Assessing Technique Applicability towards Ideation Taxonomy for Engineering Design Concept

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ABSTRACT

This paper aims to identify students' perception of the level of applicability of techniques that have been applied in the process of engineering design idea generation. Various techniques have been developed to facilitate the process of generating ideas. However, in generating engineering design concepts, a special technique involving the application of creative solutions and specific engineering analysis is required. This will need students to determine the appropriateness of the techniques to be adopted which will help to accelerate the process of generating ideas. This survey employed a questionnaire that was developed based on the Six P's creativity model; and the analysis carried out using the Rasch measurement models. The respondents consist of 160 mechanical engineering students from four local universities in Malaysia that are involved in engineering design courses. The student's data were analysed descriptively based on the frequency of use of techniques and percentage of agreement against applicability techniques. The reliability of the developed questionnaire was 0.89, while the overall five selected techniques showed an approval percentage of more than 60 percent per context. The overall findings implied that the use of a combination of creative and technical techniques helped students in the six contexts of creativity in idea generation. As a result, a hierarchy of technique application in the process of generating ideas for design engineering concept was developed. The hierarchy of techniques was used to develop a taxonomy that could serve

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as a reference guide for students and lecturers in the determination of the appropriateness of techniques for the aspects of what ought to be achieved in the process of generating ideas.

Keywords: *idea generation, taxonomy, engineering design concept.*

Introduction

In the education field, taxonomy is a model commonly used to analyse the areas of education. It relates to the classification or grouping of characterization, as well as the objectives of education; involving areas such as knowledge, attitude, and psychomotor. The taxonomy of terms in engineering education research could serve as a framework for researchers to see the connections and synthesize ideas; have a better access to the research of others; and plan for future work [1]. Although different approaches could help identify a list of terms that might be used to map research in engineering education, a standardized taxonomy would be more useful. It would guide researchers, journal editors, funding agencies, and other members of the community in creating the metadata that would enable a deeper and more extensive analysis of research and publication trends [2].

The need of students towards learning has to be recognized in order to identify the appropriate learning materials and appreciate their importance [3]. It is therefore necessary to develop a taxonomy that relates to teaching, learning, and assessment in order to ensure the success of a lesson, and eventually, the entire learning process. The Bloom’s Taxonomy or the Thinking Ability Concept is an example of a famous model as well as a representation of the many models applied in the teaching and learning system. It is a hierarchical structure that identifies skills from the low level up to a higher level [4]. However, to adapt to today’s education system, many studies have intended to improve on the already developed taxonomy. The importance of taxonomy development in engineering design as highlighted by Hubka and Eder (1988), Vincenti (1990), Rohpohl (1997), and De Vries (2005) was to help designers in the provision of information on the requirements during the design process [5].

While training students to be creative and enhancing their general creativity, one of the courses offered in the Malaysian public universities is engineering design. This course provides an opportunity for the students to apply their previous knowledge and skills as well as showcase their ability in the realization of ideas, creativity, and innovation. They are also expected to solve problems. In the learning outcome of this course, students are required to present a design concept with a detailed drawing and engineering analysis. For that, creativity is needed since it is an integral part of the engineering design process that can influence the generation of novel and commercial ideas. The process of idea generation is one of the creative learning processes commonly practiced [6].

Idea generation occurs at the stage of design conception and includes a search for creative problem solving, and systematic exploration of possible solutions. The result of the activity is a set of product concepts [7] which involve three phases - problem identification, idea creation, and idea evaluation [8]. There are various techniques that can be applied in each phase whether creative or engineering techniques. The application of an incorrect technique can slow the final design process, produce low-quality products, and lead to a lack of commercialization due to deficiencies of the product in certain customer specifications. This shows the importance of the process of design idea generation and how it influences the transformation of a concept to product [9].

According to Cross [10] and Ahmed et al [11], engineering students often face problems during the process of idea generation for concept design, especially in the generation of a diversity of ideas and in seeking alternative solutions. This is due to the lack of knowledge in the correct application of the systematic approach which involves the use of methods and techniques [12]. Similarly, there are no theories that can explain the various methods for idea generation; no taxonomy for categorizing known ideation methods; and no guidelines for selecting an appropriate method for a given ideation problem in engineering disciplines [13]. Supported by Hulten et al., [14], state that no lack of concepts, models or teaching tools and techniques from previous research on creative design which point to the importance of contributions to the field, building on previous insights. It is important, therefore, to develop a guide that allows students to correctly determine application techniques; thus, helping in the generation of creative ideas, and producing innovative solutions in a timely manner. Chen et al., [15] also recognised to develop a new model of conceptual design cannot only allow lecturers of engineering design courses to teach their students explicit and logical knowledge, but also can help researchers improve their understandings about the conceptual design process.

The objective of this study is, therefore, to identify the techniques that have been used by students, as well as the student's perception of the applicability of these techniques towards helping the process of creative idea generation. The findings of the study can be used for the creation of a useful taxonomy that can be referred to by students and lecturers, as a guideline in the process of idea generation for engineering design concepts.

Methodology

The study started with the development of a questionnaire entitled "Student's perception on idea generation techniques in developing design concept". The questionnaire was divided into three parts: part A) – Respondent's personal details, part B) – Information needs of idea generation process and part C) – Perception on the applicability of idea generation techniques. A five-point Likert scale was used for the grading of the responses. In part B, scales from "*never use*" to "*always use*" were used to identify the frequency of application of the selected methods; while in part C, scales from "*strongly disagree*" to "*strongly agree*" were used to assess the perception of the respondents towards the applicability of the selected techniques. During the development of the questionnaire, the researcher considered the theories regarding the context of idea generation previously adopted by Rhodes in 1961; as well as the six P's of creativity - *person, process, product, place, pressure*, and *persuasion* [16]. The six P's of creativity extended from the four P's framework [17] that ought to be used for the observation and measurement of creativity [18]. The reliability analysis of the questionnaire was conducted using Rasch analysis. Based on the Rasch measurement model, the reliability acceptable value of Alpha Cronbach's (α) was between 0.71 and 0.99 which shows a good reliability of the questionnaire. Table 1 showed the interpretation of the Cronbach Alpha score for reliability [19]. The study flow chart is shown in Figure 1.

Table 1: Interpretation of Alpha Cronbach Score [19]

Score of Alpha Cronbach	Reliability
0.9 – 1.0	Very good and effective with high consistency level
0.7 – 0.8	Good and acceptable
0.6 – 0.7	Acceptable
< 0.6	Item need to repair
< 0.5	Item need to reject

Meanwhile, to confirm the ability of an item to measure a construct, two values must be reviewed: (i) the Point Measure Correlation (PTMEA CORR) which detects the polarity of items, and (ii) the Outfit Mean Square (MNSQ) which assess the suitability of the items. According to Bond and Fox [19], a positive PTMEA CORR value indicates the ability of the item to measure the construct, but a negative value indicates that the item needs to be either repaired or eliminated since it cannot measure the construct. For the Outfit MNSQ, the index value should be within the range of 0.6 to 1.4. A value of more than 1.4 means that the developed item is misleading and should be eliminated. A value of less than 0.6 means that the item expected from respondents is too easy and need to be repaired.

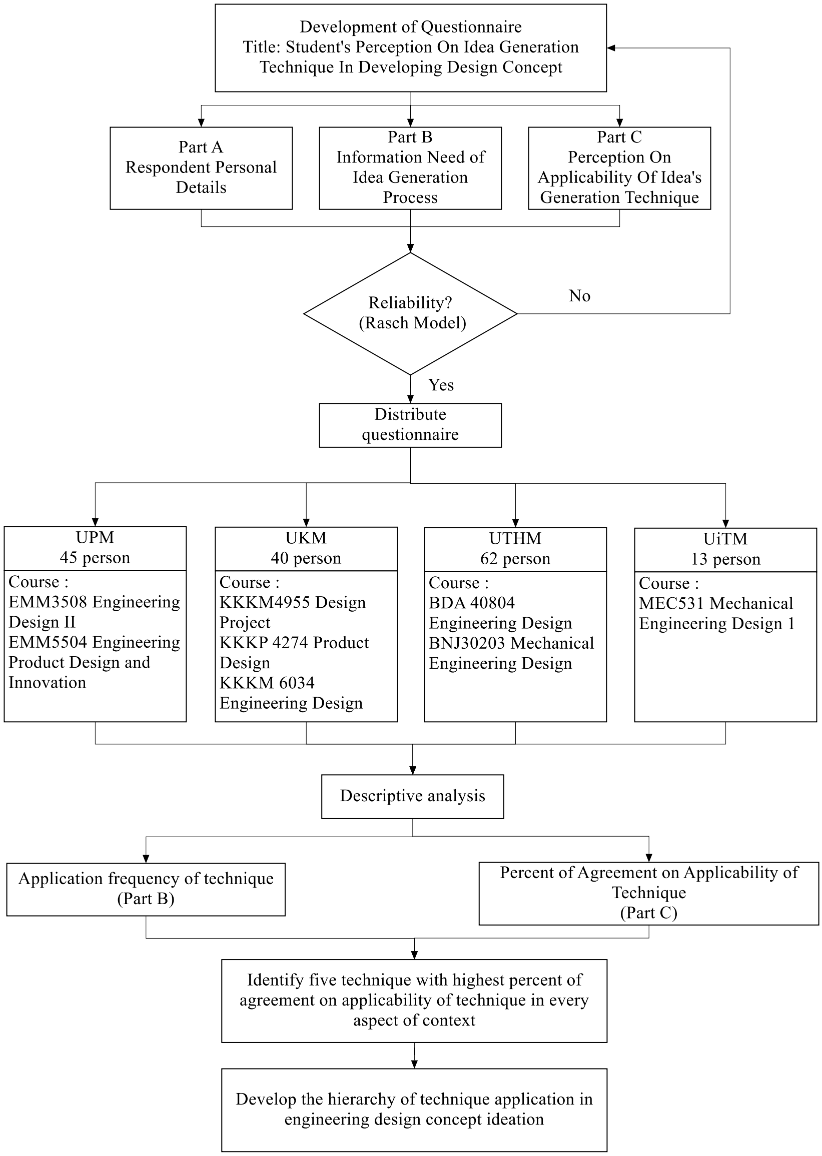

Figure 1: Flow chart of the study methodology.

The questionnaire was distributed to the mechanical engineering students of four public universities in the Peninsular Malaysia. A total of 160 students were selected for the study. All of the students engaged in idea generating methods and design process were confirmed to have enrolled for an engineering design course. The data were descriptively analysed based on the frequency of technique application and the percentage of students' agreement to their applicability. The techniques in the top five and with the highest percentage of applicability were selected as appropriate techniques for application in idea generation. The findings were used to develop a hierarchy for the application of techniques in engineering design concept ideation.

Results and Discussion

Reliability of Item

The summary of the statistical analysis of each item and the response using the Rasch measurement model analysis is shown in Figure 2. The Cronbach Alpha shows a value of 0.89, reflecting an acceptable internal consistency of the raw response pattern and suggests that the instrument can be used in the actual research. The reliability of the items and the responses was 0.82 and 0.87 respectively while their separation index and responses was 2.17 and 2.64 respectively. This shows that the item is in good condition and can be accepted in the study. According to Bond and Fox [19], a reliability of more than 0.8 and a separation index exceeding 2.0 is good [20].

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     SUMMARY OF 30 MEASURED Person
-------------------------------------------------------------------------------
|          TOTAL                         MODEL         INFIT        OUTFIT    |
|          SCORE     COUNT     MEASURE   ERROR      MNSQ   ZSTD   MNSQ   ZSTD |
|-----------------------------------------------------------------------------|
| MEAN     107.2      32.0       2.76     .35       1.00     .0    .97    -.1 |
| S.D.       9.0        .0       1.04     .04        .27    1.2    .27    1.1 |
| MAX.     122.0      32.0       4.74     .47       1.66    2.4   1.67    2.4 |
| MIN.      88.0      32.0        .73     .31        .44   -2.8    .43   -2.9 |
|-----------------------------------------------------------------------------|
| REAL RMSE    .37 TRUE SD     .97  SEPARATION  2.64  Person RELIABILITY  .87 |
|MODEL RMSE    .35 TRUE SD     .97  SEPARATION  2.79  Person RELIABILITY  .89 |
| S.E. OF Person MEAN = .19                                                   |
-------------------------------------------------------------------------------
Person RAW SCORE-TO-MEASURE CORRELATION = 1.00
CRONBACH ALPHA (KR-20) Person RAW SCORE "TEST" RELIABILITY = .89
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Figure 2: Summary of the statistics for items and respondents.

SUMMARY OF 32 MEASURED Item

	TOTAL SCORE	COUNT	MEASURE	MODEL ERROR	INFIT MNSQ	INFIT ZSTD	OUTFIT MNSQ	OUTFIT ZSTD
MEAN	100.5	30.0	.00	.36	1.00	.0	.97	-.1
S.D.	7.1	.0	.91	.04	.36	1.3	.36	1.3
MAX.	115.0	30.0	1.77	.51	2.14	3.7	2.17	3.8
MIN.	85.0	30.0	-2.22	.32	.47	-2.6	.48	-2.6

REAL RMSE .38	TRUE SD .83	SEPARATION 2.17	Item RELIABILITY .82
MODEL RMSE .36	TRUE SD .84	SEPARATION 2.32	Item RELIABILITY .84
S.E. OF Item MEAN = .16			

Figure 2: Summary of the statistics for items and respondents (continued)

The measure order of the items is shown in Figure 3. The analysis of the PTMEA CORR of the items showed positive values which indicate the ability of the items to measure the construct. The analysis of the Outfit MNSQ of the items showed that one item (F12) had a value of less than 0.6 while the other two items (F07 and D02) had values more than 1.4. The overall findings, therefore show that 91% of the items can be used in assessing the construct while 9% of the items need to be repaired.

Item STATISTICS: MEASURE ORDER

ENTRY NUMBER	TOTAL SCORE	TOTAL COUNT	MEASURE	MODEL S.E.	INFIT MNSQ	INFIT ZSTD	OUTFIT MNSQ	OUTFIT ZSTD	PT-MEASURE CORR.	PT-MEASURE EXP.	EXACT MATCH OBS%	EXACT MATCH EXP%	Item
22	85	30	1.77	.32	.72	-1.1	.70	-1.2	.55	.51	83.3	62.2	M30- identify material selection item
21	87	30	1.56	.32	1.39	1.5	1.39	1.5	.44	.51	56.7	62.2	M29- Identify item manufacturing methods of the project
7	92	30	1.03	.33	.77	-.9	.78	-.8	.38	.50	60.0	62.9	F08- Facilitate the process of analyzing the results
18	93	30	.92	.33	1.11	.5	1.10	.5	.67	.50	56.7	62.9	L26- Meet the design specification
19	93	30	.92	.33	.78	-.8	.77	-.9	.78	.50	70.0	62.9	L27- Measure of the feasibility of an idea
11	94	30	.81	.33	.47	-2.6	.48	-2.6	.53	.50	80.0	63.1	F12- Accurately determining the design objectives
5	95	30	.70	.33	1.11	.5	1.11	.5	.43	.50	60.0	63.1	G14- Generate ideas but there are members of groups that have different background knowledge
10	95	30	.70	.33	.89	-.4	.90	-.4	.46	.50	60.0	63.1	F11- Facilitate the process of selecting a final idea that meets the specifications title
16	95	30	.70	.33	.79	-.8	.81	-.8	.41	.50	73.3	63.1	L24- Generate a lot of ideas
8	96	30	.59	.33	.83	-.6	.84	-.6	.67	.50	53.3	63.3	F09- Facilitate the process of identifying the problem
12	96	30	.59	.33	.50	-2.4	.51	-2.4	.60	.50	86.7	63.3	F13- Ensure that decisions made are rational
6	98	30	.37	.34	1.95	3.2	2.04	3.5	.10	.49	26.7	63.4	F07- Facilitate the decision-making process
27	98	30	.37	.34	2.14	3.7	2.17	3.8	.14	.49	40.0	63.4	D02- Accelerate the process of idea generation
20	99	30	.25	.34	.81	-.8	.82	-.7	.57	.49	76.7	63.5	M28- Help analyze the idea in more detail
26	99	30	.25	.34	.94	-.2	.90	-.3	.60	.49	76.7	63.5	D01- Generate ideas within the period provided
9	100	30	.13	.34	.88	-.4	.85	-.6	.55	.49	73.3	63.3	F10- Facilitate the process of identifying the needs of user
24	100	30	.13	.34	1.30	1.2	1.22	.9	.25	.49	66.7	63.3	N32- Generate new idea
17	102	30	-.10	.35	1.14	.7	1.19	.8	.40	.48	56.7	63.9	L25- Produce quality ideas
28	103	30	-.23	.35	1.17	.7	1.09	.5	.44	.48	66.7	63.7	H15- Allows student try these methods and techniques
32	103	30	-.23	.35	.70	-1.3	.75	-1.0	.49	.48	73.3	63.7	J22- Showing proposal as process improvements
2	104	30	-.35	.36	.76	-1.0	.72	-1.1	.62	.47	76.7	64.1	E04- Generate ideas but there are members in the group have a different experience
3	104	30	-.35	.36	1.32	1.3	1.19	.8	.61	.47	56.7	64.1	E05- Generate ideas but there are members in the group have a different gender
23	104	30	-.35	.36	1.31	1.3	1.22	.9	.50	.47	60.0	64.1	N31- Generate a diversity of ideas
31	104	30	-.35	.36	.74	-1.1	.80	-.7	.48	.47	70.0	64.1	J21- Showing comments as process improvements
1	106	30	-.62	.37	.93	-.2	.88	-.4	.38	.46	60.0	66.5	E03- Generate ideas but there are members in the group who have different backgrounds
29	107	30	-.76	.38	1.13	.6	1.05	.3	.23	.45	53.3	67.9	H16- Allows student to experiment methods and techniques
4	108	30	-.90	.38	1.19	.8	.97	.0	.66	.44	70.0	69.2	E06- Generate ideas but there are members in the group have a different age
13	108	30	-.90	.38	.65	-1.5	.65	-1.2	.61	.44	83.3	69.2	I18- Gives student the opportunity to design projects
30	108	30	-.90	.38	.91	-.3	.87	-.3	.41	.44	63.3	69.2	H17- Allows student to sketch the ideas
15	113	30	-1.76	.45	.80	-.6	.79	-.3	.48	.38	86.7	78.8	I20- Gives student the opportunity to show their opinion
25	113	30	-1.76	.45	1.05	.3	.76	-.4	.53	.38	80.0	78.8	K23- Encourage student to speak during the discussion
14	115	30	-2.22	.51	.88	-.2	.65	-.5	.44	.34	83.3	83.6	I19- Gives student the opportunity to present the project
MEAN	100.5	30.0	.00	.36	1.00	.0	.97	-.1			66.9	65.7	
S.D.	7.1	.0	.91	.04	.36	1.3	.36	1.3			13.4	5.1	

Figure 3: The measure order of items.

Frequency of Technique Application

The frequency of the application of the techniques by the students during the process of idea generation is shown in Figure 4. From Figure 4, the creative techniques that have been applied by students during the generation of design ideas are Brainstorming (158), Morphology Analysis (139), Mind Mapping (131), Objective Tree (131), Checklist (123), 1H5W (93), NGT (70), KJ method (64), PMI (57), ATAR model (51), SWOT (51), SCAMPER (46) and Vroom-Yetton-Jago Decision Model (38). On the other hand, the engineering techniques used are PDS (123), QFD (113), Function Analysis (113), Pugh Model (100), FMEA (94), Concept Scoring Matrix (94), Concept Screening Matrix (93), and AHP (83).

This result indicates that students have applied a combination of creative and engineering techniques in the process of design idea generation. This finding was supported by the reports of Aslani et al [21] who stated that using creativity and innovation techniques in the development of creative ideas can reduce the barriers in group meetings, which influence the growth and diffusion of creative solutions and improve the ability to spread decision space and way of thinking. In another perspective, creative techniques are needed for dealing with innovative problems, while engineering techniques are for engineering analysis to determine the design specifications and user requirements. This analysis was subsequently used to make detailed engineering drawings. As proven by Vieira et al [22], creativity is a very important requirement in the engineering phase, especially in market-driven products, for attracting customers. According to Gero et al [8], using an unstructured concept generation technique (Brainstorming), partially structured technique (Morphological Analysis), and a structured technique (QFD), affects the early parts of the designing process, especially to focus more on problem-related aspects of designing, that is, design goals and requirements.

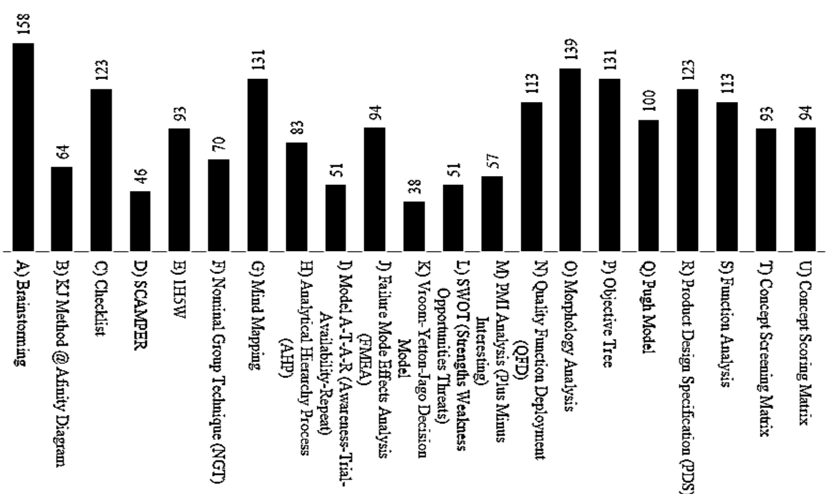

Figure 4: Frequency of technique applicability during the process of generating ideas.

Percentage of agreement on applicability of techniques

The purpose of the survey was to identify the five techniques based on the highest percentage of agreement on the applicability of techniques for each context in the six P's of creativity are which *pressure, process, person, persuasion, place,* and *product.*

Figure 5 presents the five techniques that had the highest agreement percentage for pressure. These findings revealed that students agreed that five techniques (Brainstorming, QFD, Function Analysis, Morphology Analysis, and Concept Screening Matrix) had helped them in the generation of ideas under a time constraint. This technique can be used to generate ideas and reports within the provided period. It can also help to accelerate the process of idea generation and problem-solving. Another finding shows that the students agreed that using Mind Mapping, Brainstorming, 1H5W, Morphology Analysis, and Function Analysis can allow them to try and experiment this technique in generating and sketching the ideas. According to Bordegoni [23], design and engineering activities should be supported by tools that allow the design and verification of several variants of new products in a short time. Tools for engineering should especially meet engineers' expectations. Application of creative techniques such as Mind Mapping can help significantly in projects and the further development of ideas and concepts [24]; while Brainstorming is an effective technique in getting a large number of ideas from a group of people in a short time [25].

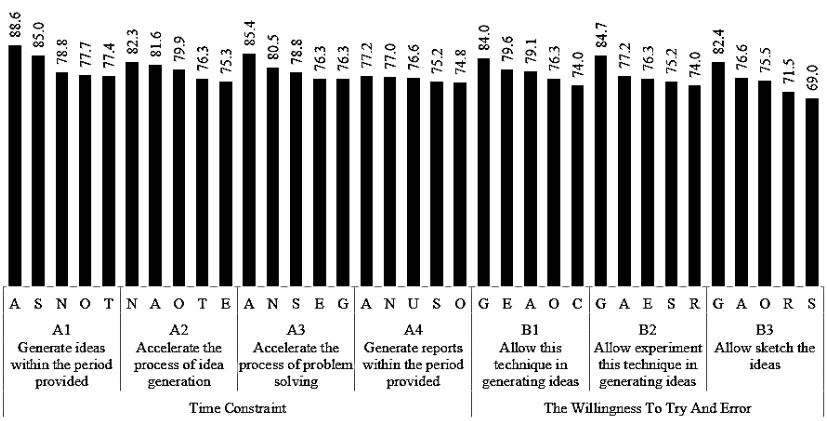

Figure 5: The five techniques that have the highest percentage of agreement for context of pressure.

The five techniques that had the highest percentage of agreement for the context of the process are shown in Figure 6. These results indicate that the techniques (Morphology Analysis, Function Analysis, 1H5W, QFD, and Brainstorming) helped the students to obtain information about users' needs and design specification. The student agreed that this technique can help them to facilitate the process of identifying the problems and user's needs, selecting a final idea that meets the title's specification, and analyse the results. Also, it can be used to determine the accurate design objective and rational decisions. Another finding shows Mind Mapping, Brainstorming, Morphology Analysis, Function Analysis, and ATAR Model as useful techniques which gave the students the opportunity to plan, present, and show their opinion about the project. According to Taura et al [26], creativity technique can be used as a generative process, especially in a problem-solving process. Among the techniques recommended in the generative process are QFD (for problem exploration), Brainstorming, Morphology Analysis, SCAMPER (for idea generation), and value engineering (for concept evaluation). The application of Morphology Analysis can be used to create enhancements on existing products and help to generate ideas quickly [27]. In the engineering design process, Brainstorming can be used to generate a large number of ideas or solutions for well-defined strategic or operational problems [28], while using QFD can help the team in identifying the product quality characteristics [29]. Mind Mapping is also a suitable technique to be used in planning a project and solving a problem [30].

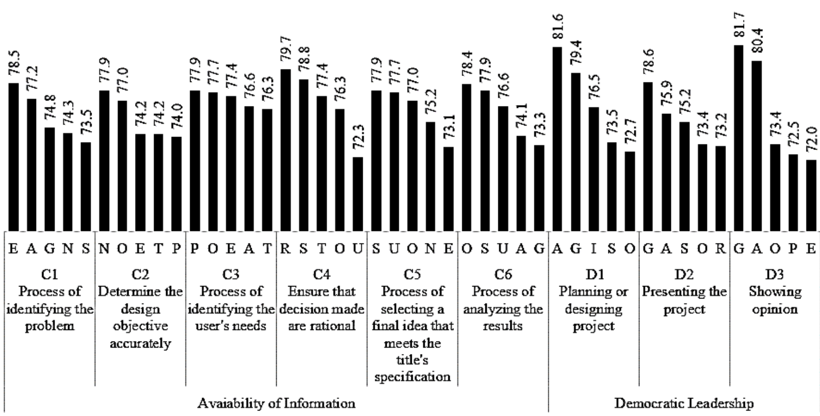

Figure 6: The five techniques that have the highest percentage of agreement for the context of process.

The five techniques that had the highest percentage of agreement for the context of the person are shown in Figure 7. The results show that

Brainstorming, Function Analysis, Morphology Analysis, Mind Mapping, and QFD are the techniques that helped the students to generate diverse ideas in a team with different backgrounds, experiences, genders, and age. This finding was supported by Chulvi et al [31] who stated that Brainstorming (intuitive technique) and Functional Analysis (structured technique) can be applied in the idea generation process to produce more creative design ideas. Also, Brainstorming is the suitable technique that can be used in a multi-disciplinary group meeting to propose and generate ideas to solve a stated problem [32]; while applying Mind Mapping in a team of learning and project work can give opportunity to make the "strange familiar", to develop synergistic interaction, assemble collective knowledge and a group minded attitude [24, 30].

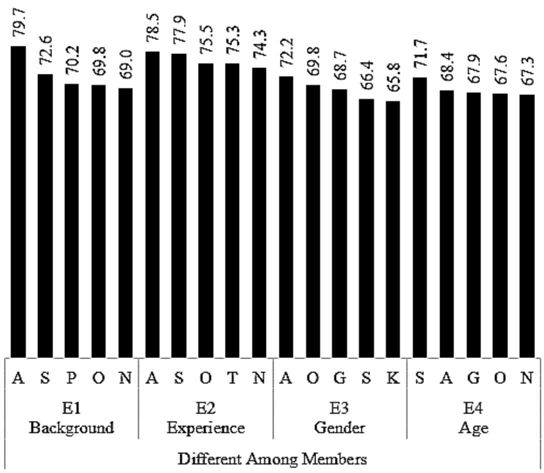

Figure 7: The five techniques that have the highest percentage of agreement for the context of person.

The five techniques that had the highest percentage of agreement for the context of the persuasion are shown in Figure 8. These findings show that Mind Mapping, Brainstorming, Morphology Analysis, Function Analysis, and QFD were applicable in helping students to get a positive comment and suggestion for improving the idea design. According to Hassan et al [29], QFD is useful in improving the effectiveness of the conceptual process plan, especially in the process quality and in giving useful information about the possible combined resources by incorporating a capability function for process elements. Seidenstricker [33] also recognized that morphology analysis is a product improvement technique which permits in-depth analysis of products or process.

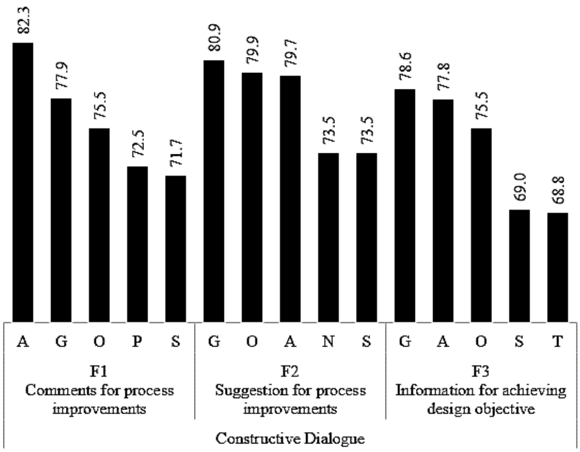

Figure 8: The five techniques that have the highest percentage of agreement for the context of persuasion.

The five techniques that had the highest percentage of agreement for the context of the place are shown in Figure 9. These findings show Mind Mapping, Brainstorming, 1H5W, Function Analysis, and Objective Tree as the techniques that gave students a chance to speak up. Using creative approaches in a discussion situation is very efficient in the development of cognitive abilities [34]. A technique such as mind mapping is a highly effective learning tool in increasing communication skills in class sessions. It also can be used as an interactive teaching technique and help to create extremely interactive and dynamic classrooms [24].

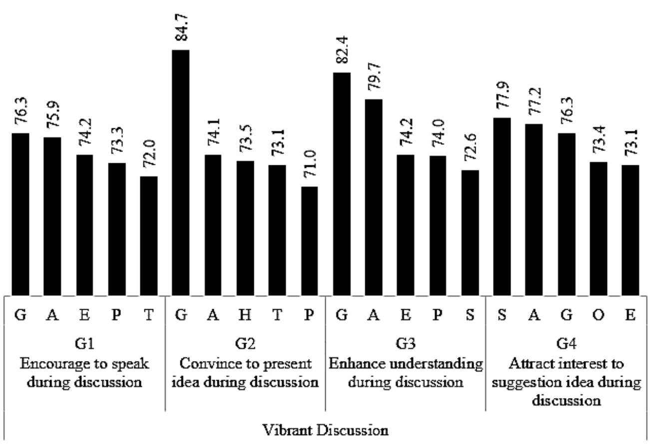

Figure 9: The five techniques that have the highest percentage of agreement for the context of place.

The five techniques that had the highest percentage of agreement for the context of the product are shown in Figure 10. The student agreed that Brainstorming, Mind Mapping, Morphology Analysis, QFD, and 1H5W were applicable in helping them generate quality ideas. Meanwhile, PDS, Brainstorming, 1H5W, Morphology Analysis and Concept Screening Matrix were applicable in helping them get deep information of an idea which includes detail idea analysis, manufacturing method, and material selection. This implies that the use of engineering techniques was needed in making an analysis of the ideas. It is to ensure that the selected idea has met the user needs and design specification. Another finding show Brainstorming, Morphology Analysis, Mind Mapping, Objective Tree, and 1H5W as applicable techniques in helping students generate diverse ideas. These findings prove that the use of creative techniques is crucial in generating the various new ideas that have interesting solutions, authentic design, and high impact quality. Johari et al [35] stated that using a combination of creative techniques, such as Mind Mapping, and conventional engineering design such as Morphology Analysis and evaluation matrix can increase students' creativity and ability to propose inventive ideas. As proven by Lo et al [36], Morphology Analysis is an ideation technique that can be used to generate alternative ideas for new product development by means of developing the generic sub-functions for a product or process, and consideration of alternative means for implementation of each sub-function; while the application of the objective tree technique in the context of product can help to integrate the entire prescriptive design cycle and demonstrate the understanding of formal design thinking process and strategies [37].

The overall findings imply the use of a combination of creative and technical techniques to help students in the six contexts of creativity in idea generation process. As a result, a hierarchy of technique application during the process of idea generation in engineering design concepts was developed (Figure 11). This hierarchy shows that a proper technique can be applied to achieve the right context.

Conclusion

This study helped in identifying the five optimal techniques in all the aspects and contexts of the Six P creativity model based on the applicability of techniques in the process of generating ideas. This, in turn, helped to determine the hierarchy of technique application for the development of the taxonomy of idea generation technique for engineering design concept. Through this study, it was also discovered that the use of a combination of creative and engineering techniques was a very effective approach in helping students to generate ideas. This is because the development of engineering design requires the use of proper techniques that are applicable to achieve the design specifications and user requirements. Using the hierarchy of technique application in engineering design concept ideation can assist students and lecturers in determining the appropriateness of techniques to be applied in generating ideas.

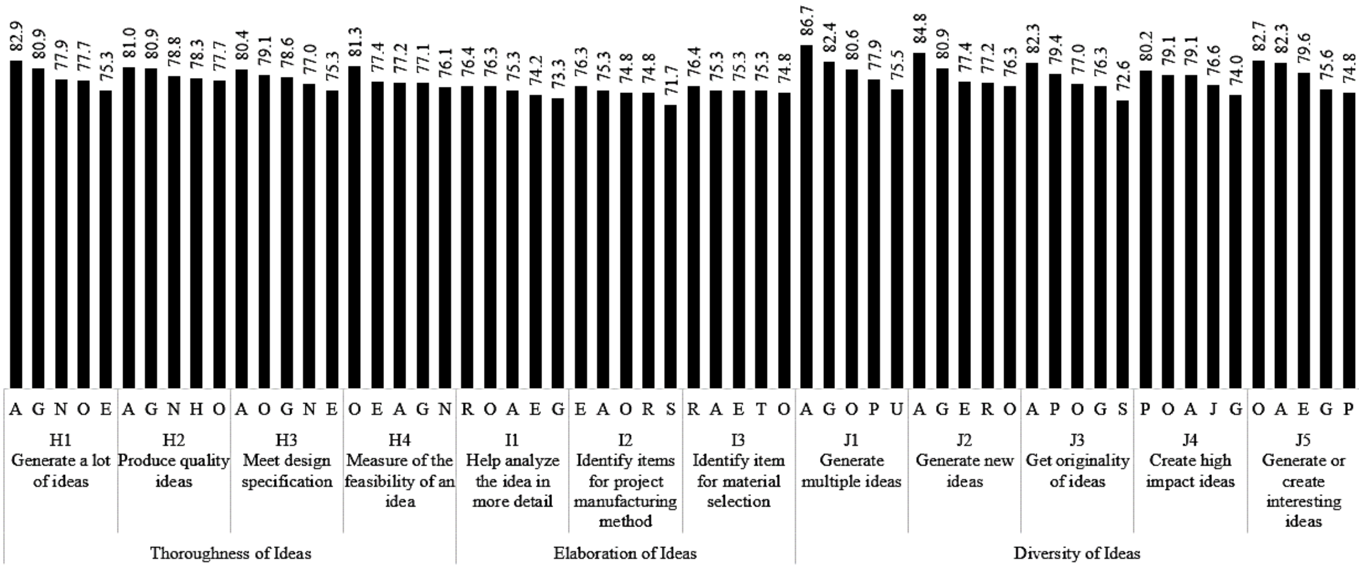

Figure 10: The five techniques that have the highest percentage of agreement for the context of product.

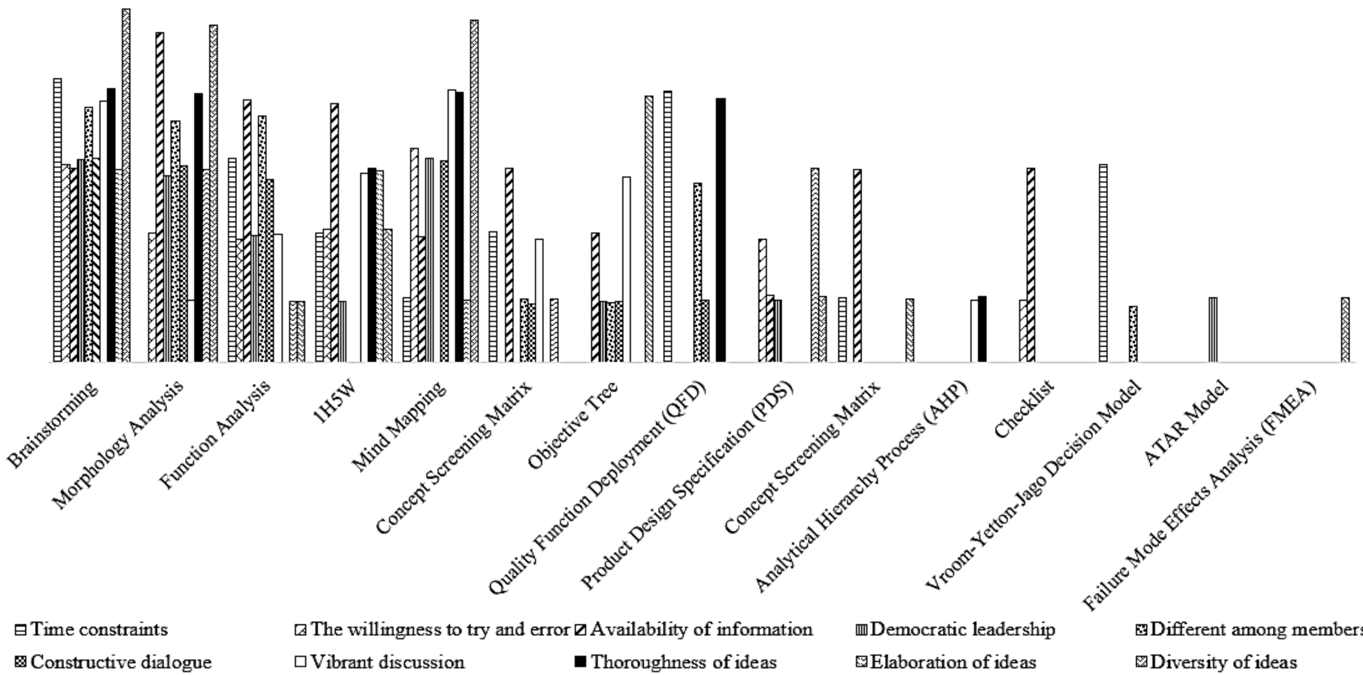

Figure 11: The hierarchy of technique application to achieve the context in engineering design concept ideation

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