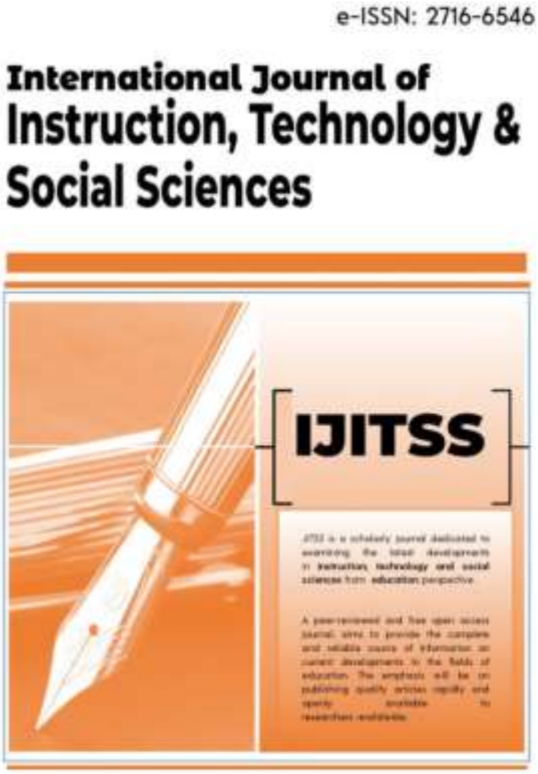

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Improving Creativity of Product Designed by Engineering Undergraduates in Malaysia by Creative Thinking Skills for Conceptual Engineering Design Module

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Abstract

This research paper presents the outcome of a study conducted to determine the effects of Creative Thinking Skills for Conceptual Engineering Design Module (CTSM) administered to mechanical engineering undergraduates at a private institution of higher learning with 30 in the control group and 32 from the intervention group, using post-test comparative design. The creativity of the product designed by engineering undergraduates was evaluated using revised Creative Solution Diagnosis Scale with 24 indicators. The outcome indicated that after intervention with CTSM the Creativity of Product designed by the undergraduates in all the five dimensions measured had improved.

Introduction

Engineers in the industry are required to acknowledge, validate and produce solutions for problems individually or in a team (Liu & Schönwetter, 2004). Solutions to problems could be in the form of different types of creative product such as products, process, system, or services (Cropley, 2015; Woodman, Sawyer & Griffin, 1993). The creativity that is required to generate solutions could be unleashed by implementing correct creativity techniques and these techniques could be taught, learnt, and are at the management of respective individuals (Hewett, 2005). Regrettably, the cultivation of creativity in students are inadequate in higher educational institutions around the world, including Malaysia (Brand, Hendy, & Harrison, 2015; Robinson, 2013; Terkowsky & Haertel, 2013; Haertel, Terkowsky, & Jahnke, 2012; Daud, Omar, Turiman, & Osman, 2012; Beghetto, 2010; Kazerounian & Foley, 2007)

A holistic higher education curriculum that focuses on both technical skills and practical skills that includes creativity is required for higher learning institutions in Malaysia to prepare engineering students with the correct skill sets, so Malaysia could remain competitive in terms of engineering technology, and consequently propel the course of Malaysia achieving developed nation status (Grapragasem, Krishnan, & Mansor, 2014). To enhance the creativity of engineering undergraduates, the Creative Thinking Skills for Conceptual Engineering Design Module (CTSM) that consist of six different creative thinking skills is designed and developed. The skills incorporated into the module are Brain Sketching, Mind Mapping, Attribute Listing, Functional Decomposition, Morphological Analysis, and SCAMPER. The CTSM is validated by five experts through external criticism validation method. The experts comprise three academia and two industrial engineers. The module scored a minimum of 70% for every criterion measured. The overall module reliability found to be 0.898 (Chua et al., 2020).

For this research, the researchers focus on the development of creative product design by engineering students. According to Cropley (2015), products are the unifying factor between engineering and creativity, and to understand the role of creativity in engineering, one must understand the novelty and effectiveness characteristics that define the level of creativeness in products. To assess the level and type of creativeness in products, the revised Creative Solution Diagnosis Scale (CSDS) developed is utilized. Currently, there are two versions of revised CSDS and they are refined versions of the original CSDS that are suited for different applications (Cropley & Cropley, 2011; Cropley & Kaufman, 2012). Various researches have proven that CSDS can provide a highly reliable assessment of product creativity among engineering students and engineers in the industry (Cropley & Kaufman, 2012; 2013; Cropley, Kaufman, & Cropley, 2011; Kaufman, et al., 2013). The newer, 24 indicators CSDS developed in the year 2012 is suitable for non-expert reviewers and have high-reliability results (Cropley & Kaufman, 2012).

This research aims to achieve the following objectives:

1. Determine the effectiveness of the CTSM in terms of enhancing the creative ability of engineering students to produce creative product design.
2. Determine the overall creativity of product designed by the engineering students by using revised CSDS.

Literature Review

Creativity

A common fallacy with regards to creativity is that it is believed that creativity is a divine gift, found only in certain individuals and could not be learnt. However, this is untrue as various researches have shown creativity could be taught and learnt (Rhodes, 1961). Rhodes (1961) categorized the characteristics of creativity into the 4Ps, representing Process, Person, Press, and Product. Torrance (1974) defined creativity as a process of becoming sensitive to problems, deficiencies, gaps in knowledge, missing elements, disharmonies, and so on; identifying the difficult; searching for solutions, making guesses or formulating hypotheses about the deficiencies; testing and retesting these hypotheses and possibly modifying and retesting them, and finally communicating the results. Creativity could be defined in countless ways by various researchers and Rhodes (1961) stated that no one theory can incorporate all different theories of creativity. Researchers widely accept the characteristics of creativity as the ability of an individual to relate ideas in new approaches that are novel and useful towards society. (Daly, Mosyjowski, & Seifert, 2014).

Product Creativity

For this research project, the only characteristic of creativity that will be investigated is the product. Cropley (2015) stated that creativity is involved in the development of tangible solutions to practical problems and only by understanding what roles creativity plays in engineering. The characteristics that define a product creative could be recognized and quantified. Cropley (2015) also stated that there are four different types of creative products namely artifact, process, system, and service. Engineers apply technical knowledge, combined with creativity to come out with novel and tangible solutions in the form of products that is a direct response to changes in the environment of society. It is evident during the current Covid-19 pandemic, the world sees various creative solutions being used to overcome the shortage of medical personal protective equipment and breathing ventilators.

Creative Solution Diagnosis Scale (CSDS)

Before the development of the Creative Solution Diagnosis Scale (CSDS), there are various instruments available to systematically rate product creativity such as the Consensual Assessment Technique (CAT) by Amabile (1983;1996), Creative Product Semantic Scale (CPSS) by Besemer and O'Quin (1987; 1999), and Student Product Assessment Form by Reis & Renizulli (1991).

CSDS was developed by Cropley and Cropley (2005) as a detailed scale for the measurement of product creativity with 30 items on the scale to facilitate the assessment of the amount of creativity and type of creativity that exist in a product or product concept. By combining the different indicators used in previous instruments to measure product creativity with the criteria of functional creativity namely relevance and effectiveness, novelty, elegance, and genesis. A judge can observe characteristics that represent operationalization of abstract criteria of creativity and quantify these criteria with the aid of the CSDS scale. CSDS has gone through revision twice, with the latest revision having only 24 indicators on the scale.

Cropley, Kaufman and Cropley (2011) proposed revision of the original CSDS tailored to measure product creativity and the revised CSDS with a total of seven dimensions was made measurable through observable indicators found in products and have a total of 27 indicators on the scale. To evaluate product creativity, raters are required to rate on a five-point Likert scale in the CSDS ranging from ‘not at all’ to ‘very much’ for each item. Qualitative data obtained from the Likert scale are then converted into numerical scored that could be used to quantify product creativity and generally, when the higher the overall score the product obtained, the overall creativity in the product is higher. Last but not least, the use of CSDS segregate different criteria of functional creativity existing in the product, thus leading to design teams being able to pinpoint criteria that require improvements if required.

Another revision of the CSDS, which comes with only 24 indicators based on confirmatory factor analysis was by performed by Cropley and Kaufman (2012). Six redundant items were removed from the original CSDS developed in 2005 and it was found that using the revised CSDS with only 24 indicators, even non-expert judges with no formal training could recognize and quantify characteristics of creative products. This version of the revised CSDS is applied for this research. The revised CSDS 24 indicators are categorized into five dimensions namely:

Relevance and Effectiveness, which refers to the functionality of the solution to accurately reflect conventional knowledge/techniques applied, does what it is supposed to do, while fits within task constraints

> *Problematization,* which refers to the functionality of the solution to draw attention to shortcomings in other existing solutions, shows how existing solutions could be improved and helps the beholder to anticipate likely effects of changes.
>
> *Propulsion*, which refers to the functionality of the solution can show how to extend the known in a new direction, makes use of new mixture(s) of existing elements, indicates a radically new approach, helps the beholder see new and different ways of using the solution, and offers a fundamentally new perspective on possible solutions

Elegance, which refers to the functionality of the solution that it is safe to use and environmentally friendly, beholder sees the solution as skilfully executed, well-finished, finds the solution neat, well done, well worked out and "rounded", well-proportioned, nicely formed, and elements of the solution fit together in a consistent way

Genesis, which refers to the functionality of the solution to suggest a novel basis for further work, offers ideas for solving unrelated problems, suggests new ways of looking at existing problems, draws attention to previously unnoticed problems, suggests new norms for judging other solutions-existing or new, and opens up a new conceptualization of the issues.

This research also looked into the overall product creativity, which is defined as the total sum of scores of the revised 24 items CSDS.

Methodology

Research Design

This research was conducted using Post-Test Comparative design as illustrated by Chua (2016) to the intervention group and control group such as descriptions in Table 1 below:

Table 1 Comparative Design Comparing Between Control Group and Intervention Group

Type of Groups	Intervention	Measurement
Control Group		M1
Intervention Group	X	M2

The intervention group students underwent a workshop of one hour each for consecutively eight weeks for the CTSM workshop while the control group students will not. At the end of the workshop, students from both groups are to design a product that will receive an evaluation by another group of experts in engineering design.

Research Samples

A purposive sampling method was applied in replacement of random sampling method in the selection and placement of subjects into the control and intervention groups. The respondents selected are the third-year mechanical engineering students undertaking a design module in the studied university. A total of 62 students were involved in this study, where 30 students formed the control group, while another 32 students formed the intervention group. The students from the intervention group will undergo the CTSM module while the control group will not. At the end of the training, both the group of students are required to work in groups of two to three students to design a product using the knowledge they have acquired. This product designed will be evaluated by a group of experienced design engineers.

Evaluation by Panel of Experts

A group of experts in engineering design had been appointed to evaluate the engineering design by the students from the control group and intervention group. The panel of experts is from academia as well as experienced design engineers from different industries. The biodata of the panel of experts appointed is illustrated in Table 2.

Table 2 Biodata of Group of Engineering Design Experts from Academia and Industries Assessing the Product Design using Revised CSDS with 24 Indicators

Expert Panel	**Biodata of Expert Panel of Reviewer Using CSDS**
E1	• Senior Lecturer of Mechanical Engineering Department of a private university • More than ten years of experience in lecturing Mechanical Engineering Degree and Diploma Programmes • TRIZ Level 2 practitioner • Formerly a process engineer of a multinational company, QA manager of a manufacturing company • Registered as a professional engineer with the Board of Engineers Malaysia

	• Registered as a professional technologist with the Malaysia Board of Technologists • Registered as a corporate member of The Institution of Engineers, Malaysia • Registered as a chartered engineer with the Engineering Council, United Kingdom • Registered as a corporate member of the Institution of Mechanical Engineers, United Kingdom • Supervised more than 50 bachelor degree students
E2	• Former senior lecturer of a private university • More than ten years of experience in lecturing Mechanical Engineering Degree and Diploma Programmes • TRIZ Level 3 practitioner, Level 1 instructor. • More than five years working as an engineer overseas • Registered as a professional technologist with the Malaysia Board of Technologists • Registered as a graduate engineer with the Board of Engineers Malaysia • Registered as companion member of The Institution of Engineers, Malaysia • Registered as a member of IEEE • Registered as a chartered engineer with the Engineering Council, United Kingdom • Registered as a corporate member of the Institution of Mechanical Engineers, United Kingdom • Currently a project engineer in an engineering firm • Supervised more than 50 bachelor degree students
E3	• Project engineer of an engineering consultant firm. • More than 15 years of experience in engineering design project using various engineering design software such as Solidworks • More than ten years of experience in the design and construct of various mechanical systems • Well experienced in engineering design standards • Registered as a graduate member of The Institution of Engineers Malaysia • Registered as a graduate engineer with the Board of Engineers Malaysia
E4	• Programme manager of a Multi-National Company (MNC), leading the systems integration program management team managing annual revenue more than $10M • Principal staff mechanical engineer of an MNC managed engineering resources and organized mechanical engineering teams to accomplish project activities ranging from project initiation to systems solutions lockdown to production readiness • Senior staff mechanical engineer of an MNC, designed, developed and innovated various product for the MNC • Registered as a professional engineer with the Board of Engineers Malaysia • Registered as a chartered engineer with the Engineering Council, United Kingdom • Registered as a corporate member in the Institution of Mechanical Engineers, United Kingdom

Results and Discussion

Normality Test Results

Before any statistical analysis can be carried out, the normality test is performed on the data collected to determine which statistical approach is applicable. The results are illustrated in Table 3.

Table 3 Results of Normality Test on the Data Collected

No	Criteria /Null Hypothesis	Group	Shapiro-Wilk p	Decision
1	Relevance and Effectiveness **H_a:** The assessment scores for relevance and effectiveness is normally distributed	Control Intervention	.001 .000	**H_a** is rejected. The data is not normally distributed
2	Problematization **H_b:** The assessment scores for problematization is normally distributed	Control Intervention	.012 .000	**H_b** is rejected. The data is not normally distributed
3	Propulsion **H_c:** The assessment scores for propulsion is normally distributed	Control Intervention	.007 .040	**H_c** is rejected. The data is not normally distributed
4	Elegance **H_d**: The assessment scores for elegance is normally distributed	Control Intervention	.000 .000	**H_d** is rejected. The data is not normally distributed
5	Genesis **H_e**: The assessment scores for genesis is normally distributed	Control Intervention	.035 .000	**H_e** is rejected. The data is not normally distributed
6	Overall Product Creativity **H_f**: The assessment scores for overall product creativity is normally distributed	Control Intervention	.003 .002	**H_f** is rejected. The data is not normally distributed

The normality test results indicated that all the data are not normally distributed, thus independent sample T-Test is not applicable. Instead, a nonparametric test, Mann-Whitney U-Test applies to all the data to determine the effects of CTSM in improving the ability of the students to come up with the creative product.

Effects of CTSM in Improving Product Creativity Designed by Students

To study the effectiveness of the CTSM in improving the creative ability of the student to come up creative product design, a series of null hypotheses are established for the various measurement criteria applied in the revised 24 items CSDS. The null hypotheses are as follow:

Null Hypothesis H_1:
There is no significant difference in relevance and effectiveness scores between the control group and the intervention group

Null Hypothesis H_2:
There is no significant difference in problematization scores between the control group and the intervention group

Null Hypothesis H_3:
There is no significant difference in propulsion scores between the control group and the intervention group

Null Hypothesis H_4:
There is no significant difference in elegance scores between the control group and the intervention group

Null Hypothesis H_5:
There is no significant difference in genesis scores between the control group and the intervention group

Null Hypothesis H_6:
There is no significant difference in overall product creativity scores between the control group and the intervention group

Effectiveness of CTSM in Improving Relevance and Effectiveness

Evaluation of the difference between control group scores and intervention group scores in relevance and effectiveness was carried out using Mann-Whitney U Test. The results revealed that there is significant difference in relevance and effectiveness scores between control group (mean rank = 24.05, n = 30) and intervention group (mean rank = 38.48, n = 32), U = 256.5, Z =-3.364, p = .001, r = -0.4272, H_1 is rejected.

Effectiveness of CTSM in Improving Problematization

Evaluation of the difference between control group scores and intervention group scores in problematization was carried out using Mann-Whitney U Test. The results revealed that there is significant difference in problematization scores between control group (mean rank = 21.70, n = 30) and intervention group (mean rank = 40.69, n = 32), U = 186.0, Z = -4.279, p = .000, r =-0.5434, H_2 is rejected.

Effectiveness of CTSM in Improving Propulsion

Evaluation of the difference between control group scores and intervention group scores in propulsion was carried out using Mann-Whitney U Test. The results revealed that there is significant difference in propulsion scores between control group (mean rank = 18.35, n = 30) and intervention group (mean rank = 43.83, n = 32), U = 85.5, Z = -5.602, p = .000, r = -0.7115, H_3 is rejected.

Effectiveness of CTSM in Improving Elegance

Evaluation of the difference between control group scores and intervention group scores in elegance was carried out using Mann-Whitney U Test. The results revealed that there is significant difference in elegance scores between control group (mean rank = 19.80, n = 30) and intervention group (mean rank = 42.47, n = 32), U = 129.0, Z = -5.097, p = .000, r = -0.6473, H_4 is rejected.

Effectiveness of CTSM in Improving Genesis

Evaluation of the difference between control group scores and intervention group scores in genesis was carried out using Mann-Whitney U Test. The results revealed that there is significant difference in genesis scores between control group (mean rank = 19.35, n = 30) and intervention group (mean rank = 42.89, n = 32), U = 115.5, Z = -5.241, p = .000, r = -0.6656, H_5 is rejected.

Effectiveness of CTSM in Improving Overall Product Creativity

Evaluation of the difference between control group scores and intervention group scores in overall product creativity was carried out using Mann-Whitney U Test. The results revealed that there is significant difference in overall product creativity Scores between control group (mean rank = 18.95, n = 30) and intervention group (mean rank = 43.27, n = 32), U = 103.5, Z = -5.312, p = .000, r = -0.6746, H_6 is rejected.

The results obtained indicated that the creativity of the product designed by the intervention group is much higher compared to the control group. There is a significant difference in scores of intervention group as compared to control group in every dimension measured by the revised CSDS, where the mean rank of intervention group scores is higher than the mean rank of control group scores in all five dimensions as well as the overall product creativity. This indicates that the creative ability of the intervention group had improved significantly after attending the CTSM workshop.

In order to successfully implement CTSM in the Engineering Education, the educators will also need to consider the implementation of the revised Bloom's Taxonomy in the design of the courses. In this revised Bloom's Taxonomy, the conventional Taxonomy of Knowledge, Comprehension, Application, Analysis, Synthesis, Evaluation has been replaced action words of Remember, Understand, Apply, Analyse, Evaluate, Create, by Anderson, L.W., Krathwohl, D.R., & Bloom, B.S. (2000). Relating to the Create in the revised Bloom's Taxonomy, there are three sub-items to further clarify this skill, namely generating (hypothesizing), planning (designing), producing (construct). Hence, it become apparent that that what is being researched in this project leads to the important development of the engineering education, producing engineers that is able to produce creative ideas in the product design.

As outlined by Markey (2014), there are various activities that need to be considered when teaching courses that include all levels of the revised Bloom's Taxonomy. The implication of such implementation is twofold. For students, they are given an opportunity to use their creativity through the use of higher order thinking skills. On the other hand, academics will definitely need to walk an extra mile in the preparation of the conduct of the classes, as the inclusion of creativity in the teaching content will be just more than the chalk-and-talk teaching, or even the collaborative learning and flip learning.

Conclusion

The major findings of the study are that the CTSM had significantly improved the capability of the students to come up with creative products. Based on the findings above, it can be concluded that engineering undergraduate students can be trained or educated to be more creative when comes to deriving various relevant design of products or solutions.

The results obtained in this study are related to engineering design, where creativity is required to develop a product. The research doesn't look into the assessment of the creativity potential of the students, the creative process in design, or the impact of the environment towards the manifestation of the creative ability.

With the implementation of the creative thinking module in the engineering programme, it is high time that the Institution of Higher Learning to look into various means that can enhance the creative potential of engineering students, including hiring lecturers who are fluent in the subject area, reducing the excessive study load on students.

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