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Developing Students' Critical Thinking Skills in Mathematics Using Online-Process Oriented Guided Inquiry Learning (O-POGIL)

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Abstract Mathematics is an essential subject in the Philippines Department of Education (DepEd) K-12 curriculum that requires critical thinking abilities because it is crucial in everyday life along with the growth of other sciences. However, the majority of Filipino students had difficulty understanding mathematical concepts that require higher-order cognitive skills. As a result, students' mathematical process abilities, such as critical thinking, must be strengthened. This study aimed to develop students' critical thinking in mathematics in an online-POGIL environment. The study was conducted to second-year Early Childhood Education students of Pangantucan Bukidnon Community College during the first term of the academic year 2020-2021. It utilized a quasi-experimental Pretest-Post Test Control Group research design. A validated 6-item teacher-made test for critical thinking skills with a reliability coefficient of 0.752 was used to measure students' critical thinking performance with a rubric scale adapted from St. Petersburg College. Mean and standard deviation was used to evaluate students' pretest and posttest scores in the critical thinking skills test. A one-way analysis of covariance (ANCOVA) was used to analyze the significant effect of O-POGIL on students' critical thinking skills. The findings showed that O-POGIL motivates students to actively participate in activities and improves their learning. Furthermore, students exposed to O-POGIL showed a substantial improvement, demonstrated on communication, analysis, and problem-solving in mathematics. To improve students' critical thinking skills, it is advised to employ the O-POGIL teaching methodology and design resources based on the O-POGIL construct. Other 21st-century process skills that O-POGIL could build and enhance can be researched further.

Keywords: *guided inquiry learning, online-process oriented guided inquiry learning, Polya's problem solving, critical thinking skills in mathematics*

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1. Introduction

Mathematics is an indispensable subject of the Department of Education (DepEd) K-12 curriculum of the Philippines which necessitates the used of critical thinking skills and perceived as important in daily living as well as in the development of other sciences. However, studies in the context of Filipino student's, reveals that majority of students excel only in knowledge acquisition but considerably low in understanding concepts which requires the use of their higher-order thinking skills (HOTS). This poor mathematics performance is evident in local, regional, national, and even international comparisons such as the National Achievement Test (NAT), Third International Mathematics and Science Study (TIMSS) and even the recent Programme for International Student Assessment (PISA) results and among others. These comparisons showed that Filipino students are underachievers in Mathematics. Braza and Supapo claimed that the shortcomings that can affect students' achievements in Mathematics could be their lack of mastery of the basic concepts and skills, lack of problem solving and critical thinking skills, diverse behavior of students, and inappropriate teaching skills and approaches of teachers in dealing the students in the class of mathematics [1].

Critical thinking is applied and use daily, specifically in decision making, systematic reasoning, analyzing information, and even in communicating ideas. Strengthening one's independent learning ability is paramount to this process skill. Proficiency with this skill is vital in enhancing fundamental knowledge in different learning areas like mathematics. Thus, this skill is important to be developed in order to successfully learn mathematics. Developing students' critical thinking and problem-solving skills is an educational goal common to perhaps every academic program or discipline [2]. However, the above propositions and results show that students' critical thinking skill is low and/or poor due to several factors. Irwanto, Prodjosantoso,

Rohaete agree state that the low level of student's critical thinking skills was caused by lecturer-centered learning [3]. Moreover, students tended to be trained to respond to problems by memorizing [4] which is a traditional practice in teaching mathematics. As a result, students have difficulty in solving problems that need reasoning and analyzing which are generally a component of critical thinking. With these, it is undeniable that there should be a modification as to how teachers should teach mathematics in order to enhance student's critical thinking skills. Teachers in mathematics learning should facilitate students in developing critical thinking processes [5]. Developing critical thinking skills impacts educational fields, with education, not only providing information to the students but aiming to raise individuals who can think, examine and solve problems [6].

One of the breakthrough methods in teaching mathematics today is the inquiry-based learning approach. Inquiry-based learning is a teaching method that facilitates asking questions, seeking information and finding new ideas related to an event [7]. One model of inquiry-based learning is the Process Oriented Guided Inquiry Learning (POGIL). It is a student-centered instructional strategy developed by chemical educators [8] for use in chemistry class [9]. POGIL is a collaborative learning technique that employs guided inquiry within a cyclic system of exploration, concept invention, and application [10]. This means that students under the POGIL method develop conceptual understanding collaboratively [8]. Additionally, in POGIL, students will conduct the activity themselves and teachers act as a guide to help them if needed [11]. POGIL shows a promising result on student's critical thinking skills. As a strategy, it would enhance students' problem-solving skills and critical thinking skills as ultimately evidenced by students' improved performance [2]. However, previous researches show that there remains a gap as to how the POGIL method is not used to promote critical thinking skills; and although these skills have been developed in the previous decades, nevertheless the students' performance needs to be improved satisfying level continuously [3]. Another teaching methodology which mathematics teachers can utilize to develop students' critical thinking skill effectively is POLYA's Problem Solving Method. As one of the fundamental goals of teaching mathematics, problem-solving has been pushed to be the central focus of the school mathematics curriculum. Solving a problem can be used to stimulate the skills of high-order thinking skills [12]. Thus, the application of problem-solving necessitates one to think critically and creatively and it is a systematic process [13]. In addition, problem-solving is about how to learn independently [14]. Polya's Problem Solving Method follows four stages; Understanding the Problem, Devising a Plan, Carrying out the Plan, and Looking back [15]. This process helps the students to easily define the problem and create a bigger picture of the problem leading them to formulate and apply appropriate methods to solve the problem and check the solution. This methodology along with its positive effect on students' critical thinking skills makes it an ideal approach in teaching mathematics. However, in reality, many students are still struggling to solve mathematical problems [16]. The effect of this is that students were found to be deficient in cognitive and critical thinking skills when they are faced with situations where they are expected to apply what they have learned to solve the specific problems [17].

Today, technological breakthroughs change many aspects of human endeavor. As the world experience a rapid shift to a "new normal" due to COVID-19, this global pandemic opted many educational institutions and researchers both local and international to utilize technological innovation to maintain student learning and progress. This paved way for educators to analyze innovative approaches and implement appropriate methods that will actively engage students towards learning and acquiring 21st-century skills even amidst the threat of COVID-19. Concomitant to this, during this "new normal", mathematics teachers teach students in order for the latter to acquire essential information and develop academically while actively strengthening their critical thinking and problem-solving skills. Hence, this scenario also prompted the researcher to shift to investigate the effect of POGIL on students' critical thinking in mathematics in an online setting.

2. Literature Review

Studies and researches that support the current study are considered as regards to guided-inquiry learning, POGIL, O-POGIL, critical thinking skills in mathematics of students.

Teachers nowadays, resort to the advantages of digital learning or online learning method to improve students' motivation. In the study conducted by Ichinose Bonsangue on their study on students' mathematical self-related beliefs in an online mathematics course, they confirmed the link between success in an online learning environment and students' beliefs in and motivation to achieve in an online environment for some, but not all, students [18]. Through instruction and content support, they suggested that online teachers and instructional designers must continue to create and implement experiences that will foster student beliefs and motivation that can accommodate students' collective as well as individual experiences. With the use of 21st-century learning technologies, college instructors can create settings that promote challenging mathematics in a safe online learning environment [19].

Online learning considerably supports access and provides opportunities not contained in the four corners of the classroom. The study of Ahn & Edwin introduced a mathematical e-learning model suitable for the modern digital era based on the learning theories of social constructivism, social realism, and connectivity. They proposed a mathematical e-learning model MCIEC (motivation, context, interactivity, evaluation, and connectivity), for making mathematical learning more interesting, meaningful, and applicable to the learners beyond the classroom knowledge. They argued that the teaching of mathematics beyond the primary level in most developing countries like the Philippines mainly emphasizes preparing students for high-stake national exams rather than linking the content to real-life problem-solving skills. To overcome these challenges, the MCIEC model emphasizes a flexible approach to teaching

mathematics in which motivation, context, and dynamic evaluation are the backbone of any content design or delivery. The model places greater responsibility on the teachers to be more innovative and create materials that suit the learners' abilities and environment. It is easier for the student to put in much effort to understand the mathematics in the content once the interest, motivation, and context have been attained [20].

Researches on the effectiveness of Inquiry-Based Learning have been widely conducted as a factor in improving students' learning performance. Ali Abdi studied the effect of the Inquiry-Based Learning method (specifically the 5E learning method) on students' academic performance in Science courses. It was a quasi-experimental study with non-equivalent groups, which includes a pretest and posttest design with the control group. The study was conducted with 20 experimental and 20 control group girl students which utilized am Academic Achievement Test to both groups. The study concluded that there is a significant difference between the achievement of the students who have been educated by the inquiry-based instruction-supported 5E learning method and the students who have been educated by the traditional teaching methods. It then follows that the students who have been educated by the inquiry-based instruction supported 5E learning method have become more successful than the students who have been educated by the traditional teaching method [21]. Moreover, Stender, Schwichow, Zimmerman, & Härtig findings provide evidence that students can indeed learn new content knowledge by using inquiry skills to answer research questions [22].

Rosadi, Sunarno & Maridi investigates the effectiveness of Process Oriented Guided Inquiry Learning to improve students' analytical thinking skills on excretory topics. The subjects of the research were 60 11th grade students that were chosen by Simple Random Sampling. Moreover, the students' analytical thinking skills were measured by a test instrument consisting of 30 multiple-choice questions. The study concluded that the developed POGIL method is effective to be used in teaching and learning to improve the students' analytical thinking skills [23].

The innovative teaching strategy is also a major factor in the study of Andrianni et al., in a study about the effect of the POGIL model on students' logical thinking ability in mathematics. T-Test was used to investigate the effect of the independent variable towards the dependent variable which results stated that the students' logical thinking ability who obtained POGIL is better than students' logical thinking ability who obtained conventional learning model [24]. In addition, Sen stated that POGIL has a positive effect on students' alternative conception. Thus, the students taught in the POGIL method had less misconception than those students who were taught using the conventional learning model [25].

Another literature stated a positive impact of POGIL in the context of education. Soltis et al. conducted a study about enhancing students' higher-level thinking skills in a pharmaceutical sciences course through the implementation of POGIL. It founds out that the use of the POGIL strategy had an overall positive effect on student learning and the classroom environment. Furthermore, it has been stated that students' critical thinking skills and problem solving were improved with the use of the POGIL strategy [2].

Irwanto, Saputro, Rohaeti, & Prodjosantoso, conducted a study in promoting critical thinking and problem-solving skills of 48 pre-service elementary teachers through Process Oriented Guided Inquiry Learning. The research consists of the Critical Thinking Essay Test (CTET) consisting of 5 items and the Problem Solving Essay Test (PSET) consisting of 4 items. The research used non-parametric statistics for quantitative data analysis, descriptive were used to describe the characteristics of the participants, Mann-Whitney U-Test and Spearman's rho correlation was performed to explore the correlation between the dependent variables. The study emphasized that the POGIL method is more effective in improving students' critical thinking and problem-solving skills. Additionally, the researchers, claimed that the high score of the experimental group students is related to course activities designed to teach content and engage students in analyzing data, discussing ideas, making a conclusion, and building their own knowledge through teamwork in accordance with the inquiry approach principles [3].

However, a study by Douglas & Chiu argued and identified that students did not recognize the benefits of working in groups, such as promoting critical thinking, learning cooperative skills, gaining a different perspective, and retaining content knowledge. This statement could further denote that POGIL, as a group-based strategy, may not promote critical thinking skills and problem-solving skills [26].

The research aims to describe the level of students' creative thinking skill in solving problems of mathematics Olympics based on the problem-solving Polya and Krulik-Rudnick model. This descriptive research employed a qualitative approach. The research participants were 27 students at State Junior High School (SMPN) on 2 Jember involving the guidance of Olympiad mathematics in the academic year 2017-2018. The data were analyzed by using the Miles and Huberman model. The findings indicated that the level of students' thinking skills based on the stages of the problem-solving model of Polya was in the category "sufficient creative. In addition, the research results indicated that the problem-solving stage of the Polya model was not always suitable to be used to solve all types of mathematics Olympiad problems. Indeed, there are advantages and disadvantages to each of them. Problem-solving Polya models are well suited to the problems of the type matter of routine while solving the Krulik-Rudnick model was more suitable for problems whose type was non-routine, but when all the students were using the stages of solving the model Krulik-Rudnick, there were still shortcomings experienced by students, namely how to find the idealized early when faced with-math Olympiad problems [27].

As per a review of the studies cited, the researcher decided to do further work on extending the POGIL approach in an online setting in improving critical thinking skills in mathematics as Ichinose Bonsangue & Ahn & Edwin suggested and emphasized to create setting that will encourage learning engagement and motivation. Ali Abdi, & Stender, Schwichow, Zimmerman, & Härtig iterated the learning success of students exposed to inquiry-based learning. Rosadi, Sunarno & Maridi,

Andrianni et al., Sen Andrianni et al., & Soltis et al., stated the positive effect of POGIL in higher-order thinking abilities of students. Moreover, Irwanto, Saputro, Rohaeti, & Prodjosantoso claimed that POGIL is effective in improving students' critical thinking skills. However, none of these researchers studied the effect of POGIL applied in an online setting. Douglas & Chiu also identified that POGIL may not promote critical thinking skills. This became an illuminating factor for the researcher to conduct a study on Online-POGIL and its effect on students' critical thinking skills.

3. Methods

This study employed a quasi-experimental Pretest-Post Test Control Group design. Mean and standard deviation was used to evaluate the pretest and posttest scores of students in the critical thinking skill test and a one-way ANCOVA was used to account for the variation and significant effect of O-POGIL on students' critical thinking skills.

The respondents were second-year Bachelor in Early Childhood Education students of Pangantucan Bukidnon Community College. A total of 64 students participated in the study. These students are taking Mathematics in the Modern World course for the 1st semester of the S.Y. 2020-2021. The respondents were randomly assigned as control and experimental group. The control group was exposed to Online Problem Solving Method while the latter was exposed to Online Process Oriented Guided Inquiry Learning (O-POGIL).

A 6-item teacher-made test for mathematics critical thinking questionnaire was utilized in this study. This 6-item critical thinking skills test aimed to assess students' critical thinking skills which follow students' ability to highlight the primary idea or problem and support it with several details using inductive and deductive reasoning that is organized logically and coherently. The instrument also measures students' ability to identify key aspects of the problem using relevant evidence and logically supports viable solutions. In addition, the test was analyzed and undergone a reliability test for which it obtained a reliability coefficient of 0.752. The Assessment Rubric for Critical Thinking Skill designed by St. Petersburg College was adapted to rate students' critical thinking skills. The said rubric features 3 levels of critical thinking constructs with 5 levels of mastery or rating scale were used to score students' pretest and posttest.

During the first day of the conduct of the study, the researcher conducted a pretest for both groups. It was followed by an orientation about the functions and applications of features of the ZOOM Meeting App. Moreover, students in both the control and experimental group were divided into subgroups with 4 members each having a distinct role; leader, writer, timer, and presenter. Both groups had a twice a week 90-minutes online session via ZOOM. Each online session was divided into two parts; the group online exploration phase and the virtual reporting of the groups' output.

The experimental group was exposed to Online Process Oriented Guided Inquiry Learning (O-POGIL). Students were oriented of their functions and roles to their respective groups and the teacher was the facilitator. There was a brief introduction of POGIL materials and activities which was followed by the designation of students to their respective breakout rooms. POGIL activities followed three learning cycles: exploration phase, concept invention phase, application phase. After the activity, all students rejoined the main meeting portal where each group presented their output. After the presentation, the researcher encouraged students from the other groups to ask questions to address and clarify any misconceptions. In addition, in order to maximize interaction, constructive feedback was also given by the researcher, and students were asked to give some insights into the things that they had learned and acquired after the presentation.

For the control group, Online Problem Solving Method was employed. At the start of every online session, students were oriented of their functions and roles to their respective groups and the teacher was the facilitator. There was an introduction to the topics and activities. Examples about the topics were given to each group for their references. It was then followed by the designation of students to their respective breakout rooms. The students were given worksheets and were tasked to work out more problems. The online Problem Solving Method strategy followed Polya's Four-Step Problem Solving Procedure. The first step was to understand the problem, devise a plan, carry out the plan and lastly look back. It was then followed by a presentation of the group's outputs. Students were also encouraged to ask questions to address and clarify any misconceptions. Constructive feedback was also given at the end. This modality was used throughout the 8-weeks duration of the conduct of the study. A posttest was administered at the end of the experimental period.

The performance of the students in the pretest and the posttest critical thinking skill test in Mathematics in the Modern World Course were evaluated and described in terms of mean and standard deviation. The variation, as well as the significant effect of O-POGIL in the critical thinking skills of students, were measured and determined by one-way analysis of covariance (ANCOVA). In testing the hypotheses, alpha is set at a 0.05 level of significance.

4. Results and Findings

The results of this study were presented in the following tables:

Table 1. Mean and Standard Deviation of Students' Critical Thinking Skill in Mathematics

Groups	N	Pretest		Post Test	
		Mean	SD	Mean	SD
NON-OPOGIL	31	15.452	3.641	33.87	5.91
O-POGIL	33	14.788	3.361	37.59	6.89

Perfect Score: 39

Mean Score	*Descriptive Level*
35.01-39	Excellent
33.15-35	Very Satisfactory
31.2-33.14	Satisfactory
27.3-31.1	Average
23.79-27.29	Below Average
23.4	Fair
Below 23.4	Did not meet Expectation

Table 1 shows the mean and standard deviation of the pretest and posttest results in their mathematics critical thinking abilities test for both the control and experimental groups. The overall pretest mean score for the Non-OPOGIL and O-POGIL groups was 15.452 and 14.788, respectively, indicating that their pretest results were at the "Did not meet expectation level". It's also worth noting that Non-OPOGIL scored 0.664 points higher than O-POGIL. This suggests that prior to the investigation, the degree of critical thinking skills among students in both groups was relative and so comparable. Furthermore, the standard deviation of O-POGIL is smaller than that of Non-OPOGIL, indicating that O-POGIL students' results are closer to the mean, whereas Non-OPOGIL students' scores have a larger dispersion.

On the posttest, both Non-OPOGIL and O-POGIL received "Did not reach expectation level." Although both groups' scores were still at the "Did not meet expectation level," there was a significant improvement, with O-POGIL scoring 3.72 points better than Non-OPOGIL. This implies that O-POGIL students demonstrated skill in identifying a concept or problem with some supporting details and using logic to make inferences. This is due to the various information-gathering techniques that O-POGIL provides during the exploration and concept invention stages. This allows students to explore and discuss several ways to solve the problem, as well as collaborate to arrive at a final solution.

Table 2. One Way ANCOVA Summary of the Students' Critical Thinking Skills

Source	Df	Adj SS	AdjMs	F-Value	p-Value
Treatment Within	1	248.38	248.38	7.24	0.009*
Error	61	2092.67	34.31		
Total	62	2341.05			

*significant at p<0.05 alpha level.

Table 2 shows that there was a significant difference in the posttest scores in the critical thinking skills between Non-OPOGIL and O-POGIL as indicated by the F-ratio of 7.24 and p-value of 0.009 which led to the rejection of the null hypothesis. Based on the result, O-POGIL had helped students improved their critical thinking skills and subsequently increased their scores.

The problem-solving nature of O-POGIL helped students to develop independent process skills, giving them the opportunity to learn varied ways and even alternative methods of solving problems. It further allows students to deepen their conceptual understanding and strengthen their analytical skills. O-POGIL promotes a good impact on student's cognitive abilities, particularly in the areas of communicating and analyzing. Through controlled group learning, students were directed to use their previously learned mathematical understanding to develop their own knowledge through O-POGIL. It has also created an opportunity for debate as students work together to identify the core idea or problem and provide supporting facts from their conceptual understanding to support their problem-solving approach. This encourages students to think and speak mathematically leading them to draw precise conclusions. Furthermore, they were able to compare and contrast available solutions during the concept invention phase. With these, students were able to support their answers with coherent and constructive reasoning.

The result shows that the use of OPOGIL significantly improves students' critical thinking skills is similar to the result of Rosadi, Sunarno & Maridi who concluded that the developed POGIL method is effective to be used in teaching and learning to improve the students' analytical thinking skills[23]. Soltis et al. also stated that students' critical thinking skills and problem solving were improved with the use of the POGIL strategy [2]. This is also similar to the results of Irwanto, Saputro, Rohaeti, & Prodjosantoso, who emphasized that the POGIL method is more effective in improving students' critical thinking and problem-solving skills [3].

5. Concluding Statements

Based on the analysis and findings of the study, O-POGIL actively engages students in activities that develop their critical thinking skills in mathematics. It enables students to develop their process skills by giving them the opportunity to construct their own understanding while learning and discussing varied ways to solve the problem leading them to provide coherent reasoning to support their answer. Improving critical thinking skills necessitates this process of communication, evaluation, and problem-solving. To improve students' critical thinking skills in mathematics, the researchers advocate using the O-POGIL teaching method and developing resources based on the O-POGIL construct. Analyzing O-POGIL in a more controlled online environment where the facilitator can observe students' progress synchronously may also yield data to deeply understand O-POGIL's effect on students thinking ability in mathematics. There may also be an illuminating area for further research through the utilization of e-learning materials and software that keeps students engaged and motivated.

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