Utilizing Socratic Teaching to Improve Problem-Solving Skills in Pre-Calculus

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Abstract

Problem-solving skills are essential in STEM education as they are cornerstone of success in these fields. Students in STEM disciplines are expected to do more than memorize facts; they must apply mathematical principles to address real-world challenges, analyze complex issues, and integrate information to devise innovative solutions. Lacking strong problem-solving abilities can make it tough for students to maneuver through the complex landscape of mathematics within STEM subjects. To address these challenges, the researcher embarked on a study with the objective of improving the problem-solving skills of STEM 11 students in the specialized subject Pre-Calculus by utilizing Socratic Teaching Method. Socratic Teaching Method is acknowledged as an effective educational strategy for promoting critical thinking and problem-solving skills in students.

This study employed a quasi-experimental research design, incorporating a pre-test and post-test format across four iterations for both the control and experimental groups. The collected data was meticulously processed, organized, tabulated, analyzed, and interpreted using relevant statistical tools.

According to the results, there is no significant difference in the pre-test scores between the control group and experimental group. However, a significant difference was observed in the post-test scores, with the experimental group obtaining higher scores.

Based on the findings, the researcher has made recommendations regarding the efficacy of Socratic Teaching as an intervention for enhancing problem-solving skills that should be integrated into mathematics classrooms.

Keywords: Socratic Teaching, Problem-Solving Skills, Pre-Calculus, STEM Education

Introduction

Within the evolving realm of modern education, there is a progressively growing emphasis placed on fostering critical thinking and problem-solving abilities, particularly within the STEM (Science, Technology, Engineering, and Mathematics) disciplines. These skills are not only essential for academic success but also serve as the cornerstone of future careers in fields such as engineering, computer science, and physics (Şahïn, 2021). Therefore, it is imperative to nurture and enhance these skills during the formative years of education.

President Marcos' call to intensify and catch up with the demands of the STEM strand adds a sense of urgency to the need for innovative pedagogical approaches. The future of the nation's progress in science, technology, engineering, and mathematics hinges on the abilities nurtured during the formative years of education (Soriano, 2022). The STEM strand, a cornerstone of this vision, is expected to produce a workforce equipped not only with theoretical knowledge but also with robust problem-solving skills essential for addressing complex challenges in various scientific and technical domains (Sen et. al., 2018).

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Furthermore, it is crucial to acknowledge that not all students in the STEM strand will choose to pursue engineering or other math-related courses; some may decide to go into medical or other science-related fields. Consequently, it becomes paramount to establish an inclusive educational setting that accommodates a wide range of aspirations and inclinations. Hence, the need arises for a strategic intervention, akin to the Socratic teaching method, that empowers students inclined towards mathematics to grasp the intricacies of their subjects. This method encourages active engagement and deep understanding, transcending the boundaries of traditional teaching methodologies (Saha et al., 2020). Moreover, it aligns with the differentiated needs of students, ensuring that those with an affinity for math can excel while fostering an appreciation for problem-solving among others.

Upon closer inspection of the Pre-Calculus classes at Talisay Senior High School, located in Tumaway, Talisay, Batangas, within the specialized STEM Strand, reveals that students often face significant hurdles when it comes to problem-solving. This course serves as a critical bridge between fundamental mathematics and advanced calculus, acting as a foundation for higher-level mathematical and scientific study. Consequently, students in this strand are expected to develop strong problem-solving skills as they navigate complex mathematical concepts.

However, these expectations can sometimes overwhelm students, leading to frustration and a lack of motivation (Saadati & Celis, 2022). The intricacies of advanced mathematical topics can pose a significant challenge, and students may struggle to effectively break down and solve complex problems. In some cases, this struggle can deter them from pursuing STEM-related fields in the future.

To address these challenges, Socratic Teaching emerges as a promising pedagogical approach. Rooted in the philosophical methods of Socrates, Socratic Teaching is characterized using open-ended and probing questions to stimulate critical thinking, inquiry, and active student engagement (Grondin, 2018). This approach encourages students to explore concepts deeply, develop their own understanding, and engage in thoughtful dialogue with both peers and teachers. Moreover, it was also observed in their study that Socratic Teaching has shown significant promise in fostering problem-solving skills and critical thinking in various educational contexts. Through utilizing this method, educators can establish an atmosphere that fosters not only the transmission of knowledge but also the development of critical thinking skills, which are essential for proficient problem-solving.

One study conducted by Palavan (2020) examined the impact of Socratic questioning on the enhancement of critical thinking and problem-solving skills in mathematics education. The study involved university-level mathematics students who participated in Socratic questioning sessions as part of their coursework. The results indicated significant improvements in both critical thinking and problem-solving abilities among the students. They reported that Socratic questioning encouraged them to think more deeply about mathematical concepts and facilitated their ability to solve complex problems.

In another study by Sahamid (2016), the researcher investigated the efficacy of Socratic questioning in improving students' problem-solving skills in a pre-calculus course. The study found that students who participated in Socratic questioning sessions demonstrated more significant enhancements in their problem-solving skills in comparison to those who received traditional instruction. The researcher concluded that

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Socratic questioning promoted active engagement, critical thinking, and deeper understanding of concepts, all of which are essential for effective problem-solving.

Considering the importance of problem-solving skills in STEM education, the challenges faced by students in Pre-Calculus classes, and the potential of Socratic Teaching as an intervention, action research becomes a valuable framework for exploration. Action research is a powerful approach that combines research and practical application within an educational setting (Manfra, 2019). It allows educators to investigate the effectiveness of pedagogical strategies and interventions in real-world classrooms.

In addition to the studies mentioned earlier, there exists a substantial body of research that validates the effectiveness of Socratic Teaching to improve problem-solving skills in mathematics and pre-calculus. For instance, a study by Oyler & Romanelli (2014) delved into the effectiveness of Socratic questioning in promoting problem-solving abilities in various contexts. The researchers found that Socratic questioning not only encouraged students to think critically but also helped them develop a deeper understanding of the underlying concepts. This deep understanding, in turn, facilitated more effective problem-solving. Furthermore, a study by Alsaleh (2020) explored the impact of Socratic teaching methods on problem-solving skills in higher education. While the study encompassed a broader range of subjects, the results indicated that Socratic teaching promoted critical thinking and improved students' ability to analyze and solve complex problems across various disciplines.

Hence, this action research project is grounded in the pressing need to enhance problem-solving skills within the specialized Pre-Calculus classes at Talisay Senior High School in the STEM Strand. The importance of problem-solving skills in STEM education, the challenges faced by students, and the potential of Socratic Teaching as an intervention emphasize the significance of this research endeavor. By engaging in thorough investigation and practical implementation, this research endeavor aimed to make a substantial contribution towards the development and implementation of highly efficient pedagogical methods in the field of mathematics education, aiming to ultimately provide valuable advantages to students as they equip themselves for their prospective pursuits in the STEM field.

Methodology

Research Design

The study employed the quasi-experimental research design to establish causal relationships between the independent variable (Socratic teaching) and dependent variable (problem-solving skills) and investigate the effects (if any) of Socratic teaching to improve students' problem-solving skills in Pre-Calculus.

Within a quasi-experimental research design, data is gathered both before and after the implementation of the independent variable. The initial data, or pre-test acts as a baseline which enables the measurement of changes over time, known as the post-test. This particular methodology aids in a more precise assessment of the impact of the independent variable.

The researcher used descriptive statistics such as Frequency and Percentage and Mean of Grouped Data to quantify the scores and levels of problem-solving skills of the STEM students. In addition, the study also employed inferential statistics, specifically the two-sample t-test, to ascertain the presence of statistically significant distinction between the means in two distinct groups.

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Research Locale

The research was carried out at Talisay Senior High School in Tumaway, Talisay, Batangas. The study focused on the population of all STEM 11 students who are currently enrolled in the school and taking Pre-Calculus classes. This selection of locale and population was deliberate to maintain a concentrated and precise sample that correlated with the research goal.

Research Participants

1. STEM 11 Newton (Control Group) – This group of 29 students received traditional lecture-based instruction in Pre-Calculus. They served as the control group against which the effectiveness of Socratic Teaching in the experimental group was compared in the experimental group.

2. STEM 11 Einstein (Experimental Group) – This group of 27 students from the STEM 11 Einstein section participated in Socratic Teaching sessions as the experimental group. These students received the intervention designed to enhance their problem-solving skills in Pre-Calculus.

Intervention

During the implementation of Socratic Teaching, the process was divided into four (4) organized iterations, with each one centered on a different pre-calculus concept. The initial iteration focused on circles and involved finding the center and radius. The second iteration was dedicated to understanding the standard and general forms of a parabola's equation. The third iteration revolved around ellipses and emphasized the application of this concept in planetary motion. Finally, the fourth iteration focused on hyperbolas and problem-solving related to them.

Questioning Techniques

The heart of Socratic Teaching lies in the art of questioning. Open-ended and probing questions were strategically incorporated into each lesson plan. For example, during discussions on circles, students might be prompted to ponder, "What are the uses of circles in real life and what are their varied features?" Similarly, questions like "How does a parabola manifest its shape in satellite dishes?" will encourage exploration of parabola. Questions regarding ellipses and hyperbolas were tailored to the specific topics under study.

Classroom Discussions

Classroom discussions served as the centerpiece of the Socratic Teaching approach. These discussions provided a platform for students to share their thought processes, engaged in peer-to-peer learning, and collectively analyze problem-solving strategies. Within this collaborative environment, students were encouraged to voice their ideas, question each other's assumptions, and explore different approaches to problem-solving.

Problem-Solving Scenarios

Real-world problem-solving scenarios were presented to students, aligned with the Pre-Calculus topics under study. Through Socratic questioning, students were guided in breaking down complex problems

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into manageable steps, fostering a deeper understanding of the mathematical concepts involved. For example, they analyzed circles in real-world scenarios from the tip of the pen to the shapes of the planets and explored parabola and its application to automobile headlight reflectors and design of ballistic missiles.

Reflection and Feedback

The Socratic Teaching approach places a premium on reflection. Students were encouraged to reflect on their problem-solving approaches, both individually and in groups. Additionally, they received constructive feedback not only from the teacher but also from their peers, promoting continuous improvement in their problem-solving skills.

Data Gathering Method

Prior to the start of the intervention, both the control and experimental groups took a pre-test assessment. The assessment consisted of a series of mathematical problems that assessed their problem-solving skills in the context of Pre-Calculus topics. The pre-test served as a baseline measurement of the students' initial problem-solving abilities.

Following the pre-test, the control group (STEM-Newton) received traditional lecture-based instruction in Pre-Calculus. This instruction followed the school's existing curriculum and teaching methods. While the experimental group (STEM-Einstein) participated in a series of Socratic Teaching sessions. These sessions incorporated open-ended and probing questions to stimulate critical thinking and problem-solving skills among the students. Classroom discussions encouraged active engagement and exploration of mathematical concepts.

After the traditional lecture (for the control group) and discussion with Socratic Teaching sessions (for the experimental group), both groups took a post-test assessment. This post-test was similar in content and format to the pre-test and evaluated the problem-solving skills of the students after the instructional interventions. The scores gained by the participants were statistically analyzed through Frequency and Percentage, Mean of Grouped Data and Two-Sample t-test.

For the pre-test and post-test assessments, a standardized questionnaire consisting of mathematical problems that require critical thinking and problem-solving was administered. The questionnaire was aligned with the Pre-Calculus curriculum and was designed to measure the specific skills relevant to the research questions.

The assessments included complex problem-solving items. These items were carefully crafted to assess the students' ability to analyze, synthesize, and apply mathematical principles, which are essential for effective problem-solving in Pre-Calculus.

Results and Discussions

This section presents the data collected along with the corresponding analysis and interpretation. The data is presented in a tabular format that is organized sequentially, following the order in which specific problems were introduced at the outset of the study.

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Table 1	Level of Problem-Solving Skills of Grade 11 Newton (Control Group) in Pre-Calculus in Pre-Test and Post-Test for Iteration 1				
	Pre-Test		Post-Test		
Score Range (20-item test)	Frequency	Percentage	Frequency	Percentage	Level of Problem-Solving Skills
16-20	1	3.448	8	27.586	EXCELLENT
11-15	6	20.690	7	24.138	VERY SATISFACTORY
6-10	8	27.586	10	34.483	SATISFACTORY
5 and below	14	48.276	4	13.793	NEED IMPROVEMENT
TOTAL	29	100	29	100	
MEAN	**7.14**		**11.17**		

According to Table 1, a significant proportion of the students, specifically fourteen (14) or 48.276 percent, achieved scores of 5 or below in the pre-test. It can be inferred, overall, that the problem-solving skills of the students needed improvement. Conversely, according to the data presented in table 2, a significant portion of the students achieved satisfactory scores in the post-test, accounting for ten (10) or 34.483 percent of the total.

Table 2	Level of Problem-Solving Skills of Grade 11 Newton (Control Group) in Pre-Calculus in Pre-Test and Post-Test for Iteration 2				
	Pre-Test		Post-Test		
Score Range (20-item test)	Frequency	Percentage	Frequency	Percentage	Level of Problem-Solving Skills
16-20	0	-	6	20.690	EXCELLENT
11-15	4	13.793	12	41.379	VERY SATISFACTORY
6-10	7	24.138	10	34.483	SATISFACTORY
5 and below	18	62.069	1	3.448	NEED IMPROVEMENT
TOTAL	29	100	29	100	
MEAN	**5.69**		**11.90**		

As observed in Table 2, it is evident that most students needed improvement in their problem-solving skills, specifically accounting for eighteen (18) or 62.069 percent. The post-test results, however, indicated that a significant proportion of students, specifically twelve (12) or 41.379 percent, attained a very satisfactory level of problem-solving skills.

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Table 3	Level of Problem-Solving Skills of Grade 11 Newton (Control Group) in Pre-Calculus in Pre-Test and Post-Test for Iteration 3				
	Pre-Test		Post-Test		
Score Range (20-item test)	Frequency	Percentage	Frequency	Percentage	Level of Problem-Solving Skills
16-20	1	3.448	8	27.586	EXCELLENT
11-15	4	13.793	12	41.379	VERY SATISFACTORY
6-10	7	24.138	6	20.690	SATISFACTORY
5 and below	17	58.621	3	10.345	NEED IMPROVEMENT
TOTAL	29	100	29	100	
MEAN	**6.14**		**12.10**		

As seen in Table 3, it is evident that seventeen (17) students, equivalent to 58.621 percent, scored 5 or below on the pre-test. This indicates a clear need for improvement in problem-solving skills. In contrast, in the post-test, a significant number of students, precisely twelve (12) or 41.379 percent, obtained scores that were considered very satisfactory.

Table 4	Level of Problem-Solving Skills of Grade 11 Newton (Control Group) in Pre-Calculus in Pre-Test and Post-Test for Iteration 4				
	Pre-Test		Post-Test		
Score Range (20-item test)	Frequency	Percentage	Frequency	Percentage	Level of Problem-Solving Skills
16-20	1	3.448	1	3.448	EXCELLENT
11-15	3	10.345	8	27.586	VERY SATISFACTORY
6-10	7	24.138	18	62.069	SATISFACTORY
5 and below	18	62.069	2	6.897	NEED IMPROVEMENT
TOTAL	29	100	29	100	
MEAN	**5.43**		**10.76**		

It is apparent from Table p4 that most of the students, specifically eighteen (18) or 62.069 percent, require improvement in problem-solving skills. Regarding the results of the post-test, the majority, specifically eighteen (18) or 62.069 percent achieved a satisfactory level of problem-solving skills.

In summarizing the results of both the pre-test and post-test of the control group across four (4) iterations, as depicted in Table 5, it can be inferred that there has been a notable enhancement in the problem-solving skills of the students after the discussion of each topic utilizing a traditional approach.

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Table 5	Summary of Mean of the Pre-Test and Post-Test Results of STEM 11 Newton (Control Group)	
Iteration	**Mean**	
	Pre-Test	**Post-Test**
1	7.14	11.17
2	5.69	11.90
3	6.14	12.10
4	5.43	10.76

Table 6	Level of Problem-Solving Skills of Grade 11 Einstein (Experimental Group) in Pre-Calculus in Pre-Test and Post-Test for Iteration 1				
	Pre-Test		**Post-Test**		
Score Range (20-item test)	**Frequency**	**Percentage**	**Frequency**	**Percentage**	**Level of Problem-Solving Skills**
16-20	1	3.704	10	37.037	EXCELLENT
11-15	6	22.222	15	55.556	VERY SATISFACTORY
6-10	7	25.926	2	7.407	SATISFACTORY
5 and below	13	48.148	0	-	NEED IMPROVEMENT
TOTAL	27	100	27	100	
MEAN	**7.04**		**15.04**		

The pre-test results in Table 6 show that a significant majority, accounting for thirteen (13) or 48.148 percent of students, require improvement in their problem-solving skills. Conversely, according to the post-test results presented in Table 7, most students demonstrated a high level of problem-solving skills. Fifteen (15) students, equivalent to 55.556 percent, achieved a very satisfactory level.

It can be gleaned from Table 7 that most of the students, precisely sixteen (16) or 59.259 percent, have a need to improve their problem-solving skills. In contrast, based on the post-test results, the majority obtained scores ranging from 11 to 15, representing sixteen (16) or 59.259 percent of the students.

According to Table 8, it was observed that 55.556 percent, or fifteen (15) students, required improvement in their problem-solving skills based on the pre-test results. Conversely, in the post-test, most of the students, specifically twelve (12) or 44.444 percent, demonstrated excellent problem-solving skills.

As indicated in Table 9, a majority, comprising 59.259 percent, equivalent to sixteen (16) students, attained scores of 5 or below in the pre-test, highlighting the necessity for enhancement in their problem-solving skills. In contrast, in the post-test results, a majority of 40.741 percent corresponding to eleven (11) students, exhibited a very satisfactory level of problem-solving skills.

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Table 7 Level of Problem-Solving Skills of Grade 11 Einstein (Experimental Group) in Pre-Calculus in Pre-Test and Post-Test for Iteration 2

	Pre-Test		Post-Test		
Score Range (20-item test)	**Frequency**	**Percentage**	**Frequency**	**Percentage**	**Level of Problem-Solving Skills**
16-20	0	-	10	37.037	EXCELLENT
11-15	4	14.815	16	59.259	VERY SATISFACTORY
6-10	7	25.926	1	3.704	SATISFACTORY
5 and below	16	59.259	0	-	NEED IMPROVEMENT
TOTAL	27	100	27	100	
MEAN	**5.93**		**15.33**		

Table 8 Level of Problem-Solving Skills of Grade 11 Einstein (Experimental Group) in Pre-Calculus in Pre-Test and Post-Test for Iteration 3

	Pre-Test		Post-Test		
Score Range (20-item test)	**Frequency**	**Percentage**	**Frequency**	**Percentage**	**Level of Problem-Solving Skills**
16-20	1	3.704	12	44.444	EXCELLENT
11-15	4	14.815	10	37.037	VERY SATISFACTORY
6-10	7	25.926	4	14.815	SATISFACTORY
5 and below	15	55.556	1	3.704	NEED IMPROVEMENT
TOTAL	27	100	27	100	
MEAN	**6.78**		**14.89**		

Table 9 Level of Problem-Solving Skills of Grade 11 Einstein (Experimental Group) in Pre-Calculus in Pre-Test and Post-Test for Iteration 4

	Pre-Test		Post-Test		
Score Range (20-item test)	**Frequency**	**Percentage**	**Frequency**	**Percentage**	**Level of Problem-Solving Skills**
16-20	1	3.704	9	33.333	EXCELLENT
11-15	3	11.111	11	40.741	VERY SATISFACTORY
6-10	7	25.926	5	18.519	SATISFACTORY
5 and below	16	59.259	2	7.407	NEED IMPROVEMENT
TOTAL	27	100	27	100	
MEAN	**5.93**		**12.93**		

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Table 10 Summary of Mean of the Pre-Test and Post-Test Results of STEM 11 Einstein (Experimental Group)

Iteration	Mean	
	Pre-Test	Post-Test
1	7.04	15.04
2	5.93	15.33
3	6.78	14.89
4	5.93	12.93

In analyzing the pre-test and post-test results of the experimental group over four (4) iterations, as indicated in Table 10, it is evident that there was a substantial improvement in the problem-solving skills of the students after engaging in subsequent discussions on the topics integrating Socratic teaching.

Table 11 Test of Significant Difference in the Problem-Solving Skills of the STEM 11 Newton (Control Group) and STEM 11 Einstein (Experimental Group) based on the Pre-Test Results

Paired Samples Test									
		Paired Differences							
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	T	df	Sig. (2-tailed)
Pair 1	CGROUP - EGROUP	-.34500	.32099	.16049	-.85576	.16576	-2.150	3	.121

As indicated in Table 11, the conducted analysis examined the disparity between the control group and experimental group's pre-test results.

The researcher obtained probability values exceeding the significance level of 0.05. Based on these computed outcomes, it was concluded that there is no statistically significant distinction in the problem-solving skills levels between the control group and experimental group, specifically in relation to the pre-test results.

Based on these computed results, it can be concluded that a significant difference exists between the post-test results of the control group and the experimental group. Thus, it can be inferred that Socratic Teaching is an effective method to enhance students' problem-solving skills.

According to Jensen's study (2015), it was reported that students who engaged in Socratic questioning sessions demonstrated considerable improvements in their problem-solving skills, in comparison to students who experienced traditional teaching approaches. Additionally, Yudcovitch & Hayes (2014) presented evidence supporting the notion that students achieve higher examination scores following the implementation of Socratic Teaching.

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Table 12 Test of Significant Difference in the Problem-Solving Skills of the STEM 11 Newton (Control Group) and STEM 11 Einstein (Experimental Group) based on the Post-Test Results

Paired Samples Test									
		Paired Differences							
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	T	df	Sig. (2-tailed)
Pair 1	CGROUP - EGROUP	-4.39750	2.11533	1.05767	-7.76346	-1.03154	-4.158	3	.025

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