different concepts.' For both groups, the quantity of radically different concepts increased (Fig. 20).

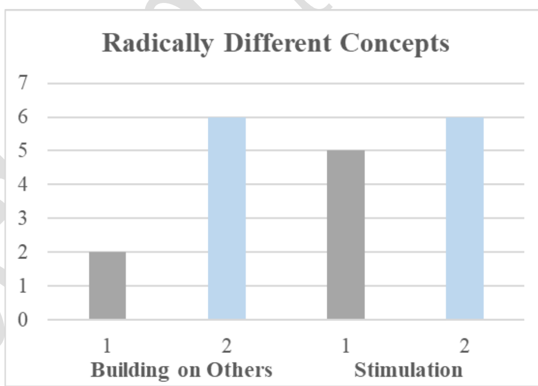

Fig. 20 Quantity of Radically Different Concept

8.4.2 ORIGINALITY OF IDEAS

Similar to experiment 2, the originality score for 245 concepts was calculated. Table 12 and Fig. 21 summarize statistics of the originality scores for each intervention group at each round. The data failed all tests of normality; thus, non-parametric test Mann-

Whitney U test was performed to compare the originality scores from round 1 of both interventions. A p-value= 0.152 confirms that the originality scores of both BoO and stimulation groups are statistically equivalent, and therefore comparable.

8.4.2.1 WITHIN GROUP ANALYSIS:

We assessed the effects caused by the interventions on the originality scores, a p-value= 0.000, and 0.004 after the BoO and stimulation interventions, respectively, show that the effect of both interventions is statistically significant. Findings indicate that the interventions resulted in the generation of concepts with higher originality.

Table 12 Engineering Concept Generation (Exp. 4) Originality Analysis Results

Group	Round	Total Participants	Mean Originality	Std. Dev.	Std. Error	P-Value
Building on Others (BoO)	1	20	2.38	2.39	0.29	0.000**
	2	20	4.81	1.62	0.25	
Stimulation	1	21	2.93	2.36	0.26	0.004**
	2	21	4.15	2.40	0.35	

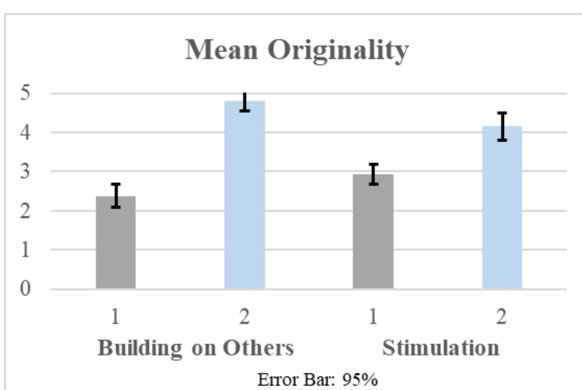

Fig. 21 Mean Originality for Both Mechanisms Per Round with Standard Error Bar (95% CI)

8.4.2.2 BETWEEN GROUP ANALYSIS:

Non-parametric Mann-Whitney U test showed that the Building on Others mechanism resulted in more original concepts than the stimulation mechanism in ($p = 0.018$).

9. DISCUSSION

In this paper, we aimed to investigate the effect of four idea generation mechanisms on creativity. For that, we asked two research questions and performed four experiments. Our findings are discussed below.

9.1 RESEARCH QUESTION 1

We wanted to determine whether two examples of process related idea source mechanisms, namely, classifying or combining, would produce more ideas with higher novelty or originality. We find that the mechanisms did not affect the idea quantity. One plausible reason could be simply running out of ideas after round 1 or a lack of motivation, as suggested by Bergendahl et al. [65]. We did not award credits or benefits for participation, which could have affected their motivation to contribute. However, we also found that classifying helped to generate noticeably more unique ideas in the second round compared to combine in both the experiments. A previous study suggests that the first ideas are more likely to have been presented by others as well, and more novel ideas start arising after the first nine ideas [62]. Our result indicates the same pattern. The reduced quantity of concepts in round 2 compared to round 1 for the ideation exercise and engineering concept generation were mostly repeated ideas.

In the engineering concept generation exercise, the quantity of radically different concepts (originality score > 7.5) increased across the groups. The control group ideated continuously; on the other hand, the other two groups had to stop to think about ways to combine or classify concepts. It might have affected the quantity due to time spent in formulating possible combinations or classifications. However, further investigation is essential to reach a specific claim about the effect of classifying and combining mechanisms on the quantity of engineering concept generation.

We further investigated whether classifying or combining ideas during idea generation produces ideas with higher novelty than the other. The results show that both mechanisms helped to generate ideas with higher novelty. When comparing the two mechanisms for all the ideas, classifying had a more substantial effect. However, we also tested the effects on the novelty of only unique ideas and found that both mechanisms helped equally. From these results, we can assume that classifying ideas during simple ideation exercise has the potential to yield more novel solutions. This does not mean combination is not a useful mechanism, but the selection and application of these mechanisms can be made as per requirement.

In the end, we analyzed the effect of classifying and combining mechanisms on the originality of engineering concepts. Comparison with the control group showed that both mechanisms significantly helped in the original concept generation. Engineering concept generation is a slightly complex task compared to ideation exercise. When both mechanisms were compared against each other, they performed equally. Kudrowitz et al. [57] found that a higher quantity of concepts could potentially lead to higher creativity. Since the students in the classify group produced the more concepts, this might be the reason for the classify group showing high statistical significance and originality score followed by the combine mechanism. However, these findings imply both mechanisms can be used as alternatives to each other or perhaps the one after another during concept generation.

The difference we noticed in the simple ideation task between the two tested mechanisms lead us to speculate on the reasons. One possibility could be that classifying ideas guides thinking toward considering a more comprehensive solution space. Combining, on the other hand, might lead one to think about and quickly regenerate the previous solutions instead of choosing features to combine into new solutions. Thus, instructions to combine ideas might even lead to limited creativity in solution unless specific attention is paid to the way ideas or elements of ideas are combined.

When using idea generation methods in ideation, it is valuable to understand the effect the chosen method has on the outcomes. Classifying and combining ideas positively affected the ideation while measuring quantity, novelty, and originality. Taking the method examples discussed earlier, Forward Steps and SCAMPER, we wonder whether the mechanisms could be swapped and how that would affect the outcomes. Knowing, for example, that classifying produced a larger amount of unique ideas, it would be appealing to try swapping ideas combining into classifying, for example, in a session using SCAMPER.

9.2 RESEARCH QUESTION 2

We studied the effects of building on others (BoO) and stimulation mechanisms. In terms of the number of ideas produced, for simple ideation tasks, BoO and Stimulation both showed an upward trend; however, this increase was not statistically significant. In engineering concept generation, we notice trends similar to experiment 2. The overall quantity of engineering concepts reduced significantly post-intervention; however, when looked into the radically different concept (originality score > 7.5), BoO resulted in a higher increase in radically different concept compared to Stimulation. This result implies, during the engineering concept generation, working in a group and Building on others' concepts could potentially lead to a more creative concept rather than working individually. Stimulation does help, but, after obtaining a certain quantity of concepts, Stimulation, at least in the form tried in this experiment, does not seem to help much in generating more radically different concepts as much as building on others.

While assessing the impact of tested mechanisms on the novelty of ideas for simple ideation generation tasks, results indicate that both these mechanisms helped equally. The novelty of only unique ideas showed a similar trend. From these results, it is safe to assume that, even though we cannot claim which one is better suited to generate the novel ideas, the within-group analysis indicated both these mechanisms help produce ideas that are more novel, and anyone or combination of these mechanisms can be integrated into ideation for better overall results. For example, if ideation is being done in a class within a group, one can adopt Building on other mechanisms for a better outcome; meanwhile, while ideating alone, Stimulation might be equally beneficial.

Finally, when the effect of the BoO and Stimulation was studied on the comparatively complex task of engineering concept generation, and we found, both mechanisms resulted in concepts with statistically significantly higher originality. The additional analysis found that Building on others was better in the original concept generation than Stimulation. This finding is important because, in academia or in industry, it is common to ideate in a group. Our finding supports team ideation. However, the other side of the finding also raises the question regarding the Kipling method as an effective stimulus. We know several different stimuli can be used [21,41,54], and each might result in a different outcome. In the previous findings, some mechanisms were stronger and some weaker than others [28]. We notice similar findings in our results for the classification and building on others mechanism. In this case, a potential approach could be to use both the mechanisms rather than relying only on one or selection of mechanism that suits the need of the ideation task.

FUTURE WORK AND LIMITATIONS

We investigated two pairs of mechanisms only and only specific instances of those mechanisms. To understand the big picture of the effect of idea generation mechanisms, it would be valuable to extend the studies to include other mechanisms. Future work should also focus on a variety of solutions created by the individuals and compared groups in order to gain an understanding of the causes of the effect these mechanisms have on idea generation outcomes. Another interesting question is, how do these mechanisms affect idea generation "in the wild," where other mechanisms and factors cannot be controlled? Could we still improve idea generation outcomes and maybe even choose the mechanisms that best support each situation? In a more futuristic thought, it would be appealing to assemble tailored sets of mechanisms for each problem under solving instead of using existing methods.

CONCLUSION

This study aimed at adding knowledge on the mechanisms that make up idea generation methods by understanding the effect of four mechanisms, classifying, combining, building on others, and stimulation, have on idea generation outcomes. Idea quantity, novelty, and originality were measured compare the effect of each mechanism.

The results show that when ideating alone, different mechanisms have a different influence on idea novelty and originality. Classification resulted in ideas with higher novelty during simple idea generation and Building on others generated concepts with higher originality during engineering concept generation. Mechanisms did not affect the number of ideas produced; however, they did help generate unique or radically different concepts. Testing of these mechanisms in two contexts, simple ideation generation task and slightly complex engineering concept generation task, proved their effectiveness in enhancing different aspects of creativity.

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