# ENHANCING STUDENTS' MATHEMATICAL CREATIVITY IN CALCULUS THROUGH PRE-WITHIN-POST PROBLEM POSING TASKS

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***ABSTRACT:*** *This study investigated the effect of utilizing pre-within-post problem posing activities in enhancing students' mathematical creativity in Differential Calculus. This study was conducted in two semesters composed of 75 regular third year BSEd Mathematics students during the first semester of school year 2017-2018 and 57 irregular engineering students enrolled in special class in Differential Calculus during the second semester of school year 2016-2017 at the University of Science and Technology of Southern Philippines-CDO campus. Using quasi-experimental pretest-posttest control group design in gathering quantitative data, a 4-item Multiple Solutions Tasks (MST) test intended to measure students' level of mathematical creativity measured in terms of their level of mathematical fluency, flexibility and originality of solutions were given to the participants before and after the experiment. Participants of the study were also given survey questionnaire to determine their perceptions on the use of pre-within-post problem posing activities integrated in their work text in Differential Calculus. Data collected were analyzed using mean, standard deviation and two-way analysis of covariance (ANCOVA). Results of the analysis revealed that the students' level of mathematical creativity increased as influenced by their exposure to pre-within-post problem posing activities. The mathematics education students performed better than the mixed engineering students in terms of their mathematical creativity scores as influenced by their use of problem posing activities. Hence, the researcher recommended that mathematics teachers may use pre-within-post problem posing activities in teaching mathematics to help improve students' mathematical creativity design classroom activities which requires students' to posit different solutions to mathematical problems and develop a work text in their mathematics subjects handled integrated with pre-within-post problem posing activities. Furthermore, similar studies may be conducted to show associations between students' mental ability and levels of mathematical creativity,, study how technology rich classroom environment can effectively foster mathematical creativity and finally on how mathematics Olympiads exhibit and develop their multiple solutions to a mathematical problem.*

**Keywords:** Mathematical Creativity, Pre-Within-Post Problem Posing, Multiple Solutions Task (MST) Test

## 1. INTRODUCTION

Philosophers summed up the emerging present world system in four principles which are universalism, globalism, interdependence and creativity, while other contemporary scholars viewed creativity as the "cultural capital of the 21st century" for it is among the most important and pervasive of all human activities [1]. Creativity requires experimentation, formulation of new hypotheses and open possibilities. Britten [2] attributed economic success to innovative thinking and he stated that creativity reduces inequalities and improves the quality of living. Hence, creativity is one of the fundamental requirements to live in this present generation.

Contemporary schools need to prepare students to work in current workplaces and teachers must help students to develop these skills needed for success. Among the most important 21st century skills which may help students adapt to the changing society is to develop their creativity and intellectual curiosity. Creativity is an integral part of mathematics. It is traditionally supposed to attribute to art and literature, but recently doing meaningful science has also been considered as a creative act. In mathematics classroom, students who are creative seem to possess the quality of good problem solvers with excellent critical thinking skills which the present society needs. In relation to the teaching and learning of mathematics concepts, students need to possess creative thinking and problem solving skills which mathematics educators must also design activities that promote creativity among students. Creative learners are those students who can easily think in many ways to find alternatives to answer problems in mathematics. Considering the importance of creativity, the role of mathematics educators is to design activities that can foster the development of students' mathematical creativity. Mathematical creativity was first explored by Poincare and Hadamard at the beginning of the 20th century. But nevertheless, this concept was not discussed in detailed until the recent years [3]. In fact the National Council of Teachers of Mathematics (NCTM) Standards for Mathematics Education did not listed creativity explicitly as one of the strands of focus. However, the elements listed in the NCTM and the Common Core State Standards (CCSS) of the United States focal points are considered by many researchers as one of the fundamental components of creativity.

Inquiry-oriented mathematics instruction which includes problem posing tasks in mathematics classes is considered essential and effective ways of developing achievement and creativity among students [4]. Yuan & Sriraman [5] and Kontorovich, *et al*. [6], linked problem posing skills with creativity and citing flexibility, fluency and originality as creativity categories. However, Siswono [7], argued that creativity lies in the interplay between problem posing and problem solving and classified problem posing according to whether it takes place before (pre-solution), during (within-solution) or after (post-solution).

In order to evaluate students' level of mathematical creativity in terms of their level of mathematical fluency, flexibility and originality of solutions, Kontorovich, *et al.*, [6], used a Multiple Solution Tasks (MST) test. In this test, students are tasked to answer the problem in many different ways aimed to measure the mentioned categories of creativity.

In view of the above background, this present study investigated the effect of pre-within-post problem posing activities integrated in the work text in Differential Calculus on students' creativity in mathematics.

## 2. THEORETICAL FRAMEWORK

Creativity can be found in all areas of human activity such as in the arts, sciences, work and play and everyone was born with enormous creative abilities. However, these skills need to be developed and teachers need to select appropriate tasks [8]. In mathematics education, recent studies have elaborated the works of Guilford [9] and Torrance [10] who first explored the concept of the development of mathematical creativity.

It is a fact that learning is heavily dependent on teachers. Teachers must interpret the curriculum and select good curricular materials and strategies to be used in the classroom. To achieve this, teachers should prepare tasks that allow students do creative solutions to be mathematically competent. Research shows that what students learn is greatly influenced by the tasks they have experienced [11]. Therefore, it is important to have creative mathematical tasks in the classroom. Mathematical tasks must provide avenue for multiple solutions in order to allow students show their mathematical ideas, flexibility of thought and originality in their responses. Teachers must encourage students to create, share and solve their own problems, as this is a very source of learning and development of their ability to solve problems and their mathematical knowledge. Creativity should be an intrinsic part of mathematics for all programs.

Looking back in the history of human thought, Socrates (469 BCE-399 BCE) established an efficient method of learning through continuous dialog based on posing and answering questions to stimulate critical thinking and illuminate ideas. The focus on the nature of critical thinking has continued ever since and is a contemporary issue that has become more and more important in education. Problem posing helps students to gain control of their own learning and at the same time this encourages them to create new ideas by giving them a more expanded view on what can be done with problems [12]. This process can also assist teachers as problem posing opens a window in on students' thinking [13]. In this way, teachers can better understand students' cognitive processes; find out possible misconceptions early in the learning process and gather information about students' achievement levels (Silver, 1997) [13]. As a consequence their program of study can be tailored according to individual needs of students that is designed to enhance learning [14]. The process of problem posing can be considered as a problem solving process in which the solution is ill-defined, since there are many problems that could be posed [13].

In view of the theories presented, the researcher formulated this theory that creativity can be well developed through problem posing activities in Calculus and to achieve the desired results, a work text in Differential Calculus integrated with pre-within-post problem posing activities was developed by the researcher. Based on the above discussion, the problem has been formulated. Specifically, the present study investigated the effects of pre-within-post problem posing activities on students' creativity in mathematics which was measured in terms of students' level of mathematical fluency, flexibility and originality of solutions.

## 3. LITERATURE REVIEW

Creativity is most commonly associated with the arts, but it is also a fundamental part of mathematics, technology, economy and politics. In reality, it forms an integral part of a person's everyday life. According to Robinson and Beesley [15], every person was born with enormous creative abilities but these skills need to be developed and Henri Poincare was the pioneer is the study of creativity in mathematics. This was supported by Pelczer and Rodriguez [8], which they added that this can be promoted using tasks with adjusted structure. Despite the perception on the importance of developing students' mathematical creativity, Vale and Pimentel [16] reported that creativity is a forgotten subject by teachers during their mathematics lessons since the teachers have no knowledge on the subject and have not been aware of its relevance in all levels of education. Leiken [17] argued that teachers need to develop the mathematical creative potential of each students and this creative development should be given focus in school mathematics because this skill will help students possess critical thinking ability which is the ultimate goal of teaching mathematicss.

Creativity is also categorized with regards to specific characteristics. Torrance as cited by Kattou, *et al.*,[18] describes creativity with regards to three components, i.e. fluency, flexibility, and originality. Fluency in the context of mathematical problem posing and solving, refers to the ability to generate or create multiple solutions; flexibility refers to the ability to easily change the focus, direction or approach while doing the problem solving tasks; and originality refers to the level of novelty in the development of new, unique solutions other than the solution given by the teacher. These components are still used by researchers to identify creativity [19,20].

The fact that creativity is closely related to problem solving in mathematics, and specifically the solving of complex real life problems. It is delicately knit like a golden thread through the literature on the definition of creativity. The importance of mathematical creativity is discussed by various authors[20] and many of the existing definitions refer specifically to the complexity of the construct. Creative students do not merely pour forth mathematical knowledge that they have learned when they are solving problems, but use new and unusual strategies in their solutions (Sternberg, *et al*., [21]. Sternberg further said that mathematical analytical reasoning abilities are not necessarily sufficient to solve real-life problems - a solid combination of analytical, practical and creative thinking is also necessary. Sriraman [22] extends the general definition of creativity to mathematical creativity. He describes mathematical creativity as a process that opens doors to new, unusual and insightful outcomes that is generated through solving problems - a viewpoint that is generally supported by Westerners, while the Eastern viewpoint of creativity focuses on the reinterpretation of a known problem from a different angle.

Wu and Chiou [23] emphasized the difference between process and product in their definitions of creativity. Mathematical creativity is seen as a thinking process that manifests in three products characterized by fluency, flexibility and originality. Fluency can be defined as the ability to get a correct answer in different way of solving familiar and unfamiliar question given to students, flexibility refers to different actions taken to solve mathematical problem connecting different concepts using it with coherence without flaws and originality refers to the uniqueness of solution not patterned from previous solutions of problems.

*Students' Creativity and Achievement in Mathematics*

The essence of mathematics is thinking creatively, not simply arriving at the right answer. Yet typical school mathematics programs often focus on what the student does rather than what the student thinks.

Mathematical creativity is difficult to develop if one is limited to rule-based applications without recognizing the requirement of the problem to be solved. The visionary classrooms as described by the Principles and Standards for School Mathematics of the National Council of Teachers of Mathematics (NCTM) enable students to confidently engage in complex mathematical task, draw knowledge from a wide variety of mathematical topics, approaching the same problem from different mathematical perspectives and representing the mathematics concepts in different ways until they find new methods that enable them to make progress. [24].

Mina [25] in her paper presented during the International Congress on Mathematical Education in Mexico on how to promote creativity for all students concluded that every student can be creative. The theory of multiple intelligence supports this possibility, though might be in different areas. According to the developmental nature of these intelligences, mathematical creativity can be for all. Further, he added that creativity can be seen as the ability of man to establish new relationships to change reality. Mathematical creativity can be seen as the mental activity in the area of mathematics education which is directed towards establishing new relationships which go beyond those given in a non-routine mathematical situation.

Yacoubi [26] conducted a survey on some actions undertaken in detecting and nurturing gifted students in Mathematics in Africa. Results showed that until now, there was no attention given to measure, foster and encourage the mathematical creativity in the continent. They added that students who are talented in Mathematics could play an important role in the nation economic growth. So the mathematically gifted students who are creative thinkers should be given special attention in all the educational efforts in Africa. It is essential that the most creative children would be identified early in the life and provided with an efficient assistance that would bring all their skills to full fruition.

Yuan ( [27] conducted a study using the theoretical lens of Guilford's Structure of Intellect model and Torrance's tests. He concluded that it does not seem necessary to limit creativity to divergent thinking as opposed to convergent thinking as some have done. However, he noted that novelty and usefulness are considered to be the key elements of creativity resonating with the requirement of originality in Torrance formulation.

Kattou, Pitta-Pantazi and Christou [18] developed a theoretical model in which mathematical creativity constitutes a predictor of mathematical ability. Also, they examined the existence of group of students that differ across mathematical ability and investigate whether these groups present differences in their mathematical creativity. Using 359 elementary students in Cyprus, results showed that mathematical ability may be predicted by mathematical creativity and the categories of students present statistically differences in their mathematical creativity, suggesting that level of mathematical ability depends on their level of mathematical creativity.

Savic, Karakok and Tang [28] developed a creativity in proving rubric to frame creativity within proof and the proving process. They recommended that the rubric can be an effective tool in the learning environment which fosters creativity such as those requires students' reasoning abilities.

Vale and Pinheiro [33] conducted a study on creativity in mathematics associated with problem solving and problem posing at elementary level. They developed a didactical experience for which they carefully selected tasks that can provide different productions, representing diverse and creative ways of thinking of each dyad, calling forth their creative potential and given the freedom to communicate creatively. They concluded that the proposed tasks promote creative potential in students bringing out in them the habit of discovery and making a difference as compared to other students.

Lomibao, *et al*. [29] studied influence of mathematical communication on mathematics performance and mathematics anxiety of high school students in Bulua National High School. Result of the analysis revealed that the students' exposed to mathematical communication approach have significantly higher achievement and conceptual understanding compared to the Dynamic Learning Program (DLP). In addition, the mathematical communication approach has also significantly reduced their mathematical anxiety. Her study was related to the present study because doing the Calculus tasks work in a group using the work text so they can communicate to create problems as they pose and solve the problem.

Ubalde, *et al*. [30] determined the effects of bridging the knowing-doing gap through zone of generativity on the grade six pupils' achievement and retention score and on their anxiety towards mathematics. The bridging of the zone of generativity has some semblance of creativity because the method use appropriate materials in the process. Results of the analysis revealed that the pupils exposed to the zone of generativity approach have significantly better achievement and retention score compared to the pupils exposed to lecture method with groupings. In addition, the zone of generativity also have significantly lessened the pupils' anxiety towards mathematics. The present study will use original idea as they pose and solve problems which are contextual.

Parcutilo, et al. (2008) [31] studied the effect of quiz buddy, a pair assessment on students' performance in Calculus, mathematics anxiety and retention level. She found out that students' who were assessed with quiz buddies performed significantly better in the calculus test than those who were assessed individually. The result further revealed that students in quiz buddies had a better retention of concepts in calculus and had decreased their level of test anxiety.

*Problem Posing in Mathematics*

Problem posing is recognized as an important component of mathematics teaching and learning (NCTM, 2007) [24]. Problem posing involves generation of new problems and questions aimed at exploring a given situation and reformulation of a problem during the process of solving. Lavy and Shriki [32] conducted a study to determine the development of mathematical knowledge and problem solving skills of prospective teachers' as a result of their engagement in problem posing activity. Analysis of the data revealed that the prospective teachers developed their ability to examine definition and attributes of mathematical objects, connections among mathematical concepts and validity of an argument. However, they tend to focus on common posed problems because they are afraid of their inability to prove the answers to their problems posed. This finding suggests that overemphasizing the importance of providing a formal proof prevents the development of mathematical knowledge and problem solving skills.

Singer, Pelczer and Voica [33] explore different types of behavior during the problem posing process by looking at the ways students value the problem data in solving and extending their own posed problems. Based on the outcomes of these analyses they explained the differences in students' success and failure in the problem posing approaches in relation to the level of understanding the solution of a problem and the novelty of the posed problems. They noticed that the more the student advances in the abstract dimension of the problem and its context, the more mathematically relevant are the newly obtained versions. The abstraction level of the solution process determines the novelty of the newly posed problems and it seems to be a good predictor of the child's creative potential.

Georgiev and Nedyalkova [34] studied group creativity and development of mathematical problem posing and solving capabilities. The work treats the impact of problem posing and solving activities on development of group creativity in Secondary School Math Labs formed by students and teachers. The problem was studied analyzing problems posed and solved by different Labs for relatively longer period of few months. This action was compared with classical group Math competition, where the same students from the Labs solved problems for shorted period of few hours. The results show that the impact of problem posing and solving activities on development of group creativity can be manifested more effectively when students have less time restrictions.

Tan [35] conducted a study on the influence of problem posing and sense making on students' conceptual understanding, procedural knowledge, retention and anxiety towards mathematics. She concluded that problem posing and sense making was effective in enhancing students' conceptual knowledge and retention and not in procedural knowledge. Furthermore, she concluded that problem posing and sense making significantly reduced students' mathematics anxiety and they have a positive regard with problem posing and sense making.

## 4. METHODOLOGY

*Research Design*

The study utilized a mixed method of research which includes the quantitative quasi-experimental control group and qualitative design. The quantitative part of this study examined the effect of integrating pre-within-post problem posing activities in the work text in Differential Calculus. The extent of the significant difference of the performance of both the experimental and control groups was tested using the Pretest-Posttest Control Group Design.

*Research Setting*

The study was conducted at University of Science and Technology of Southern Philippines (USTP). USTP is a state university established on August 16, 2016 by virtue of Republic Act 10919 through the amalgamation of the Mindanao University of Science and Technology (MUST) in Cagayan de Oro City, Misamis Oriental and the Misamis Oriental State College of Agriculture and Technology (MOSCAT) in Claveria, Misamis Oriental. Both campuses are located in Northern Mindanao, the Gateway to Mindanao, which offers a strategic location advantage for the institution to train and develop students from all the other regions of Mindanao. USTP's mission is to bring the world of work (industry) into the actual higher education and training of students, offer entrepreneurial opportunities to maximize their business potentials through a gamut of services from product conceptualization to commercialization, and contribute significantly to the National Development Goals of food security and energy sufficiency through technology solutions. The university envisioned to become a nationally-recognized Science and Technology university providing the vital link between education and the economy. The University also has satellite campuses in Jasaan, Misamis Oriental, Panaon and Oroquieta, Misamis Occidental. The USTP-CDO campus has five colleges (College of Engineering and Architecture, College of Science and Mathematics, College of Technology, College of Information Technology and Computing and College of Science and Technology Education) offering courses which are aligned to the university mandate or mission, mostly on science, engineering and technology allied courses.

## 5. RESULTS AND FINDINGS

**Table 1. Two-way ANCOVA Unequal *n* Summary for Students' Creativity in Differential Calculus**

| Source | df | Sum of Squares (SS) | Mean Squares (MS) | F | p-value |
|---|---|---|---|---|---|
| Factor A | 1 | 704.46 | 704.46 | 40.54 | 0.000* |
| Factor B | 1 | 113.76 | 113.76 | 6.55 | 0.012* |
| Interaction Effect | 1 | 117.85 | 117.85 | 6.78 | 0.010* |
| Error | 127 | 2206.94 | 17.38 | | |
| Total | 130 | 3143.01 | | | |

*significant at 0.05 level

Table 1 above shows the result of analysis of covariance on students' level of creativity in Differential Calculus. For the type of participants, the analysis yielded an F-ratio of 40.54 and probability value of 0.000 which led to the rejection of the null hypothesis. This implies that the scores of mathematical creativity among BSEd-Mathematics and mixed engineering group of students are significantly different as indicated by the probability value less than 0.05. This implies that the BSEd-Mathematics students performed better compared to the mixed engineering students which suggests that the ability of the type of students have an influence on their mathematical creativity. It is worthy to note that the BSEd- Mathematics students have to possess better creativity because they will become teachers and they can share their ability when they will practice their profession. This implies that the type of students matters in training the skill of creativity. This means that the BSEd-Mathematics students with row mean of 30.76 is significantly higher than the mixed engineering students with a row mean of 24.56. The mathematics education group performed better because they are exposed to mathematics subjects which requires them to create solutions or prove mathematical statements which the engineering students did not experience. These mathematics subjects which the mathematics education majors have taken are Logic and Set Theory, Number Theory and Plane Geometry which requires them to make use of their higher order thinking skills especially on proving mathematical statements in these subjects which is lacking for the engineering students. The mixed engineering students enrolled in the special class have failed previously in their Differential Calculus class or they failed in their previous prerequisite subjects like College and Advanced Algebra, Plane and Spherical Trigonometry, Analytic Geometry and Solid Mensuration. The maturity level of the mathematics education students might also helped them performed better as compared to the engineering students. The mathematics education students take up Differential Calculus during their junior year while the engineering students take up Differential Calculus during their sophomore year. Considering that the engineering students have taken this subject twice, it may sound that their level of maturity is not as solid as compared to the mathematics education students which they are exposed to subjects which requires them to elicit critical analysis. The engineering students are exposed to mathematics subjects which are procedural in nature and might not very helpful in improving their mathematical creativity besides their exposure during the experiment period. This result supports Shriki [36], Leikin [17], Vale and Pimentel [16] and Leikin & Lev [20] findings that problem solving approaches and problem posing activities is an ideal way of fostering creativity among students.

Table 1 further shows that result of the analysis of covariance for the method of problem solving. The analysis yielded an F-ratio of 6.55 and a probability value of 0.012 which led to the rejection of the null hypothesis. This implies that the experimental group who underwent using the work text with all types of problem posing performed better than the control group who were exposed to Polya's problem solving heuristics with post problem posing activities. The control group also showed an increase as explained by the previous tables however the increase of 26.86 is lower than the experimental group with a mean of 28.77. Their exposure to Polya's problem solving and post problem posing activities helped them improve but not comparable to the experimental group. The creativity scores of both groups showed an increase but the experimental group benefited more because they are required to solve problem in many different ways which might be the reason why the experimental group showed a better performance in creativity test compared to the control group. As NCTM [27] pointed out that teachers need to make use of mathematically rich tasks that allows the introduction of mathematical concepts which enables them to use different approaches in solving challenging problems (Vale & Pimentel, [16] and Leikin (2009) considered Multiple Solutions Tasks (MST) test as an avenue to exhibit their mathematical creativity. In this way, students will be able to develop their mathematical creativity which is evident in the problem posing activities. Also, it can be noted that students' collaboration in the classroom also helped them improve their mathematical creativity because the teacher grouped the students and present their assignment problems as a springboard of the topic in the class. In this way, students in the experimental group improved in their creativity scores which supports Scribner, *et al.*, [37] which he expresses that collaboration is a secret key to creative breakthroughs.

Finally, the table further show the result of the analysis. The result revealed that there is interaction effect of the type of participants and the methods of problem solving on their creativity scores which yielded an F-ratio of 6.78 and a probability value of 0.010 which led to the rejection of the null hypothesis. This implies that the type of students who are mathematics education and mixed engineering group of participants and the treatment with all types of problem posing in the work text have mixed effect on the mathematical creativity of the students. This means that there are students in the BSEd-Mathematics who got high scores, some are low and some remain the same and also the same phenomena also may have happened to the scores of students in the experimental and control groups. This result may be due to the effect of giving problem posing to both groups. This affirms the ideas of Leikin [17], Yuan & Sriraman [5] and Kontorovich *et al.* [6] that creativity is an interplay between problem posing and problem solving and Polya's [38] noted that problem solving in mathematics class will be impoverished without augmenting with problem posing.

## 6. CONCLUSIONS AND RECOMMENDATIONS

Based on the findings, the researchers concluded that the use of pre-within-post problem posing is effective in improving students' level of mathematical creativity and recommended that mathematics teachers may use pre-within-post problem posing activities in teaching content subjects in mathematics to improve not only students' achievement but more so in their mathematical creativity. Also, teachers may regularly design activities in their mathematics classes which requires students' to posit novel solutions to problems in order to develop their creative potential and similar studies may be conducted to show the association between students' mental ability and level of mathematical creativity and how technology integration can effectively foster mathematical creativity and how students joining mathematics competition exhibit and develop their novelty of their solutions.

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