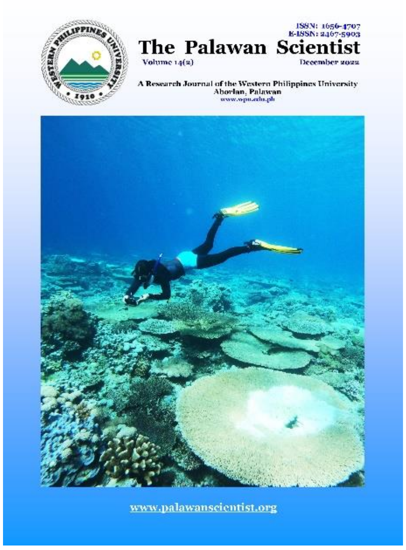

Predictors of students' conceptual understanding on finding volume of solids of revolutions in Integral Calculus

Arnel S. Travero and Dennis B. Roble*

University of Science and Technology of Southern Philippines, CM Recto Avenue, Lapasan Highway, Cagayan de Oro City
**Correspondence:* dennis_roble@ustp.edu.ph

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ABSTRACT

Learning calculus concepts frustrates a lot of learners. This study assessed self-efficacy and previous mathematics performance (PMP) of Integral Calculus students and described the impact of these variables on their conceptual understanding on finding volume of solids of revolution (VSOR). This study utilized a quantitative non-experimental predictive research design for 86 students enrolled in Integral Calculus at the University of Science and Technology of Southern Philippines. A 6-item teacher-made open-ended test was used to quantify students' conceptual understanding on finding VSOR. Frequency, percentage, mean and standard deviation, were used to determine students' level of self-efficacy, previous mathematics performance, and their score in conceptual understanding test. Multiple regression analysis was used to determine if self-efficacy and previous mathematics performance are predictors of students' conceptual understanding. Results showed that self-efficacy was a predictor of students' conceptual understanding on finding VSOR and an important factor in the development of the profound understanding of the concepts of VSOR in Integral Calculus among students. Hence, it is recommended that calculus teachers should give emphasis on the development of the conceptual understanding moving away from teaching anchored merely on procedures. Moreover, calculus teachers need to explore on strategies that can effectively enhance students' self-efficacy which is instrumental for students' profound conceptual understanding of calculus concepts. Future research may be conducted in the face to face classes to establish generalizability of the results obtained because this study was conducted during the pandemic where the mode of instruction was online.

Keywords: conceptual understanding, Integral Calculus, previous mathematics performance, self-efficacy, volume of solids of revolution

INTRODUCTION

Calculus is considered to be a fundamental branch of mathematics (Zakaria and Salleh 2015), and learning this course supports components of students' intellectual development (Rajagukguk 2016). As a matter of fact, Calculus concepts are considered the foundation for many theories in our life. Yet, calculus classes internationally face high drop-out rates, failure and negative attitude (Khoshaim and Aiadi 2018). Hence, Calculus learning seems frustrating to most learners, leading to researchers spending time analyzing students' difficulties in the subject.

Volume of solids of revolution (VSOR) is one of the most important concepts in Integral Calculus. The topic of finding the volume of solids of revolutions is one of the applications of definite integral. This involves solving for the volume of three-dimensional solids through disk, washer, or shell method. These solids of revolution are very common in manufacturing and engineering (Larson and Edwards 2012). Difficulties in this topic among the students are also undeniable. Mofolo-Mbokane et al. (2013) found that students have difficulty in the selection of representative strips used in the approximation of the bounded region and even if the students correctly gave the formula, they found it hard to draw the representation of the solid generated.

The difficulties in learning Calculus, and Mathematics in general, may be attributed to a lack of conceptual and superficial understanding of the mathematical concepts. Conceptual understanding, also referred to as conceptual knowledge, is pointed by the National Research Council (NRC) as one of the five strands in building mathematical proficiency. This strand becomes the main concern of educators since it allows students to become flexible in analyzing and solving real-life problems (Maglipong et al. 2015). Several researchers emphasized the importance of conceptual understanding in learning Calculus (Carlson et al. 2015; Drlik 2015). This is parallel with the study of Hamid et al. (2019) who stipulated that students' difficulties in learning Calculus topics, especially derivatives, were due to their lack of conceptual understanding; and that this lack of conceptual understanding was due to their weak foundation in Mathematics and their problems in determining the type of functions to be derived. Pointing out the necessity of conceptual understanding in learning topics in Calculus, misconceptions, and difficulties in most of the Calculus topics can be attributed to other factors (Maglipong et al. 2015). One of these factors considered to be affecting students' conceptual understanding, based on literature, is self-efficacy.

Self-efficacy is a person's belief and confidence in his/her ability to accomplish a task (Liu and Koirala 2009). Self-efficacy is considered to be an important concept in social cognitive theory and is demonstrated to affect a person's persistence, efforts, motivation, perseverance, behavior, and achievement (Ayotola and Adedeji 2009; Liu and Koirala 2009; Marchis 2011; Marchis 2012; Cheema 2018). Self-efficacy in mathematics shows the self-belief of the learners in their ability in surpassing challenges in solving math problems (Ministry of Education 2009). Marchis (2011, 2012) further emphasized the significance of students' self-efficacy in problem solving. Another factor considered to affect students' conceptual understanding is students' previous mathematics performance.

Previous mathematics performance (PMP), in the context of the present study refers to students' performance in topics from Arithmetic, Algebra, Analytic Geometry, Limits and Derivatives, and Antiderivatives. These courses are pre-requisites to the course Integral Calculus. The study of Maglipong et al. (2015) found previous mathematics performance to be a predictor to students' conceptual understanding in determining area of plane regions in Calculus, making PMP to be a viable predictor of students' conceptual understanding on finding volume of solids of revolution.

Noting the importance of conceptual understanding and the studies showing relationship of self-efficacy and previous mathematics performance (PMP) to mathematics achievement, the present study sought to 1) assess the self-efficacy and previous mathematics performance of Integral Calculus students; 2) determine the students' level of conceptual understanding on finding the volume of solids of revolution (VSOR); and, 3) determine the impact of self-efficacy and previous mathematics performance to students' conceptual understanding on finding VSOR.

This study was mainly anchored to Bernstein (1996) framework and Kilpatrick et al. (2001) five strands of Mathematical Proficiency. Bernstein (1996) framework involves knowledge transmission and acquisition where knowledge transmission refers to the teaching process while the acquisition refers to the learning process. Recognition and realization rules are accordingly involved in the latter process. On the other hand, Kilpatrick et al. (2001) framework talks about the five strands of mathematical proficiency: conceptual understanding, procedural fluency, strategic competence, adaptive reasoning and productive disposition. The five strands of mathematical proficiency are believed to be necessary to successfully learn mathematics (Mofolo-Mbokane 2011). In the present study, students' conceptual understanding on finding volume of solids of revolution was given emphasis and how this strand is predicted by other factors in the learning process. These factors considered were self-efficacy and previous mathematics performance. Recognition and realization rules were evident as the students aimed to explain each question in the conceptual understanding test, and thus, the way the students' recognition and realization were interpreted was according to Bernstein's framework.

METHODS

Research Design

This study utilized a quantitative non-experimental predictive research design. Predictive research is chiefly concerned with forecasting (predicting) outcomes, consequences, costs, or effects. This type of research tries to extrapolate from the analysis of existing phenomena, policies, or other entities in order to predict something that has not been tried, tested, or proposed before. In this, the students' self-efficacy, previous mathematics performance and conceptual understanding on VSOR were quantitatively described.

Research Instruments

Data were gathered through survey questionnaires. The mathematics self-efficacy scale was adapted from Liu and Koirala (2009). The Mathematics Self-Efficacy Scale was used to measure students' confidence level in completing mathematics courses, solving mathematics problems, and dealing with everyday mathematics-related tasks. The five-item questionnaire was found to have a reliability coefficient (Cronbach's alpha) of 0.933, inter-item correlation of 0.736 and standard deviation of inter-item correlations of 0.141. The Cronbach alpha indicates high internal consistency, while the inter-item correlation and its standard deviation shows acceptability of the questionnaire.

The PMP test composed of the 25-item questionnaire from Arithmetic, Algebra, Analytic Geometry, Limits and Derivatives, and Antiderivatives. It was a teacher-made test that was constructed using a Table of Specifications (TOS) and passed reliability and validity tests. This test obtained a reliability coefficient of 0.71. This same process was employed to the conceptual understanding test questionnaire which was composed of 6-item questions.

Data Gathering Procedure

The researchers sought permission from the Vice-Chancellor for Academic Affairs (VCAA) of the University upon the recommendation of the College of Science and Technology Education (CSTE) Dean to conduct this study. When the permission was secured, the researchers administered the self-efficacy and previous mathematics performance questionnaires to the participants. After the discussion on VSOR, the researchers administered the conceptual understanding test. Furthermore, in order to ensure the anonymity of the respondents of this study, informed consent was carried out and data coding of the respondents was applied.

The participants of the study were the third year Secondary Education major in Mathematics students and second year engineering students of University of Science and Technology of Southern Philippines (USTP). These students were enrolled in Integral Calculus in the second semester of school year 2020-2021. There were a total of 86 participants involved in the study selected purposively as these students are taking board exams with Calculus items after graduation and handled by the researcher.

Data Analysis

Descriptive statistics, specifically frequency, percentage, mean and standard deviation, were used to present the students' level of self-efficacy, previous mathematics performance, and their score in conceptual understanding test. Moreover, to determine the impact of self-efficacy and previous mathematics performance to students' conceptual understanding, multiple regression analysis was utilized.

RESULTS

Self-Efficacy

As portrayed by Table 1, the overall mean of the participants' self-efficacy is below 3. This showed a fair level of self-efficacy among the participants. Each item also showed a fair level. The items with the lowest mean score were numbers 2, "I'm certain I can understand the most difficult material presented in math texts" and 3, "I'm confident I can understand the most difficult material presented by my math teacher." This showed that participants had low confidence in their understanding in the materials and resources presented to them by their math instructor.

Previous Mathematics Performance (PMP)

In terms of participants' PMP, the majority of them scored average (Table 2). It was noteworthy that 27.91% scored above average; however, 2.32% were below average. The mean score and standard deviation of 17.26 ± 3.60 favored to average showed a homogeneity of the participants' scores. PMP questionnaire involved questions coming from Algebra, Analytic Geometry and Differential Calculus, all of which were pre-requisites of Integral Calculus. Participants could have forgotten some concepts from these courses.

Conceptual Understanding

It can be observed in the next table that the majority of the participants (68.60%) portrayed partial understanding of facts and ideas. Fourteen (14) participants had high level of facts and understanding while the remaining thirteen (13) participants had superficial understanding of facts and ideas. No one was categorized to have poor understanding and profound understanding of facts and ideas. The mean score of 42.74 and a standard deviation of 5.76 showed the spread of participants' scores.

It can be observed in Table 4 that students had satisfactorily scored in almost all of the problems in the conceptual understanding test, except for Problems 2 and 6. Participants only scored fairly for Problem 2 and scored very satisfactorily for Problem 6.

Table 1. Mean distribution of students' self-efficacy. Note: 1.00 - 2.33 = Low Self-efficacy; 2.34 - 3.66 = Fair; 3.67 - 5.00 = High Self-efficacy.

	Items	Mean	Standard deviation	Verbal Description
1.	I'm confident that I can do an excellent job on my math tests.	2.94	0.84	Fair
2.	I'm certain I can understand the most difficult material presented in math texts.	2.79	0.79	Fair
3.	I'm confident I can understand the most difficult material presented by my math teacher.	2.79	0.82	Fair
4.	I'm confident I can do an excellent job on my math assignments.	3.02	0.81	Fair
5.	I am certain I can master the skills being taught in my math class.	3.05	0.66	Fair
	Overall Mean	**2.92**	**0.66**	**FAIR**

Table 2. Participants' scores in previous mathematics performance test.

Description	Score Ranges	Frequency	Percentage	Mean and Standard Deviation (±) Score
Below Average	1-9	2	2.32%	17.26 ± 3.60
Average	10-19	60	69.77%	
Above Average	20-25	24	27.91%	

Table 3. Participants' scores in conceptual understanding test.

General Description of Conceptual Understanding	Overall Score	Frequency	Percentage	Mean and Standard Deviation (±) Score
Profound understanding of facts and ideas	63-70	0	0	42.74 ± 5.76
High level understanding of facts and ideas	49-62	14	16.28	
Partial understanding of facts/ideas	35-48	59	68.60	
Superficial understanding of facts/ideas	21-34	13	15.12	
Poor understanding of facts/ideas	Below 21	0	0	

Table 4. Participants' performance in the conceptual understanding test. Note: 4.5-5 = Excellent; 3.5-4.49 = Very Satisfactory; 2.5-3.49 = Satisfactory; 1.5-2.49 = Fair; 1-1.49 = Poor. Grand Mean Performance: 3.08

Problem	Performance Mean	Standard Deviation	Descriptive Level
1a	2.81	0.86	Satisfactory
1b	2.94	0.76	Satisfactory
1c	3.23	0.81	Satisfactory
2a	2.34	0.68	Fair
2b	2.30	0.81	Fair
2c	3.24	0.94	Satisfactory
3a	3.83	0.91	Satisfactory
3b	3.22	1.04	Satisfactory
4a	3.38	0.91	Satisfactory
4b	2.91	0.83	Satisfactory
5a	2.90	0.74	Satisfactory
5b	2.87	0.82	Satisfactory
6a	3.62	0.78	Very Satisfactory
6b	3.59	1.06	Very Satisfactory

To provide a glimpse of these problems, Figure 1 below displays Problem 2. The problem presented two (2) solutions and two (2) figures in solving one (1) problem. One of the figures used horizontal strip, while the other used vertical strip. Both solutions (and figures) arrived to the same answer. Participants had a hard time differentiating which of the figures properly represented the given problem. Both figures and solutions were correct; however, the participants preferred a solution, saying that the other one was wrong and complicated.

Problem 2.

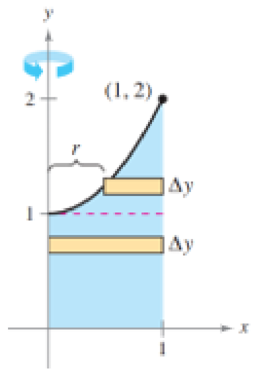
Mary and Anna are having an argument on how to answer the following questions.

Exercise: *Solve for the volume of the solid formed upon revolving the bounded region of* $y = x^2 + 1$, $y = 0$, $x = 0$, *and* $x = 1$.

Mary believes that to answer it, she should use washer method, choose a horizontal representative strip, and perform two integrals. Anna, on the other hand, believes that she should use vertical representative strip and use shell method. Their solutions and figures are shown below.

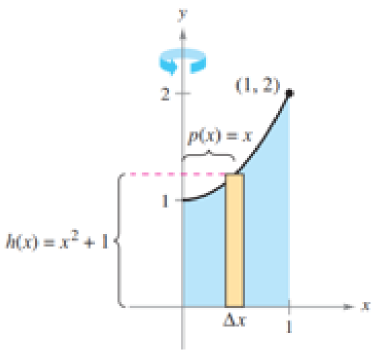
Mary's Answer and Figure

$$
\begin{aligned}
V &= \pi \int_0^1 (1^2 - 0^2)\, dy + \pi \int_1^2 \left[1^2 - \left(\sqrt{y-1}\right)^2\right] dy \\
&= \pi \int_0^1 1\, dy + \pi \int_1^2 (2 - y)\, dy \\
&= \pi \Big[y\Big]_0^1 + \pi \left[2y - \frac{y^2}{2}\right]_1^2 \\
&= \pi + \pi\left(4 - 2 - 2 + \frac{1}{2}\right) \\
&= \frac{3\pi}{2}
\end{aligned}
$$



Anna's Answer and Figure

$$
\begin{aligned}
V &= 2\pi \int_a^b p(x)h(x)\, dx \\
&= 2\pi \int_0^1 x(x^2 + 1)\, dx \\
&= 2\pi \left[\frac{x^4}{4} + \frac{x^2}{2}\right]_0^1 \\
&= 2\pi\left(\frac{3}{4}\right) \\
&= \frac{3\pi}{2}
\end{aligned}
$$



Interestingly, both Mary and Anna arrive with a volume of $\frac{3\pi}{2}$ cubic units.

Based on this situation:

a. Explain why both solutions give the same answer.
b. Whose figure do you think properly represented the volume to be solved? Why?

Figure 1. Problem 2 of the conceptual understanding test.

Figure 2 presents sample answers of the students for Problem 2a. As shown on this figure, students interpreted that the usage of horizontal strips and washer method were not appropriate for the problem. The same outcome was manifested for Problem 2b, as shown on Figure 3.

Student A	2.) (a.) MARY, USES WASHER METHOD, WHICH I BELIEVE IT WAS NOT THE APPROPRIATE ONE BUT SINCE, MARY FIND TWO AREAS BY PUTTING TWO HORIZONTAL STRIPS FROM THE BOUNDED REGION THIS MADE MARY'S SOLUTION TO BE CORRECT, HOWEVER ANA USED THE MOST APPROPRIATE METHOD WHICH IS THE SHELL METHOD, CUTTING ONE VERTICAL STRIP TO CUT MAXIMIZE THE BOUNDED REGION.
Student B	2.) a.) Mary uses washer method, which I believe it was not the appropriate one but since Mary find two areas or she cut two horizontal strips from the bounded region this make Mary's solution to be exact. However Anna uses the most appropriate method which is the Shell method, cutting one vertic strips to maximize the bounded region.
Student D	2. a) The method that Mary uses in answering the problem is washer method, which is for me not the appropriate method since, Mary finds two areas from the bounded region this comes up to a correct answer. While, Anna uses shell method where she cuts one vertical strips to maximize the bounded region this makes her method appropriate.

Figure 2. Sample answers of student-participants for problem 2a.

Student K	(b) The figure that I think properly presented the volume to be solve is Anna's figure, because Anna's presentation is properly labelled and it is much easier to use rather than Mary's figure, wherein she choose the complicated way.
Student L	b. Anna's Solution and figure properly represented the volume to be solved, because she only used what was given in the problem, Her solution was also easier to understand
Student M	b. For me, Anna's figure is properly represented the volume to be solved. On the given curved or the bounded region, Mary's figure is complicated where she cuts two horizontal strips from the bounded region Whereas Anna's figure only got a strip that is parallel to the axis of rotation.
Student N	b.) I think the figure is properly represented the volume to be solved was Anna's answer. As we look in the figure of Mary, the solution is complicated because she did not use the correct method on finding volume based on the given curves or the bounded region. Since that Anna's way of answering given method she used arrived [illegible] from the proper method and correct answer.

Figure 3. Sample answers of students for problem 2b.

On the other hand, Problem 6 as shown on Figure 4 seemed to be easy for the participants. As shown, this problem provides the figure and students are tasked to choose which between two given equations best represent the figure. Almost all of the participants answered this question correctly. Samples of students' answer on this problem are shown on Figure 5.

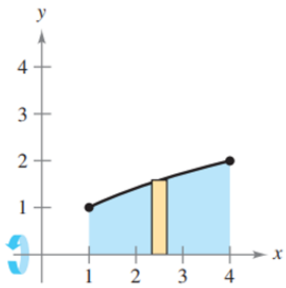
Impact of Self-efficacy and Previous Mathematics Performance on Students' Conceptual Understanding

Regression analysis was used to determine the impact of self-efficacy and previous mathematics performance to the conceptual understanding of students on finding volume of solids of revolution. R-square of 0.0645 showed that the predictors indicated the variance of students' conceptual understanding. The coefficient multiple correlation R of 0.2540 showed weak direct relationship between the predicted and observed data.

It can be inferred that self-efficacy has significantly influenced the conceptual understanding of the students. With a probability of 0.0201, self-efficacy could be considered as a predictor of students' conceptual understanding. On the other hand, previous mathematics performance showed weak impact to the conceptual understanding of students which is indicated by its probability value that is greater than 0.05. This implies that previous mathematics performance does not hinder students' conceptual understanding.

Teacher Joy asked her student to solve for the volume of a solid formed by revolving the shown region about the x-axis.

$y = \sqrt{x}$



To start answering, Bart represented the indefinite integral as $V = \pi \int_1^4 (\sqrt{x})^2\ dx$. Ben on the other hand, represented it as $V = \pi \int_0^2 (\sqrt{x})^2\ dx$.

a. Between Bart and Ben, who provided the correct representation of the volume?
b. What would be the volume of the solid formed?

Figure 4. Problem 6 of the conceptual understanding test.

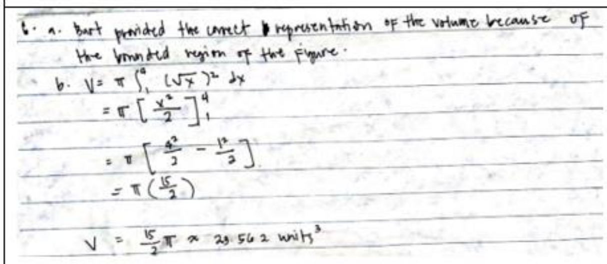
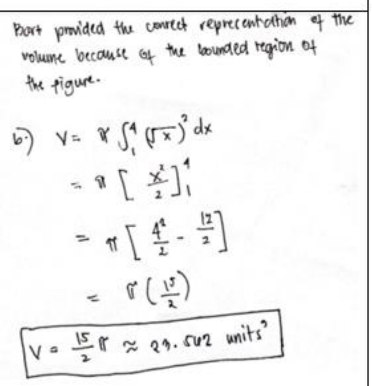
Student U	Student V
	

Figure 5. Sample answers of students for problem 6.

Table 5. Multiple regression analysis of predictors of students' conceptual understanding. *Test is significant at the 0.05 level (2-tailed).

Variables	Coefficient	Standard Error	*t*-value	*p*-value
Self-Efficacy	0.4393	0.1854	2.3692	0.0201*
PMP Test	-0.0964	0.1708	-0.5647	0.5739
Constant	37.9965	3.8478	9.8748	<0.001*
Standard Error of Estimate = 5.64209 R-square = 0.0645 Multiple R = 0.2540				

DISCUSSION

Students' Self-efficacy and Conceptual Understanding

While self-efficacy refers to students' belief and confidence in their ability to accomplish a task (Liu and Koirala 2009), it is important to note that self-efficacy is content-specific. One may have high self-efficacy in one task but low in the other asks. Moreover, as much as self-efficacy and self-concept are sometimes mistakenly used interchangeably, the former includes "organize and execute" and is used in reference to a particular goal, while the latter referes to individual's evaluation and belief on themselves. A student may have a negative self-concept for mathematics class but can have high self-efficacy for a certain class task (Schaal and Hurst 2022). This is true in the context of the present study where participants could have a fairly high self-concept, but a fair self-efficacy.

In terms of participants' performance in the conceptual understanding test, Mofolo-Mbokane et al. (2013) explained that students have difficulty in the selection of representative strips used in the approximation of the bounded region. They further expanded that even if the students correctly gave the formula, they found it hard to draw the representation of the solid generated.

Mofolo-Mbokane (2011) posited that students perform poorly in tasks that involve three-dimensional thinking. Accordingly, students were more competent when solving problems focusing on procedural skills, rather than those requiring conceptual skills. Volume of solids of revolution is recommended to be evaluated conceptually.

The study of Maglipong et al. (2015) which showed that students were able to correctly pair definite integral to the given figure for area of plane regions in Integral Calculus supports students' performance in Problem 6 of the present study. Further, since Problem 6 already gives the figure, the participants only had to correctly do the procedures. Students' competence in solving for procedural skill is more evident than their conceptual skills (Mofolo-Mbokane 2011).

Self-efficacy is a Predictor of Students' Conceptual Understanding on Finding Volume of Solids of Revolution while PMP is not

The results of this study have shown that student's self-efficacy influenced their level of conceptual understanding on finding volume of solids of revolution. Students' belief and confidence in their ability that they can accomplish a task allowed them to perform better in understanding the concepts in Integral Calculus, specifically, on finding volume of solids of revolution. This was supported by the findings of the study of Liu and Koirala (2009) that mathematics self-efficacy was a significantly positive predictor of mathematics achievement, in the case of this study was their conceptual understanding on finding volume of solids of revolution in Integral Calculus.

Self-efficacy has always been proven to affect students' performance in mathematics. It shows significance in mathematical problem solving (Marchis 2011, 2012); it significantly predicts mathematics achievement (Liu and Koirala 2009); it displays significant relationship to mathematics literary of students (Cheema 2018).

On the other hand, students' previous mathematics performance does not guarantee profound understanding on finding volume of solids of revolutions which is a contradiction of the study of Maglipong et al. (2015) where students' previous mathematics performance can significantly predict students' conceptual understanding on finding areas of plane regions. As much as previous mathematics performance may affect conceptual understanding of students, if there are times gap, students tend to forget concepts.

From the results of the study, the following conclusions were derived: Students' self-efficacy is a relevant predictor to students' conceptual understanding on finding VSOR in Integral Calculus, and previous mathematics performance is not a predictor for students to have profound understanding on finding VSOR.

Implications to Practice and Future Directions

Moreover, the following recommendations are generated: Calculus teachers should give emphasis on the development of the conceptual understanding moving away from teaching anchored merely on procedures; they also need to explore on strategies that can effectively enhance students' self-efficacy which is instrumental for their profound conceptual understanding of Calculus concepts; this study may be replicated to a bigger population and with consideration to other factors that may affect students' conceptual understanding on finding VSOR; and, to establish generalizability of the results obtained, future research may be conducted in the face to face classes because this study was conducted during the pandemic where the mode of instruction was online as well as alignment of the number of items of the questionnaires.

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ROLE OF THE AUTHORS: *AST – conceptualized, drafted the paper, consolidated the data, analyzed data, wrote the manuscript; DBR – conceptualized, conducted the data gathering, reviewed the data analysis, edited the manuscript*