Creative Thinking of Engineering Undergraduates through Brainstorming during Mathematical Problem Solving

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***Abstract*—One of the tools that are widely used to develop creative thinking is known as brainstorming. This paper report on a research carried out to determine engineering undergraduates' creative thinking by using SCAMPER as a brainstorming technique. The purpose specifically is to determine the occurrence of using SCAMPER in solving the problems by the students. The research adopt exploratory case study methodology with mixed method research design. Three engineering undergraduates participated in the study. Videotaping is use to collect data during the process of problem solving in order to clarify the students' opinions and behaviors during the sessions of observation and interview. The results of this research suggest that the engineering undergraduates would use brainstorming as a strategy to discuss among themselves, and to generate ideas to solve the given problem. The findings were also consistent with the findings from previous studies showing that brainstorming helps in developing and supporting creative thinking. This give indications that brainstorming is useful as a creative thinking tool to stimulate students' thinking in many fields of study including mathematics.**

Keywords—brainstorming, creative thinking, mathematical problem solving, engineering mathematics

I. INTRODUCTION

There has been growing concern over the mathematical skills needed for prospective engineers and how these skills might best be acquired. Mathematics is about problem solving and problem solving is a creative process [1][2], one that involves discovering and analyzing a problem and then coming up with the best possible solution. Creativity appears central to solving complex problems. De Bono define creativity as a search for alternatives or creating alternatives [3]. It is used intrinsically in complex problem solving as solution found might not necessary be the best and the search for the best solution is continuously done. Harnessing creative thinking among students is therefore deem essential to help them cope in problematic issues that need creative solutions. This kind of thinking would enable them to look for alternative approaches, to come up with possibilities of solving a problem in many different ways and to generate many creative ideas.

Improvement in creative thinking would help learners to think in different ways, opportunities to explore and discover, being critical, reduce errors and simplify task-at-hand. With the advent of the Fourth Industrial Revolution, problems at workplace are more complex and consequently the resulting problems are becoming more complicated. Thus, students need to be prepared and equipped to meet the challenges in problem solving.

Upon completion of mathematics courses, engineering students are expected to have the ability to cope with the mathematical challenges they encounter in their area of study and later on in professional life [4][5]. However, studies indicate that even good students struggled as they encounter previously learnt mathematical ideas and concepts in a new setting and faced various difficulties in using their knowledge and skills [6][7]. Furthermore, the transfer of knowledge remains problematic since the application of the mathematics learnt to the specific engineering discipline was done in a general manner. The concern is on how mathematics can be better integrated into engineering education to support the flexible thinking skills that are critical for engineering practice as well as for creativity and innovation [8][9][10]. Notably the most challenging and difficult is the task of motivating students to see the applicability of the mathematics learnt to their specific engineering discipline. How can we deliver the material in a way that is conducive to this goal?

It is our contention that creating a problem-solving culture in mathematics classroom could provide support to the development of the creative process, enhance the ability to generate ideas and identify solution methods. There are many tools recommended to develop creative thinking. One of the tools that are widely used is brainstorming. This idea-stimulating tool was developed by Osborn, known as the father of brainstorming, used to generate multitude of ideas. It was suggested that through brainstorming, group discussions can produce as many as forty four percent of worthwhile ideas [11], and allows the selection of the best one in the process of creative problem solving (CPS). Since first introduced in 1953, brainstorming had been widely used in various sectors such as business, science, technology and education.

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Therefore, the goal of this study is to promote brainstorming among engineering undergraduates as a technique to enhance their creativity and problem-solving skills in solving open-ended mathematical problems. An exploratory study was carried out where students were introduced to SCAMPER and other brainstorming and creative tools to solve mathematical problem effectively and to select the best approach or solution for a given problem. Students were first introduced to all stages of creative problem solving starting with the problem definition stage, followed by ideas generation, ideas evaluation, and ideas judgment up to the final stage of solution implementation. Students learnt how to gather relevant information to define the problem, to generate ideas to solve the problem, to select the best solution for the problem and also to evaluate the ideas and judge the ideas selected critically.

In this paper, we present some of the results found particularly on the use of brainstorming as one of the strategies to solve open-ended mathematical problem. Data was collected through observation and interviews, and qualitative data are analyzed using thematic coding.

II. Effects of Brainstorming

Studies have been done to investigate the use of brainstorming as strategies to develop creative thinking skills. For example, Taleb et al. used it in teaching science [12]. In this study, two groups of sixth grade students, the experimental group and the control group with thirty students respectively took part in the experiment. Torrance Test of Creative Thinking was used to measure creative thinking level of the students based on fluency, flexibility and originality. The results showed that the experimental group out-performed the control group after being taught with brainstorming strategies [12]. In a similar study, Al-Khatib studied the effect of using brainstorming to develop creative thinking. The study involved two groups of students with the experimental group consist of forty seven students and the control group consist of fifty one students. The findings showed that there was significant difference between the experimental group and the control group. After the brainstorming strategies training program, the experimental group performed better than the control group. Torrance test of creative thinking was used to measure the creative thinking levels in this study [13].

Aiamy and Haghani carried out an investigation on the effect of synectics and brainstorming on third grade students to develop their creative thinking skills [14]. One hundred and ninety six third grade students with ninety nine males and ninety seven females were divided into three groups based on different teaching methods such as synectics, brainstorming and traditional teaching methods. Torrance Test of Creative Thinking was again used to assess students' creative thinking levels. The results showed that brainstorming teaching method had more significant effect than traditional teaching method [14]. While a study by Rizi et al. [15] examined the effect of using brainstorming method on fifth grade students. Sixty students were divided into two classes with thirty of them in the experimental group based on brainstorming teaching method and the other group, the control group with thirty students based on traditional teaching method. Experimental research methodology was carried out and *t*-test was used to compare the academic achievement means of experimental and control groups. The result showed that brainstorming teaching method had positive effect on students' academic achievement.

It appears that the results of the studies carried out previously present some similarities and support the importance of using brainstorming as a new teaching methodology to increase students' capabilities.

III. Brainstorming Techniques

In this study, SCAMPER is used as a brainstorming technique. It provides a systematic and practical method to scaffold students' creative thinking and stimulate their divergent thinking and imagination. SCAMPER is an acronym which stand for *Substitute*, *Combine*, *Adapt*, *Modify* (Magnify, Minify), *Put* to other uses, *Eliminate* and *Rearrange* (Reverse) [16]. As a technique, it is use to spark the creativity of the students and provide a checklist for them to find out more ideas to solve a problem. Besides, it is normally used at the stage of ideas generation to help the students to come out with many possible ideas to the problem.

Substituting (*Substitute*) can be used as a means to try something else in order to see whether the idea works, for example, the students can use other approaches to solve the same problem. They can also use the method of trial and error by substituting one part for another with the use of a formula or by using guess and check. Combining (*Combine*) other people's ideas or part of their ideas can create something new. For example, combination can be used to combine existing mathematical equation with another equation to form a new equation to solve the problem.

Adaptation (*Adapt*) can help students think about what they have already known about the similar existing problem in other field of study and how others are solving it. They can consider applying the ideas in a different way, adapt and use them in a new problem. They can also incorporate their ideas in other field of study by using something similar to their problem but in different context. As an example, they can solve the same problem by drawing a graph, a table or chart to help them to understand better about the given problem. Through Modification (*Modify*), students can modify the problem by changing the form of equation, say. They can even modify the problem either by magnifying or minifying it in order to make it larger or make it smaller. For instance, they can add extra feature or value to their existing problem to make the problem more complicated in order to discover something new. Students can also reduce some part of the existing problem to make it simpler.

Put to other uses can help the students to think of using another way to solve the problem. For example, they can use their logical reasoning to understand more about the existing problem. Students can solve the existing problem with the use of say geometry, algebra or trigonometry. Elimination (*Eliminate*) is another a creative way to tackle a problem as students can omit and subtract some part of the problem in order to help them come out with new ideas of solving the problems. For example, part of the equation can be taken away so as to eliminate other possibilities. *Rearrange* is another

creative way that can be used by reordering the data of the problem in a new way in order to find out the patterns of the arrangement. A table, a tree diagram or a chart can also be used to organize the data in a list. Students can even use symmetry to find out the characteristics of the problem. Likewise, Reversing is used in SCAMPER to help students in problem-solving by reordering their process of thinking. They can solve the problem by working it backward or by reversing the order of problem solving. The components of the problem can be interchange to make working easier. For example, by changing the positive value of the equation into negative can bring about a new discovery.

IV. Objectives

A research is set to determine the use of SCAMPER as a brainstorming technique during problem solving. The aims are firstly, to determine the occurrence or frequency of SCAMPER used by the engineering undergraduates as a technique and secondly, to determine students' creative thinking during the process of problem solving.

A study of group learning such as creative problem solving has been widely researched to find out the impact of learning among the students in various fields of studies such as business, science, accounting and arts. However, the impact of using creative problem solving (CPS) to enhance learning in mathematics of engineering undergraduates remains a challenge. There is limited research reporting on creative problem solving in advanced mathematics. Thus, a research done on the implementation of CPS in mathematics gives a better understanding of the situation. The research adopt an exploratory case study with mixed method research design. The purpose is to investigate how the students used creative problem solving skills to solve open-ended mathematical problems while working collaboratively.

Students are encouraged to learn together in a small group or in pairs so that they can improve their communication and generic skills by learning how to negotiate and share ideas with others. During the process of learning, they also learn how to construct and maintain shared conceptions of tasks. The progression in CPS is explored based on the five different stages, namely identifying and defining the problem; finding out alternative solution method or approaches to solve the problem; evaluating the strength and weakness of each approach and solution method; making judgments to find out the best approaches or solution method; and carrying out the plan to solve the problem.

Document analysis, was carried out in order to identify the methodology and instruments used in previous study of CPS in different fields. This provides us with an understanding of developments in CPS in respective fields, so that we will not re-invent the wheel. This can also help us to find out the gap in previous studies and to generate a theoretical framework. At this stage too, the tasks and activities is constructed. Data collected through observation is analysed qualitatively and coded accordingly. Coding are categorized in different themes to enable interpretation be made. Data from different sources allows triangulation be made in an attempt to provide reliable and valid evidence.

V. Methodology

A. Research Design

Observation and interview were used as data collection method to find out the students' ways of finding their ideas to solve open-ended mathematical by using brainstorming. The video-taped session was then transcribed for further investigation.

The instructor acts as a researcher and facilitator to facilitate the students to work together and collaborate with each other. The instructor also provides scaffolding for the learners to identify the problem based on their knowledge and skills at the stage of problem definition. Graphic organizer such as KWL (Know-Want-Learned) chart help the students to look for relevant information to the problem and organize their thoughts about the given problem. A range of tools is provided to help the students gather, present and explore the data obtained. They were encouraged to use multiple strategies to solve the same problem in order to generate many unique and alternative ideas in the stage of ideas generation. Students were also encouraged to share their ideas and combine with others to come out with more different approaches. Prompts and questions provided helps to invoke students prior knowledge, to make connections with the current problem and to use different mathematical representations during the problem solving process.

During the stage of ideas evaluation, students were encouraged to make justification and evaluate the strategies based on the pros and cons. They have to select the best strategies based on their decision at the stage of ideas judgment. In the stage of solution implementation, students have to show all the steps in their method to arrive at the solution. In the final stage of evaluation, they were required to verify their answers and provide justification for their solutions.

This research employs a mixed method research design [17]. First, we would like to know the qualitative results of students who used creative problem solving to solve mathematical problem collaboratively with the support of their peers. Quantitative data complemented and supported the qualitative data. The quantitative data is obtain from the analysis on the coding of observation and documents analysis.

Case study is used here as it can be considered as a practical and useful tool in the research of a small sample size [18]. It can also provide a better insight and more detail understanding of the situation in the real life context. By using both the quantitative and qualitative data in the case study, provide in-depth explanation of the process and outcomes of the study [19]. Furthermore, the qualitative data from the case study was also be used to explore and provide very good description in the complex real-life situations, which cannot be obtained with the use of other research methods.

There are several categories of case studies, namely exploratory, explanatory and descriptive based on constructivism [20]. Different types of case studies are developed to serve different purposes. For example, exploratory case study is used to explore a phenomenon in real-life context with no clear outcome; explanatory case study is to

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explain a phenomenon with causes, while descriptive case study is used to describe a phenomenon occurs in real life context. We followed Roworth-Stokes' suggestion of eight stages in conducting case study [21], that is getting started, selecting cases, crafting the instrument and protocols, entering the field, analysing data, shaping hypothesis, enfolding literature and reaching closure.

The initial stage is getting started as to thoroughly understand the research objective. The second stage is known as selecting cases as to find out the suitable sample frame in order to carry out the research. We can select extreme cases to consider for the limited number of cases in the study [22]. The third stage is crafting the instrument and protocols as to establish the most appropriate research tools based on literature review so that they provide better insight in the study. The fourth stage is entering the field as to gain access in order to implement the research design to obtain data. This is followed by analysing stage to transcribe all the data collected in a systematic way. All the data was coded and labeled into different categories based on their themes. The sixth stage is shaping hypothesis to find out the patterns of the causality cross cases. Open-coding was employed so as to make the connections of the different categories and put back all the data in a totally new different way [21]. The next stage is enfolding literature so as to show the relationships among the concepts formed from the different categories based on literature review and thus show a contribution to new knowledge. The final stage is reaching closure to justify and present the findings from the research.

As stated by Patton [23], the reliability and validity are the two important factors to be concerned in order to design a qualitative study, to analyse results obtained and to evaluate the quality of the study. Besides, Golafshani [24] stressed that the term reliability in quantitative research can be replace with the term of dependability in qualitative research to ensure the consistency of process and product in carrying out the research. The term validity in quantitative research can also be replaced with the term trustworthiness in qualitative research to ensure the quality and the rigor of the study [25][17][26]. Trustworthiness is also considered as an important factor to ensure reliability and validity in qualitative research [27]. The ideas of finding the truth based on the measurement of reliability and validity in quantitative research is also replaced with the ideas of trustworthiness in qualitative research [28].

There are certain strategies to achieve trustworthiness in the case study [29]. We are required to find out whether the case study designed is suitable for the research question. We also have to know whether purposive sampling is appropriately applied in the data collection, data are systematically collected and properly handled, and correctly analysed [30]. Thus, by providing detailed descriptions of the phenomenon in terms of questions, we established a good context of the study based on the use of background data and making comparisons to make sure the achievement of transferability. Dependability can be obtained by the use of overlapping methods in the research and providing in-depth methodological descriptions of the phenomenon so as to ensure that the study can be repeated. The triangulation of data and providing integration of research findings with the use of in-depth methodological descriptions can also be used to ensure a comprehensive understanding can be achieved [31].

This research study employed purposive sampling to help us identify information-rich cases [26]. Through purposive sampling, we can learn a great deal of the information by focusing in depth on the carefully and purposely selected sample [21]. This help us to understand how students are using their strategies and creativity to solve open-ended mathematical problems. There was an intervention on creative problem solving in mathematics after the students have solved the first problem in the process of mathematical problem solving. The students were to use all the stages of creative problem solving in the second mathematical problem. Therefore, a CPS training program would help the students to get familiar with all the processes of CPS.

From the meta-analysis on the impact of creative problem solving, Fontenot [32] had used eight hours of CPS training program for business people and came out with behaviour towards fluency. While Runco and Basadur [33] used twenty hours of CPS training programs to train twenty five managers with the outcome of behaviour towards fluency and originality. A twenty-hour training program was thus, planned. The training program starts with an introduction to CPS until the application of CPS to solve mathematical problems. A class of 25 engineering students participated in the program, working in a group of three and four people. During each meeting, they will try to solve one CPS problems. Gradually the students had learned to solve ten problems, using CPS skills with scaffolding by the instructor. At the end of the program, the students have to solve an open-ended mathematical problem collaboratively using CPS skills on their own. A lesson plan provided act as a guide to the instructor as well as to the students. The results were evaluated using rubrics for assessing CPS in mathematics.

For the purpose of further investigation, three students selected based on performance and awareness (low to high) towards SCAMPER during the training program, took part in the study. They were ask to solve an open-ended mathematical problem collaboratively using SCAMPER as CPS tool. The problem-solving session was video-tapped, and the transcriptions then used to clarify opinions and behaviors during the process of problem solving.

B. Data Collection

The data collected from observations was transcribe to reveal how the students were using different type of methods in SCAMPER to help them in brainstorming. In each case, the students were named anonymously. The following was one of the transcripts of observation to illustrate how the students used and handled the different methods in SCAMPER.

One of the problems given in the study for students to solve is as follows:

> *"Triangulation is applied in GPS and it used three satellite as reference points to triangulate in order to find the location anywhere on earth. How many lines can be drawn to connect eight satellites and how many triangles can be formed with the eight satellites?"*

The students first proceed to the stage of problem definition to try to find out whether there was enough information to solve the problem. They had to find out the number of lines and triangles formed based on the information that there were one receiver, one transmitter and eight satellites. However, they could not relate all the unknowns with an equation or formula. They realized that they needed to find out the position of all the satellites and the distances between them to find out the number of lines and triangles. Later, they tried to find out the connection between the unknown and the data. They also checked whether they had used all the data and information given. They even restated the problem and made it simple.

They discussed their methods and strategies used in solving this problem. The focused was on the impractical ideas and they revert to a second round of brainstorming to make sense of the problem. They ranked their list of ideas based on pros and cons of all the criteria that they had selected. Then, they checked their solution whether it fulfilled all the given condition in the problem. They also listed out the suitable method to solve the problem based on their carefully developed judgment criteria. In the last stage of solution implementation, they discussed what they had done from stage one of problem definition until the last stage of solution implementation.

VI. Results and Discussion

Creative thinking is a way of thinking about a problem, in exploring many possible solution methods or approaches and in generating many creative or new ideas. It is determine by fluency, originality and flexibility of the solver, and thus used to generate many responses for open-ended problem solving [36]. Fluency refers to the ability to generate many possible ideas and solutions; originality is the ability to create unusual and unique ideas; and flexibility is the ability to create alternative solutions. As proposed by Kirby and Goodpaster [37], we can superimpose one concept into another to modify and come up with new ideas. They further suggest that we can practice creative thinking by using unstructured process such as brainstorming.

In this research, we found that brainstorming could help students come out with creative methods, and stimulate their creative thinking in generating creative ideas based on fluency, flexibility and originality. The following excerpts obtained from the transcripts highlight the episode of progress:

Student Goh used *Substitute* as his method in SCAMPER to help him in solving the problem.

"right, so, arr...for me, I am using a method substitute as well... I try something else like err... I used draw and then, I try to use equation and eventually cannot, err... draw ..." (C4day12(d)transcript)

He tried to solve the problem by using equation but failed. He then used drawing to help him to understand the problem. First, he randomly assumed the position of the satellite and drew eight satellites at different position, and then connected the lines among them. He tried to find out the number of intersections of the lines in order to find out how many triangles can be form by connecting all the lines. He also would like to know the distance between the transmitter and the receiver. Finally, he found out that there were altogether thirty-seven lines

Student Ng used method of *Substitute* in SCAMPER as he put the satellites in different location and then tried to find out how to connect the satellites with the transmitter and the receiver. He also used the method of *Minify* in SCAMPER to solve the problem.

"...next, my is idea method, err… substitute, I try something to see if it works to help me solve the problem where I put the satellite in different position and then, I use minify." (C171day12(c)transcript)

"minify to solve the simple, just simple draft problem, simple problem and the…" (C173day12(c)transcript)

Ng made the problem simple by considering the satellite in only two dimensions and not in three dimensions. He found out that GPS could locate an object by using satellites as reference points in x, y and z-axis. He used transmitter as a reference station and receiver as a mobile station. He thought that the number of triangles formed would depend on the position of the satellite, if the satellite located in the middle of the transmitter and receiver, it would form two triangles at the same or different ground level. However, if the satellite were at the position of ninety degree to the receiver, then it would form one triangle. If the satellite, transmitter and receiver were located along the same line, then they will form no triangle at all. He finally found out that there were twenty-four lines.

Student Chin used the method of *Minify* in SCAMPER as he started to solve the problem in smaller parts in order to find out the number of lines used.

"oh... my method use for SCAMPER is just, this time is minify, so, I start from small... from a whole picture, hmm... I start from small, I mean like part by part to check the number of triangles." (C167day12(c)transcript)

He assumed the number of triangles found by determining the location of the satellites. He thought that GPS would be more accurate by connecting more lines and finding more triangles. He considered the satellites had to be located at its orbits and would be practical to put all the satellite along the circle as the orbits of the satellites were in round shape. Later he found out that there were fifty intersections of lines.

Student Goh used two creative methods in SCAMPER namely *Substitute* and *Combine* the most in problem solving. He first tried to use his idea or combined with other ideas searched from the internet to solve the problem.

The data obtained from SCAMPER used Checklists in problems 3 to 12 to draw a diagram. Figure 4 showed that Goh used different creative methods in SCAMPER. He used *Combine* the most in the problem solving followed by *Substitute*, *Adapt* and *Modify*. For Goh, he did used SCAMPER unconsciously. Further, he mentioned that this had helped him a lot in solving the problems.

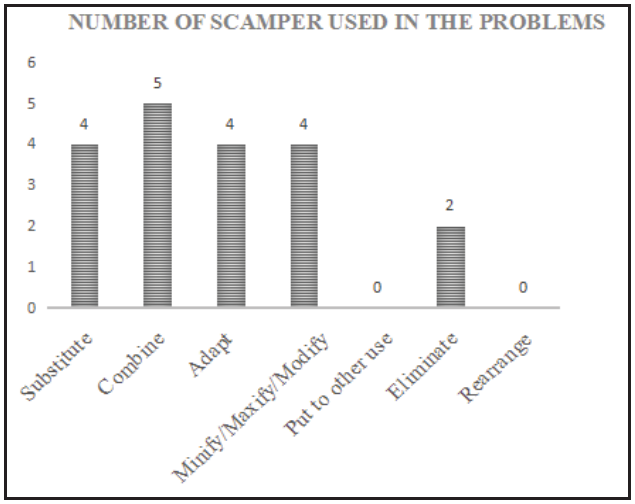

Fig. 1. Number of SCAMPER used by Student Goh

In another situation, student Ng used the creative method of *Modify* the most. He modified his ideas based on the solutions of others. He also used *Substitute* to see whether the ideas were practical and works.

The following figure showed that Ng used *Modify* the most, followed by the creative method of *Substitute*.

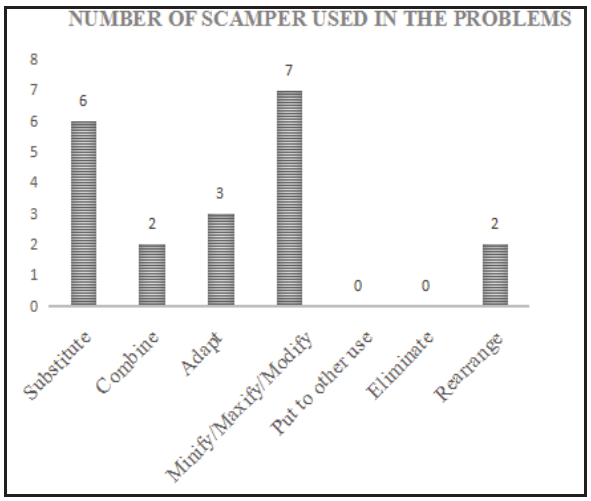

Fig. 2. Number of SCAMPER used by Student Ng

Ng did not believe that SCAMPER can really help him but he thought it could be use as guidelines.

Another student Chin believed that SCAMPER is use as a guideline to help him to solve problems in the future. To him he had used creative method of *Substitute* to try to see whether his idea would work.

From the diagram presented (see Figure 3), showed that Chin used the creative method of *Adapt* the most, follows by *Modify* and *Combine*.

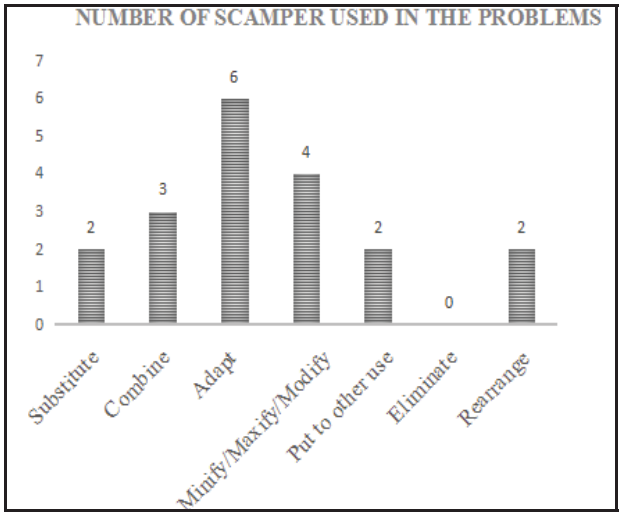

Fig. 3. Number of SCAMPER used by Student Chin

The following diagram (see Figure 4) summarized the methods used by the three students in problem solving. It showed that the students used the creative method of *Modify* but hardly used the method of *Put* to other use to help them in solving the problems. Students prefer to modify others' ideas to come out with something new.

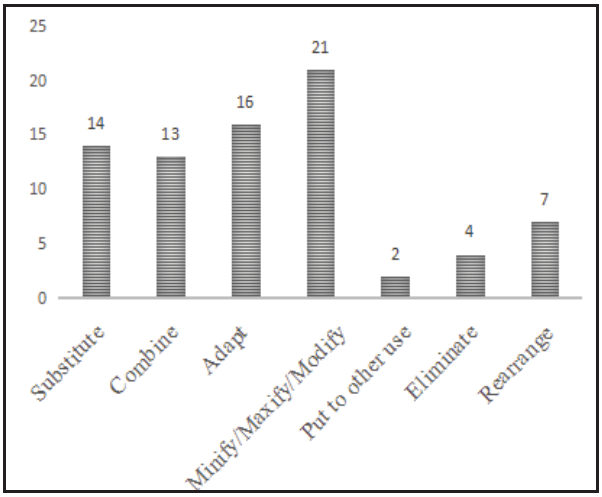

Fig. 4. Number of SCAMPER used in the problems

The following table showed the ideas generated by the students with their creative methods. There were altogether eight ideas generated by the students in solving the problem such as drawing a picture, randomly putting the satellites in different positions, calculating the number of lines formed, connecting all the lines, using imagination, using a circle, considering 3-D and 2-D to solve the problem.

TABLE I. IDEAS USED IN THE PROBLEM

Ideas	Goh	Ng	Chin
A1. draw	√	√	√
A2. random put	√	√	
A3. calculate	√		
A4. connect			√
B1. imagine			√
C1. circle			√
C2. consider 3D		√	√
C3. consider 2D		√	
Fluency	3	4	5
Flexibility	1	2	3
Originality	0	0	1
Total	4	6	9

Keh et al. [39] came out with an assessment method to find out the creativity among the engineering students based on the components of fluency, flexibility and originality. Fluency refers to the total number of ideas generated by each student and flexibility is the different type of ideas generated by them. The occurrence of each idea generated is denoted one point. Originality was the unique idea came out by the student. In a similar manner, one point denotes the unique idea generated by the students. The results showed that there were three different categories of ideas generated by the students based on visualization, imagination and basic mathematical operation. The result also showed that student Chin generated the most unique, the most numbered and variety of ideas in solving problem number 12.

The findings suggest that students used all types of methods in SCAMPER to help them to come up with ideas. The results also showed that SCAMPER can be used as one of the brainstorming techniques to solve open-ended mathematical problems. Based on the observations, the engineering students were able to use SCAMPER as creative thinking tools to help them generate ideas as well as as a strategy to prompt discussions for initiating possible methods in solving the given problems.

VII. CONCLUSION

The results indicate that the students would use brainstorming to discuss with others and to come out with ideas to solve the problems. The findings were consistent with those from previous studies that showed that creative thinking can be developed by using brainstorming (for example see [13]), support that brainstorming had a significant effect (for example see [14] and [15]), and that brainstorming is one of the most well-known creative thinking tools used to stimulate students' thinking capacity in many areas of study (for example see [34]). Thus, brainstorming can be seen as a potential tool to stimulate students' creative thinking capacity in the mathematical education of prospective engineers.

The result also showed that SCAMPER is a systematic and practical way for the development of students' creative thinking. As pointed out by Ozyaprak [38], there is "no one size fits all" technique and SCAMPER is not the only brainstorming technique used to help the students to develop creative thinking. However, it helps to enhance divergent thinking and in producing a variety and numerous ideas.

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