Engineering Ideation Method Efficacy Study

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Introduction

A key component of the engineering discipline is the ability to solve problems and come up with innovative solutions. This study seeks to understand how introducing different engineering ideation methods to participants during a problem-solving workshop impacts participants' productivity, creativity, and confidence in their ideas during a short problem-solving session. Additionally, through analyzing how the different methods impact participants' problem-solving processes, it is possible to understand the strengths of the different ideation methods and assess when they could be most useful.

Background

According to the American Society of Quality, problem solving is the process of defining, determining the cause, creating or identifying a variety of solutions, and then selecting and implementing one of the solutions to a problem [1]. The ability to problem-solve is consistently one of the most sought-after competencies that a prospective employee can have [2]. Additionally, the ability to problem-solve impacts critical thinking, teamwork, and leadership skills, all of which are also considered important competencies needed for career readiness. However, despite their importance, many employers note a proficiency gap in several of these competencies in recent graduates [2].

One of the most important parts of the problem-solving process, especially emphasized in the field of engineering, is called brainstorming [3][4]. Most papers describe "brainstorming" in general as a method which is used to generate a lot of different ideas to solve a problem within a limited amount of time [5]. However, in this paper, to avoid confusion between brainstorming and the ideation methods, brainstorming will be the process of evaluating a problem, then developing and analyzing solutions to the problem. Ideation will specifically refer to developing solutions to problems, and ideation methods are the means through which these solutions are generated [6].

There are a lot of papers researching different aspects of problem-solving, brainstorming, and ideation. Much of this research stems back to the book *Applied Imagination,* first published in 1953, which was one of the earliest records of the importance of creativity and problem-solving [7]. Since then, several studies demonstrating the merits of problem-solving, different brainstorming methods, and different ideation methods have arisen. The outcomes of these various research papers show that participants who are trained in brainstorming over a set amount of time improve their problem-solving and creativity skills [8][9]. Other studies which demonstrate the effects of brainstorming compared to alternative problem-solving methods, such as design heuristics, Theory of Inventive Problem Solving (TRIZ), or the SCAMPER approach, detail the differences in participant's design outcomes [10][11]. Further still, many papers address different ideation methods and their efficacy [12] [13]. However, all previously referenced papers follow participants who all have similar engineering and problem-solving experience. This paper not only addresses the different ideation methods but also compares the outcomes between student and practicing engineers. By understanding the importance of learning

different ideation methods and detailing how to use them effectively, this paper describes how to optimize problem-solving to best demonstrate the competencies that employers are seeking.

This paper and associated research is for a Senior Honors Project within the engineering discipline. The inspiration behind this project comes from the success of 3 different design-challenge workshops hosted by the primary author on this paper. Two were hosted at a medium-sized university in Portland, OR (March 2022 and March 2023), and one was presented at an honors conference in Missoula, MT (March 2023). In these workshops, student participants were introduced to one of the ideation methods used in this paper, Chindogu, and used it to solve an engineering challenge. Following each of these workshops, participants commented about their increased creativity while using the method and how they wished they could bring that creative spirit into all their problem-solving sessions. Inspired by how participant's problem-solving skills were impacted in these first three design challenges, additional workshops were created to study the research question; "how do different engineering ideation methods impact productivity, creativity, and confidence in one's ideas while problem solving?"

Ideation Methods

Justification

Four unique ideation methods were used in this paper. Because this paper and associated research is for an engineering Senior Honors Project, the methods used were introduced to the researcher during different engineering classes where this research took place. The methods selected could be introduced and implemented effectively during the 2-hour workshop time limitation. The methods were unique from one another, which helped facilitate the data analysis process and ensured that there was no confusion between the methods. Additionally, the four methods chosen could be broken up into categories based on how they influence the participant's ideation process. Two of the methods, Chindogu and Biomimicry, influence the ideas that participants generate by reframing the lens through which the participants solve the problem. The other two methods, Mind Mapping and Rapid Ideation, influence how the participants organize their thoughts.

Several other ideation methods were explored but ultimately not used. One method was the TRIZ method, which requires an understanding of a database of contradictions and solutions, which made the method difficult to introduce in the limited workshop timeframe [14]. Another method which was not used required participants to model their idea out of clay, which was also not feasible given the materials used in this workshop [15].

Chindogu

Chindogu is a Japanese art and design style created by Kenji Kawakami [16]. Chindogu could be referred to as "worst possible solution", though it differs in the fact that it does not analyze solutions as "good" or "bad", but rather allows all ideas to coexist and later be analyzed for their different strengths. The example given to participants of a Chindogu solution is an alarm clock that wakes you up by dumping a bucket of water on your head. It serves the primary

purpose of an alarm clock, to wake you up in the morning, but it does so in an inconvenient and impractical way.

Mind Mapping

Mind Mapping is a common ideation technique used to connect related ideas while brainstorming. A primary category is placed in the center of the page and related ideas are connected via lines expanding out from the primary category. This process gets repeated, such that main categories are located closer to the center of the map and smaller, or more detailed, ideas are extended out. It is an effective way to visualize the different components of a design or idea and expand on those thoughts while logically ordering your work. An example branch given to participants was "Alarm clock- digital devices- loud noise machine."

Biomimicry

Biomimicry is a design method which uses inspiration from nature to develop or streamline designs. It stems from the idea that nature has been evolving for billions of years and humans can use designs inspired by nature to be more effective in their engineering practices [17]. One prominent example of Biomimicry is a study in which a slime mold was used to map out an alternative subway design which was more resilient and effective than the existing design [18]. This occurred because the slime mold has an evolutionary need to find and transport food in the most efficient way possible. The example given to participants was "an alarm clock design could have been designed from thinking about how a loud rooster wakes you up in the morning."

Rapid Ideation

Rapid Ideation is the process of generating as many ideas as possible in a limited amount of time. The rapid pace of this method and continual writing is beneficial because it allows no time to analyze any of the solutions generated until after the time is over. This method is commonly used at the beginning of a brainstorming session to generate initial ideas which will be expanded on later. The example given to participants who were assigned to continuous writing were "to design an alarm clock, continuously draw different ideas without stopping to evaluate any of them, just draw or write whatever next pops into your head."

Participants

This research was conducted over two workshops. The first workshop was conducted for 11 senior students of various engineering majors from a mid-sized University in Portland, OR. The students attended the workshop as an optional breakout session hosted during a Senior Capstone class. The Senior Capstone class was chosen based on their availability and their prior experience with the engineering problem solving process and a few different problem-solving methods. The second session was with a group of 13 practicing engineers from a medium-sized manufacturing company in Hillsboro, OR. This group of engineers was chosen based on availability and professional experience with problem solving in engineering applications. The presentation was part of a monthly meeting traditionally used to discuss new research related to the company.

Experimental Methods

The data for this project was collected over the course of two different workshop sessions following procedures approved by the University of Portland institutional review board [19] [20]. Before beginning, participants were given a pre-session survey to assess their current comfort level with engineering problem-solving and their current ideation process. All pre- and post- workshop survey results were received anonymously via a Google survey. Following the pre-workshop survey, participants were introduced to the engineering challenge used throughout the workshop. The design challenge was to design something which improves pedestrian or vehicle safety. This broad-natured challenge was chosen because it is a topic with which each participant has had first-hand experience. Additionally, because both presentations were interdisciplinary within the engineering field, this challenge could have solutions derived from several different engineering disciplines.

For the workshop hosted for engineering students, there were three different brainstorming periods of 15 minutes each for participants to work to gather solutions to the engineering challenge. The first period was used as a baseline to understand participant's problem-solving process before being assigned an ideation method to use. This period was called the "free brainstorm" because participants were creating ideas without a method assigned to them. Following the free brainstorm, a short presentation was given to all participants to describe the different ideation methods and were given a randomly assigned method to use. Due to the uneven number of participants, there were two participants assigned to each method except Chindogu. Participants were then asked to brainstorm using their assigned method individually. This was the "solo method" period. Then, participants were asked to group with others who had the same ideation method, discuss their ideas, and continue to work on the challenge in a "group method" period. Having both a solo period and a group period was important to this study because both independent and group results were analyzed to incorporate the critical skill of teamwork to the workshop.

The protocol of the professional workshop was similar to that of the student workshop. However, due to time constraints with the professional engineering presentation, the brainstorming sessions were shorter and there were only two different periods. During this workshop, the participants were given 3 minutes to solve the engineering problem without being introduced to the methods. Following this, a short presentation was given to all participants detailing the ideation methods. Participants were then asked to select one of these methods and use it to solve the engineering design challenge for 5 additional minutes. Participants either worked independently or in a group, which were self-assigned when the participants started problem-solving.

At the end of the final problem-solving phase for each group, all participants who were able to stay for the duration of the meeting (all student participants and 7 practicing engineering participants) were asked to fill in a post-workshop survey to assess their opinions related to their brainstorming and how it was impacted by the given ideation method. The data presented in this paper and resulting analysis is based on the subjective responses of the participant's survey

results. This data is supplemented with subjective observations about how the participants worked together in a group and the ideas listed on their brainstorming sheets.

Results

Engineering Students

Before the participants were assigned to their ideation method or given the challenge, a pre-survey was administered. The results of the pre-survey questions can be seen in Table 1. Students ranked the highest in feeling comfortable sharing their ideas in groups, which had an average of 7.54 ± 2.162, and lowest in confidence in their own ideas, which ranked a 5.91±1.97.

Table 1. Engineering student pre-workshop survey results. Answers were based on a 1-10 Likert rating with 1 being never and 10 being all of the time.

In engineering applications…	Average	Standard Dev
How often do you feel stuck while problem solving?	6.00	1.55
How confident do you feel about your ability to problem solve?	6.18	2.04
How productive do you generally feel while problem solving?	6.82	1.40
How creative do you generally feel while problem solving?	6.54	2.62
How confident in your ideas are you while problem solving?	5.91	1.97
How well do you work in groups?	6.91	2.43
How comfortable do you feel sharing your ideas in groups?	7.45	2.16

Following the challenge, the participants were given a post-workshop survey to analyze how much they thought they improved in their problem-solving while using their assigned method. The results of the key post-survey questions can be seen in Table 2. Of the participants who were assigned an engineering method to use, creativity was the most improved category with an average score of 8±2.83, while productivity was the least improved category with an average score of 5.33±1.94. The control group, the students who were not assigned a method, responded a 1 to all of the questions in the post-workshop survey. They were not directed to do this, however, their results have been omitted from the post-survey averages and standard deviations.

Table 2. Results of the engineering student post-workshop survey. Responses were ranked on a 1-10 Likert scale with 1 being not at all improved and 10 being significantly improved.

	Compared to your usual problem solving method, did you feel more _____ when using your assigned ideation method?			
Which engineering style were you assigned to use?	**Productive**	**Creative**	**Confident in your ideas**	**Comfortable sharing your ideas in a group**
Chindogu	6	10	7	10
	1	10	10	10
	7	10	8	10
Mind Mapping	6	8	6	7
	7	1	3	4
Biomimicry	4	9	6	3
	5	9	4	10
Rapid Ideation	7	7	7	7
	5	8	7	4
No Method*	1	1	1	1
	1	1	1	1
Average	5.33	8	6.44	7.11
Standard Dev.	1.94	2.83	2.07	2.85

*Results were not included in averages or standard deviations

Grouping the data based on ideation method used, it is possible to see how the some of the strengths and weaknesses of the different methods (Table 3). This table shows that Chindogu had the strongest overall improvement with its creativity and comfort sharing ideas in a group, with an average of 10±0.

Table 3. Student responses grouped by ideation method used. Responses were ranked on a 1-10 Likert scale with 1 being not at all improved and 10 being significantly improved.

	Compared to your usual problem-solving method, did you feel more _____ when using your assigned ideation method?			
Method Used	**Productive**	**Creative**	**Confident in your ideas**	**Comfortable sharing your ideas in a group**
Chindogu	4.67 ± 3.21	10 ± 0	8.33 ± 1.53	10 ± 0
Mind Mapping	6.5 ± 0.71	4.5 ± 4.95	4.5 ± 2.12	5.5 ± 2.12
Biomimicry	4.5 ± 0.71	9 ± 0	5 ± 1.41	6 ± 4.24
Rapid Ideation	6 ± 1.41	7.5 ± 0.71	7 ± 0	5.5 ± 2.12
None	1 ± 0	1 ± 0	1 ± 0	1 ± 0

Practicing Engineers

In their pre-workshop survey, the 13 practicing engineers in attendance ranked the highest in their confidence regarding their ability to problem solve in engineering applications, ranking it a 7.38±1.39. However, their lowest pre-survey ranking was their confidence in their ideas, with a ranking of 6.31±1.03. The results from the pre-workshop survey can be seen in Table 4.

Table 4. Practicing engineers pre-workshop survey results. Answers were based on a 1-10 Likert rating with 1 being never and 10 being all of the time.

In engineering applications…	**Average**	**Standard Dev**
How often do you feel stuck while problem solving?	5.77	2.13
How confident do you feel about your ability to problem solve?	7.38	1.39
How productive do you generally feel while problem solving?	7.08	1.60
How creative do you generally feel while problem solving?	6.54	2.22
How confident in your ideas are you while problem solving?	6.31	1.03

Because of time limitations, the practicing engineers selected a problem-solving method from the methods presented and used it for the duration of the problem-solving challenge. Additionally, some of the engineers had to leave the meeting and were not able to complete the post-workshop survey. However, of the 7 practicing engineers who stayed, 5 chose to continue the challenge using the Chindogu method. The largest increase can be seen in the category of creativity, which had an average of 8±1.73. In contrast, the smallest increase was in the category of confidence in ideas, which was ranked a 4.43±1.39. The results from the post-workshop survey can be seen in Table 5.

Table 5. Results of the practicing engineers post-workshop survey. Responses were ranked on a 1-10 Likert scale with 1 being not at all improved and 10 being significantly improved.

	Compared to your usual problem-solving method, did you feel more _____ when using your assigned ideation method?		
Which problem-solving method did you use?	**Productive**	**Creative**	**Confident in your ideas**
Chindogu	7	10	5
	5	8	6
	6	7	5
	6	9	3
	4	6	6
Biomimicry	2	6	3
Rapid Ideation	2	10	3
Averages	4.57	8	4.43
Standard Dev.	1.98	1.73	1.40

All Participants

Across all participants, Rapid Ideation was the most common method that participants knew and used in their practice. No participant had used Biomimicry in practice, but 12 participants had heard of it. Figure 1 demonstrates which problem-solving method participants usually used and what methods they had previously heard about. One note is that more participants stated that they use the method of Chindogu in their practice (n=4) than had previously heard about Chindogu (n=2). This could be because the participants felt that they use the principle of Chindogu without having heard the term for the method. Also, the person who said they had never heard about the methods before is not the same as the person who said they do not use one of the introduced methods in their usual practice.

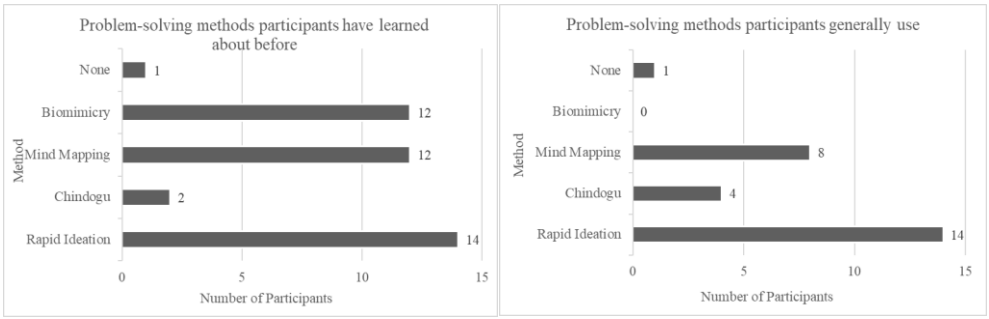

Figure 1. (Left) Problem solving methods that participants have learned about before. (Right) The problem-solving methods that participants generally use.

Additionally, all participants agreed with the statement that different problem-solving methods should be introduced and utilized as part of engineering education. 15 out of the 18 participants who completed the post-workshop surveys agreed with the statement that they feel more confident in their ability to problem-solve after being introduced to different ideation methods. Finally, participants ranked a 7.78±2.21 when asked "how likely are you to use one of the introduced problem-solving methods in the future?"

Discussion

16 out of the 18 participants who completed the post workshop survey knew two or more of the methods which were introduced before the workshop began. However, often when confronted by a design challenge, the first thing that comes to mind is to jump in and list as many ideas as possible without having structure. When analyzing the 11 brainstorming sheets from the student workshop session, 6 participants jumped straight into listing ideas for solutions and 5 participants identified a traffic-related problem and worked to find solutions by breaking the problem down. While there were many different ideas presented, it is interesting that all student participants used one of these two methods to solve the problem.

The differences in the outcomes of the different problem-solving methods can be seen on the worksheets from the student group when they were assigned an ideation method. The Chindogu group continued to list out their ideas, but their solutions became more varied. An interesting note about this group is that 2 of them wrote "Iron-man suit" and 2 of them wrote

“convert roads into roller-coaster like trams”. Another unique notable Chindogu solution was “converting all roads to lazy rivers.” This solution certainly uses the Chindogu principle of solving the problem in the most impractical or inconvenient way possible. However, many of the ideas listed by the Chindogu group during their solo method period were very similar to the ideas listed by other groups, such as increasing public transportation, adding barriers between sidewalks and the road, moving sidewalks away from roads, or clumping business together to create more walkable cities. This highlights the fact that while Chindogu ideas are often outcast as “bad ideas”, it is important to explore solutions without immediately labeling them as infeasible. Additionally, the Chindogu group, during their group brainstorming period, worked to turn their infeasible ideas into practical ideas. This group showed improvement in almost every category in the post workshop survey, and the change in their work is shown on their workshop papers.

The two participants in the Mind Mapping student participant group each approached Mind Mapping differently. One of them followed a single idea and connected the different components of the idea together while another used the mind map to branch off and create a lot of smaller ideas in two central categories. This shows the strength of Mind Mapping as a modular ideation method which is good for organizing and connecting ideas related to a set topic. In the post-workshop survey, this group showed mixed opinions regarding how this method influenced their problem-solving abilities. However, the highest-ranking improvement they noted on a scale of 1-10 was 6.7 in their productivity, which makes sense, as this method is a great way to organize existing thoughts and plan out next steps.

The results from the Biomimicry group are interesting because when assigned their method, both participants first wrote a comment pondering how to connect their ideas to nature before getting into their problem-solving. Also, both participants only developed one solution each when assigned to the method of Biomimicry, one of which was an expansion on the free brainstorm idea with added connections to nature. Despite this, both of them in the post-workshop survey rated the increase in their creativity to be a 9, which is a strong indication that they felt more creative when using Biomimicry. Overall, both participants used Biomimicry to streamline, improve, and justify an existing idea, which highlights the benefits of this method. It introduces a new way to analyze solutions and understand the solution’s effectiveness.

For the Rapid Ideation group, the most notable difference between their free brainstorm and their brainstorming with a method is that their ideas went from having descriptions and examples to being more of an overview of different thoughts. Then, during the group discussion, both participants highlighted their key ideas and expanded on them as a group. Rapid Ideation is a good method for generating a lot of ideas quickly while restricting the ability to go back and analyze the different solutions until a later time. It is beneficial at the beginning of a problem-solving session to jump into the task at hand.

Another thing to note is that during this workshop, due to the already short nature of the problem-solving session, the Rapid Ideation group had the same amount of time to problem solve than the group that was not assigned a method at all. Because Rapid Ideation is a method that relies on having a short period of time to develop ideas but does not impact any other aspect

of the problem-solving process, the only difference between these methods during the workshop was an additional sense of urgency instilled by the quick nature of the Rapid Ideation prompt. Despite this, and the groups ending up with a similar number of ideas, the participants who were assigned the method of Rapid Ideation noted an increase in productivity and confidence in their ideas. Furthermore, an interesting thing to note is that a majority of the participants stated that this is their usual problem-solving method over none (no method). Even so, compared to their usual problem-solving methods, the participants who used this method in this study reported increases in their creativity, and the student participants noted an increase in their confidence in their ideas. This could be because participants are not given time to get stuck on a single idea, as the point of Rapid Ideation is to continually generate new solutions.

Limitations

There were several setbacks and limitations which impacted the development of this paper. Initially, 40 students were expected at the student workshop and there was only one workshop planned with 8 different problem-solving methods and an expected 5 participants per method. This would have resulted in a significant sample size to assess each method and compare the participants both individually and as a group. Because of scheduling conflicts, the actual turnout was 11 students total, leading to the addition of the second workshop which was hosted for the practicing engineering group. A comprehensive list of the ideation methods which were going to be introduced in the presentation were Chindogu, Mind Mapping, Biomimicry, Rapid Ideation, Problem Definition Process, SWOT Analysis, and What, So What, Now What Analysis. Because of the small number of participants, the only methods assigned were Chindogu, Mind Mapping, Biomimicry, Rapid Ideation, and no method.

Once an additional workshop was developed, time limitations when scheduling with the practicing engineering group led to a much shorter workshop, and of the 13 initial participants who completed the pre- workshop survey, only 7 completed the post- workshop survey. The small sample size from both workshops dramatically reduces the significance of the data shown in this paper. Additionally, because nearly half of the professional engineers left between the pre- and post- survey, a majority of the participants who stayed worked together in groups using the Chindogu method, which is why there were so many participants who reported using that method in the post-workshop survey.

Another limitation is in how the questions were worded in the post- workshop survey. The questions in the post-workshop survey were written to reflect the questions in the pre-workshop survey. However, the questions were not written such that an equitable statistical comparison could be made between the participants before the study and after the study. The questions in the post-workshop survey asked how participants felt that they improved in the different categories, with the Likert scale ranging from no improvement to significant improvement. What was needed instead was a question of direct comparison (i.e. during the workshop, how productive did you feel?) and the same Likert scale as was used in the pre-workshop survey of “never” to “all of the time”.

Conclusions

This paper shows that different ideation methods impact how people think in different ways. These methods are also useful in different situations, based on the goals of the problem-solving session. Out of the four introduced methods, Chindogu and Biomimicry are methods which lead to the greater increase in creativity when coming up with unique solutions. These two methods are great when trying to work with a team to generate new ideas, because it changes the perspective through which participants view the problem, leading to unique ideas. On the other hand, Mind Mapping and Rapid Ideation influence the flow of the problem-solving session and how ideas are organized. By changing the pace of problem-solving, either by speeding up the process or slowing it down to have people map out and connect their thoughts, it can lead to increased productivity and creativity.

Learning about different problem-solving methods and understanding when they are most useful is a powerful skill to have as an engineer. All participants agreed that learning about different problem-solving methods is an important part of an engineering education, and for good reason. Before being introduced to any ideation methods, participants effectively generated unique solutions to the engineering challenge. They “solved the problem”. However, when the participants were introduced to methods beyond what they usually use, they integrated the benefits of the different methods to be more productive, creative, confident in their ideas, and more effective as a group. All of these improved outcomes can increase career readiness in undergraduate students, in addition to generally improving the ability to tackle engineering problems.

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