Available online at: https://journals.researchsynergypress.com/index.php/ijrse
International Journal of Research in STEM Education (IJRSE)
ISSN 2721-2904 (Online) | 2721-3242 (Print)
Volume 3 Number 1 (2021): 36-46

STEM Students' Engagement in Horizontal Transfer from Calculus to Physics and their Difficulties

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Abstract

The majority of science students are facing different problems in applying their calculus knowledge to physics courses. Researchers started to develop an integrated approach to address this problem. However, many schools are still teaching calculus and physics as two separate subjects. Moreover, there has been no significant research on senior high school students' transfer of learning and difficulties in calculus-based physics subjects. It is crucial because this is when the students first experience applying calculus in a physics context. Hence, the study investigated the engagement of senior high school STEM students to horizontal transfer from Basic Calculus to General Physics subjects and the difficulties they experience in solcalculus-based physicsysics problems. A correlational study research design was employed to explore the relationship between the students' physics and calculus performance using a physics worksheet. Both qualitative and quantitative methods were also employed to determine the students' difficulties in calculus-based physics problems. The Pearson correlation revealed that there is a significant positive correlation between the students' physics and calculus performance. Although this could not serve as strong evidence of transfer, this strong correlation implies that senior high school STEM studcouldle to construct the similarities between the calculus-based physics problems and their calculus schema. As revealed in the questionnaire and the student's responses in the worksheet and interview, students have difficulty in solving calculus-based physics problems in terms of identifying the variable that needs to be integrated, setting up the limits of integration, evaluating the limits of integral, and identifying the appropriate rules of integration and applying it in solving the physics problem. These difficulties are rooted in the fact that students have little experience using calculus in word problems, especially in the physics context.

***Keywords**: horizontal transfer, calculus-based physics problem, students' difficulties*

INTRODUCTION

The K to 12 Basic Education Curriculum was implemented in the Philippines in 2013. It covers kindergarten, six years of elementary education, four years of junior high school, and two years of senior high school. Students under the Science, Technology, Engineering, and Mathematics (STEM) strand are required to enroll in General Physics 1 and 2 after taking the Pre-Calculus and Basic Calculus subjects (Department of Education, 2016). STEM students need to take conceptual and algebra-based physics and calculus-based physics as Basic Calculus is a pre-requisite of the two General Physics courses.

The majority of science students are facing different problems in transferring their calculus knowledge to physics courses. In the study of Nguyen et al. (2011), they investigated the common difficulties the students experience when answering physics problems that involve the use of integral calculus. The results reveal that even though students acknowledge the use of calculus in solving physics problems, they fail to apply it in their solution, especially in setting up the correct integral. Moreover, Bollen et al. (2015) explored college students' difficulties in applying vector calculus in a physics context. The researchers discovered that students are good at performing vector calculations, but they struggle in interpreting and applying calculus in different physics

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problem contexts. They believed that traditional instruction in physics and calculus are not enough to solve this problem.

Based on the reports that the majority of students experience problems in calculus-based physics courses, researchers started to develop an integrated approach to Physics and Calculus. Their common goal is to enhance the abilities of the students to connect their knowledge between the two subjects meaningfully. For example, Dominguez et al. (2016) proposed a curricular sequence called Fis-mat integrated physics and mathematics, for which they reorganized the calculus and physics courses to integrate both disciplines. This provides an instructional model that gives the students the tools to address their difficulties when the two subjects are taught separately. Another study proposed an instructional model that integrated the two subjects to establish to the students how calculus is used and applied in Physics. The model includes the rearranging of course content and combining the different effective teaching approaches for the two subjects and the use of educational technology. The students perceived the positive effect of the instructional model as it provides them a valuable learning experience that lessens the boundaries between the two subjects (Domínguez et al., 2015).

Despite several studies exploring the difficulties of the students in calculus-based physics and different studies proposing an integrated approach between Physics and Calculus subjects, especially in engineering courses, many schools are still teaching calculus and physics as two separate subjects. Several studies are assessing the problems and challenges of college students in calculus-based physics, but there has been no significant research on senior high school STEM students. This is crucial because this is when the students first experience applying calculus in a physics context. Moreover, the connection between the two subjects is evident in different perspectives, but few studies focus on the transfer of learning from calculus to physics (Cui, 2006). Hence, the present study investigates the engagement of senior high school STEM students in horizontal transfer from Basic Calculus to General Physics subject and the challenges they experience in answering calculus-based physics problems.

The theoretical framework developed by Rebello et al. (2007) is used in the study, which is based on the associations and control framework of Redish. This framework distinguishes the different types of transfer processes significant to problem-solving. A small number of physics textbook problems require a vertical transfer. Commonly, students do not need to activate different schema and decide which of them is applicable or not to create a new schema and solve the physics textbook problem (Cui, 2006). Thus, vertical transfer of learning is beyond the scope of this study. This study centers only on the students' horizontal transfer of learning from an actor-oriented view of transfer perspective and the challenges they encounter in solving calculus-based physics problems. Horizontal transfer in an actor-oriented idea occurs when students successfully construct the similarities between the new situation (calculus-based physics problems) and prior knowledge (calculus schema). In horizontal transfer, students need to activate a schema related to the question when reading and analyzing the given information. Students do not require to explore whether their activated schema is applicable or not, nor do they need to choose between different possible valid schema to solve the problem. The majority of the textbook's issues are categorized under this kind of transfer (Rebello, et al., 2007).

RESEARCH PROBLEM

This research seeks to investigate the students' difficulties in calculus-based physics problems and horizontal transfer from essential calculus to general physics subjects. The study focuses on answering the two research questions:

ISSN 2721-2904 (Online) | 2721-3242 (Print)

1. Can senior high school STEM students engage in horizontal transfer by connecting their physics problem with calculus schema?
2. What are students' difficulties in solving calculus-based physics problems?

METHODOLOGY

Research Design

The study aims to assess the students' difficulties and horizontal transfer from calculus to physics. A correlational study research design was employed to determine the horizontal transfer and explore the relationship between the students' performance in physics and calculus. Both qualitative and quantitative methods were employed to answer the problems.

Research Setting and Participants

This study identifies the participants' engagement in horizontal transfer from Basic Calculus to General Physics subjects and their challenges in calculus-based physics problems. The study was implemented in a private high school in Metro Manila. One Grade 12 STEM section with 29 students is the participant of the study. The researcher also served as the teacher of this section. At this school, essential calculus and general physics subjects are taught separately.

Research Procedure

Four stages were followed in the study to answer the research problems.

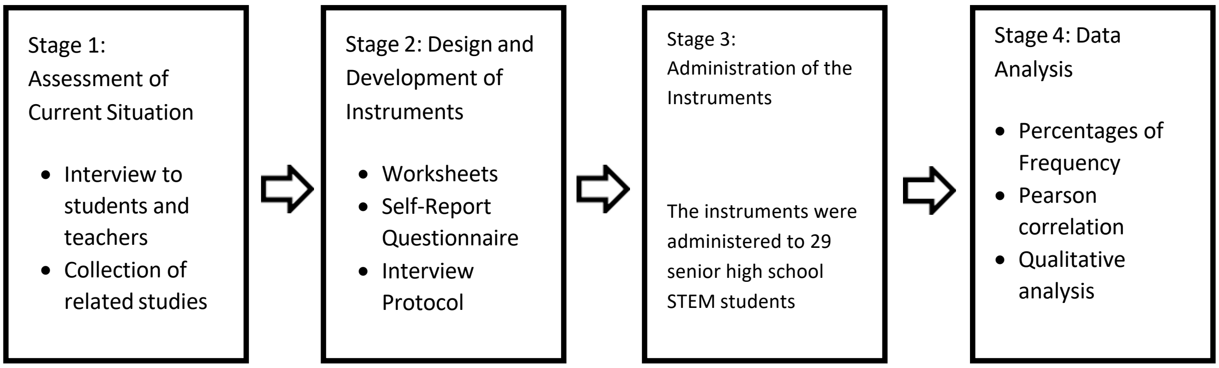

Figure 1. Schematic Diagram of the Research Procedure

1) Stage 1. Assessment of Current Situation

The researcher examined the curriculum guide of General Physics 2 subject for Grade 12 STEM students especially the topics that require the use of Calculus. Interview with the physics and calculus teachers and some STEM students was also done to assess the current situation in the school and the learning experiences of both teachers and students. Lastly, resources and materials about the calculus-based physics topics were collected.

2) Stage 2. Design and Development of the Instrument

Based on the data collected during stage 1 of the study, the researcher started to develop the instruments that will be used as the sources of data.

Source of Data

The data used in conducting the study are the following: (1) scores in the worksheets using scoring rubrics; (2) results in the self-report questionnaire; and (3) interview.

ISSN 2721-2904 (Online) | 2721-3242 (Print)

a) *Scores in the Worksheets using the Scoring Rubrics*

The worksheet has two parts: Part A is composed of physics problems that align with the sample problems presented during the lecture/ discussion. In contrast, Part B is composed of physics problems that are new to students but related to the topic discussed in the lecture/ discussion. In addition, physics problems are problems that are commonly appeared in the majority of physics textbooks.

For each physics problem in the worksheet, the student's performance in physics and calculus are measured individually using the calculus and physics performance rubric. This was done to assess the student's physics performance and calculus performance using one calculus-based physics problem. The rubrics that were used in the study are modified versions of Cui (2006).

Each answer of the students in the worksheet is analyzed qualitatively to determine the typical difficulties of the students in answering the calculus-based physics problems.

b) *Self-Report Questionnaire*

The self-report questionnaire was administered through *Socrative*. Socrative is an online platform that allows students to take an online assessment that provides immediate feedback. The questionnaire identified the students' difficulties solving calculus-based physics problems and their learning experience in their calculus and physics classes. The questionnaire uses a five-point Likert scale from strongly agree to strongly disagree.

c) *Interview*

An interview with students was conducted after administering the worksheets to obtain insights into the student's learning experiences and difficulties. Semi-structured questions are utilized to collect the students' answers. The questions comprise the students' problems solving calculus-based physics problems and their learning experiences in their calculus and physics classes.

3) *Stage 3. Administration of the Instrument*

After Gauss's Law and Electric Potential topics were discussed, the researcher administered the worksheet to 29 STEM students. A few days after, the self-report questionnaire was administered through *Socrative.* Moreover, interviews with the students (n =12) were conducted to counter-validate the gathered quantitative data. Using a developed interview protocol, students were questioned about their learning experiences in their Physics and Calculus class and their difficulties in solving calculus-based physics problems.

4) *Stage 4. Data Analysis*

To answer each research problem, the following analysis methods for every source of data were implemented in the study.

a) *Worksheet Analysis*

Each physics problem was assessed using two scoring rubrics: the physics performance rubric and the calculus performance rubric. The Pearson correlation coefficient was calculated to determine whether the students' performance for each physics problem in calculus and physics was significantly correlated.

The method of analysis used by Cui (2006) will be implemented in the study which is based on the following premise:

- Having a statistically significant correlation between calculus and physics performance is one evidence of transfer of learning. Conversely, a not statistically significant correlation will mean an absence of transfer.
- Having a statistically significant correlation between calculus and physics performance is not the only requirement for transfer. Correlation does not always show transfer, but it can indicate a transfer from different physics and calculus sources.

Qualitative analysis was also done on each student's answer in the worksheet to determine the students' common difficulties in solving calculus-based physics problems.

b) Self-Report Questionnaire Analysis

For each rating, percentages of the frequency were computed. The frequency of ratings indicates the difficulties in solving calculus-based physics problems of the students and their learning experience in the calculus and physics class. The reported difficulties of the students in the questionnaire will also be used to support the analyzed results in the worksheets.

c) Interview Analysis

Three groups of students were selected to probe deeper into students' difficulties in solving calculus-based physics problems. The selection is based on the students' total scores in the worksheet: the first group consists of three students who got the highest scores; the second group consists of three students who got the lowest scores; the third group consists of students with average scores. The responses in the interview are transcribed and analyzed to validate and acquire more insights about the students' difficulties in solving calculus-based physics problems and their learning experience and background in calculus and physics subjects.

RESULT AND DISCUSSION

Students' Horizontal Transfer from Basic Calculus to General Physics Subject

The Pearson correlation between students' physics and calculus performance on each problem in the worksheet was calculated to assess whether students were able to engage in horizontal transfer by connecting the physics problem with their background knowledge in calculus. As stated in the data analysis, a significant correlation is necessary to indicate horizontal transfer. However, this is not adequate proof for a dynamic transfer.

Table 1. Pearson Correlation between Students' Calculus and Physics Performance

	Worksheet Item		**Pearson Correlation**	**Sig. (2-tailed)**
Gauss's Law and Electric Potential Worksheet	Physics Scores in Problem1	Calculus Scores in Problem 1	0.735	0.000
	Physics Scores in Problem 2	Calculus Scores in Problem 2	0.474	0.009
	Physics Scores in Problem 3	Calculus Scores in Problem 3	0.839	0.000
	Physics Scores in Problem 4	Calculus Scores in Problem 4	0.763	0.000

ISSN 2721-2904 (online)

The results of the Pearson correlation for problems 1 to 4 revealed that there is a significant positive correlation between the students' physics and calculus performance in the worksheet at the $p<0.001$ significance level as shown in Table 1. The four problems in the worksheet are shown in the appendix. A strong correlation between the scores of the students in calculus and physics in each item reveals that students were able to construct the similarities between their calculus schema and the calculus-based physics problems in the worksheet. This shows a possibility of students' engagement in horizontal transfer from calculus to physics. This result is consistent with Part B (Problems 3 and 4) which are physics problems that are new to students but related to the topic discussed in the lecture/ discussion.

Cui (2006) stated that Pearson correlation analysis is not sufficient to assess the transfer of learning. Although the positive results indicate that the students were able to connect calculus and physics internally, this is not enough to measure transfer dynamically. The result of the correlation could not serve as strong evidence of transfer, but having a positive result is necessary for determining the possibility of horizontal transfer. The question of how far students can connect their calculus schema in solving the physics problem cannot be answered in this study, but to extend the investigation. The researcher examined students' difficulties in solving calculus-based physics problems using the same worksheet, questionnaire, and interview.

Students' Difficulties in Solving Calculus-based Physics Problems

Students' difficulties in solving calculus-based physics problems are determined using a self-report questionnaire. The result of the questionnaire is validated by the results of the worksheets and the interview. As shown in Table 2, students perceived that they have difficulty identifying the variable that needs to be integrated, setting up the limits of integration, and evaluating the limits of integration. This result is aligned with the study of Nguyen, et al. (2011) and Bollen, et.al. (2015).

Table 2. Students' Difficulties in Solving Calculus-Based-Physics Problems N=29

Indicators	Strongly Agree (5)		Agree (4)		Undecided (3)		Disagree (2)		Strongly Disagree (1)	
	f	*%*	*f*	*%*	*f*	*%*	*f*	*%*	*f*	*%*
I have difficulty identifying the variable that needs to be integrated/ differentiated.	0	0	11	38	9	31	8	28	1	3
I have difficulty setting up the limits of integration.	1	3	13	45	3	10	11	38	1	3
I have difficulty evaluating the limits of integral.	1	3	15	52	7	24	6	21	0	0
I have difficulty identifying whether calculus is applicable in a given physics problem.	2	7	10	34	6	21	7	24	4	14
I have difficulty choosing the appropriate rules of integration.	4	14	12	41	4	14	9	31	0	0
I have difficulty applying the integration rule in solving physics problems.	3	10	12	41	3	10	10	34	1	3

ISSN 2721-2904 (Online) | 2721-3242 (Print)

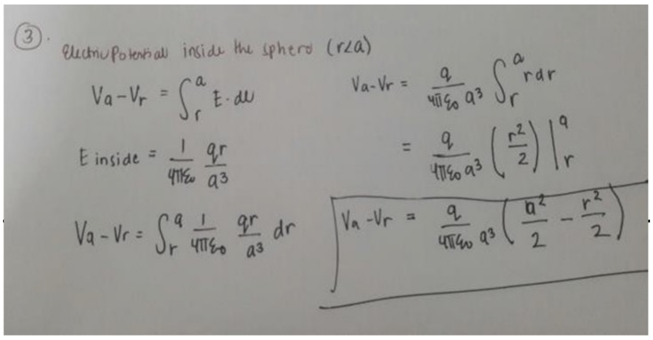

Figure 2. Student's Actual Solution in Problem 3

In problem 3, the students were asked to solve the electric potential inside and outside a conducting sphere. As shown in Figure 2, the student used the correct formula for electric potential and substituted a correct equation for the electric field. However, the limits of integration are wrong. He used a to r, instead of r to a, where a is the radius of the sphere. This revealed that students have difficulty in setting up the limits. In addition, when the students were asked why a^3 is put outside the integral sign, they are not sure about the reason. He is just aware that the variable attached to d (derivative) is the only variable that needs to be integrated. This reflects that student are not aware of determining the variable that needs to be integrated and not. This particular student got three points for his calculus performance because he completed the integration correctly. However, he got only two points for the physics performance. The majority of the students retain their knowledge in calculus; however, they have difficulty recognizing when to activate it.

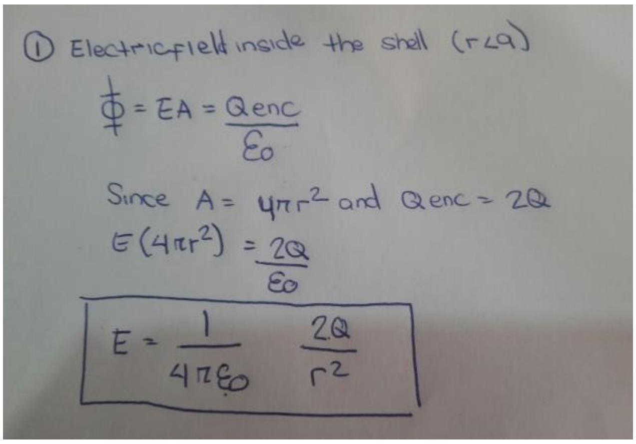

Figure 3. Student's Actual Solution in Problem 1

Table 2 also revealed that students have difficulty identifying whether calculus is needed or useful in solving a particular physics problem. As shown in Figure 3, the student did not show in his solution that the electric flux (Φ) is equal to the surface integral of E.dA ($\Phi = \oint E.\,dA$), instead, he proceeded to use the formula $EA = \frac{Q_{enc}}{\varepsilon_0}$ which he based on the sample problem in the lecture. When asked about this, he stated that he doesn't know the significance of that equation in the problem. This implies that most of the students are not aware why they use integration in solving a particular physics problem, they just copied the method on how to solve it in a similar sample problem. Moreover, some of the students' solutions started from $EA = \frac{Q_{enc}}{\varepsilon_0}$ even though the teacher reminded them to start the solution with the surface integral of E.dA. This suggested that they prefer to use a pre-derived equation instead of showing how to derive it using integration.

Nguyen et al. (2011) explained why students who finished calculus subjects and enrolled in a physics class commonly have difficulties identifying whether calculus is applicable in the physics problem. Since students during their calculus course typically received integrals to solve, physics problems commonly do not have prearranged or set integrals. Thus, students need to identify whether integrals are necessary for a particular physics problem and to write the correct integral appropriate for the problem. Students are not used to doing these two tasks in their calculus course. This is also revealed by some of the students based on their interviews.

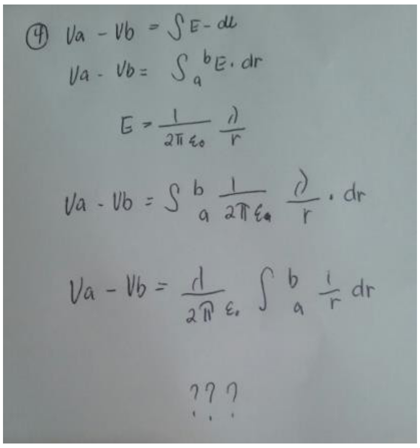

Figure 4. Student's Actual Solution in Problem 4

As also revealed in the questionnaire, most students perceived that they have difficulty choosing the appropriate rules of integration and how to apply them in solving the physics problems. For example, when asked to calculate the electric potential of a non-conducting infinite long wire with radius R, the student was able to use the correct equation for electric potential, and he was able to set up the correct limits of integration as shown in Figure 4. However, he was not able to finish the solution. When asked if insufficient time is the reason why he did not finish the solution, he stated that he did not know how to integrate dr, but based on his worksheet, he was able to integrate r^2dr This revealed that students in other problems. This is true with the majority of the students. have limited knowledge with regards to identifying the integration rules to be used.

Students Learning Experience in Basic Calculus and General Physics Subject

Table 3 shows the learning experience of the students in their Basic Calculus and Physics subjects. The majority of the students believed that they had learned the necessary calculus topics in their Basic Calculus subject. Still, they also perceived that they have little to no experience connecting and applying calculus in physics topics during their calculus classes. Based on the interview, they had few experiences applying differential calculus in physics during their calculus classes, and applying integral calculus in physics is new to them.

ISSN 2721-2904 (Online) | 2721-3242 (Print)

Table 3. Learning Experience in Basic Calculus and General Physics

Indicators	Strongly Agree (5)		Agree (4)		Undecided (3)		Disagree (2)		Strongly Disagree (1)	
	f	%	*f*	%	*f*	%	*f*	%	*f*	%
I learned the necessary calculus topics in basic calculus.	7	24	16	55	4	14	1	3	1	3
I learned the knowledge and skills in calculus class that is useful in physics.	4	14	16	55	5	17	3	10	1	3
I learned the connection between calculus and physics topics in my physics class.	7	24	14	48	5	17	1	3	2	7
I learned the connection between calculus and physics topics in my calculus class.	3	10	8	28	7	24	10	34	1	3
I learned how calculus is applied in physics problems in my physics class.	12	1	10	34	4	14	3	10	0	0
I learned how calculus is applied in physics problems in my calculus class.	6	1	3	10	8	28	12	41	0	0

Students are used to receiving integrals to solve and they seldom solve word problems in their Basic Calculus subject. This is also revealed in the study of Hu and Rebello (2013). Hence, students need more practice applying calculus in physics. Some students stated that having word problems in their calculus, even not related to physics, can give them an idea of how to apply calculus in different physical situations and help them prepare to solve calculus-based physics problems. There is one student who suggested integrating calculus and physics subjects to strengthen their understanding of how calculus is applied in physics. This revealed that students recognized the connection of the two subjects and acknowledged that they need more practice applying calculus in word problems, especially in physics subject.

CONCLUSION

The study aimed to investigate the senior high school STEM students' horizontal transfer from Basic Calculus to General Physics subjects and their difficulties in solving calculus-based physics problems. The study used a worksheet, self-reported questionnaire, and interview to examine the students' transfer of learning and difficulties. Frequency, percentage, and Pearson correlation are utilized to analyze the data.

The study revealed the following results:

Question 1: Can senior high school STEM students engage in horizontal transfer by connecting their physics problem variables with calculus schema?

As revealed in the results of Pearson correlation for problems 1 to 4 of the worksheet, there is a significant positive correlation between the students' physics and calculus performance. The strong correlation presented a possibility that senior high school STEM students were able to engage in a horizontal transfer. However, as stated by Cui (2006), Pearson correlation analysis is not sufficient to measure the transfer of learning. Transfer should be measured from a different perspective. Hence, for future research, the researcher recommends utilizing a calculus test as one of the instruments that will measure students' calculus knowledge needed in physics and correlate it to the students' scores in the calculus-based physics exam. Also, the researcher recommends extending the research by evaluating the ability of the students to engage in horizontal transfer with regards to applying differential calculus in physics. Moreover, since the Philippine Educationis utilizing online learning because of the pandemic, having a recorded video of the students while solving a calculus-based physics problem will give more information on how the students activate their calculus schema to solve a calculus-based physics problem and engage in the horizontal transfer.

ISSN 2721-2904 (Online) | 2721-3242 (Print)

Question 2: What are the students' difficulties in solving calculus-based physics problems?

Students' difficulties in solving calculus-based physics problems are determined using the worksheets, five-point Likert scale self-reported questionnaire, and interview. Based on the results, the majority of the students have difficulty identifying the variable that needs to be integrated, writing the limits of integration, evaluating the limits of integral, and identifying whether calculus is useful in a particular problem or not. This result is aligned with the study of Nguyen, et.al. (2011) and Doughty, McLoughlin, and van Kampen (2014). Moreover, based on the result of the worksheet, students also have difficulty identifying the appropriate rules of integration to be used and how to apply them in solving the physics problems which is parallel to the results of the study of Bollen et al. (2015). Students perceived that even though they have learned the necessary calculus topics in their Basic Calculus subject, they have few experiences applying calculus in physics topics and other contexts. They used to receive integrals to solve but they rarely solve word problems in their Basic Calculus subject. Students believe that having word problems in their calculus, even those not related to physics, can prepare them to solve calculus-based physics problems. For further improvement of the study, the researcher recommends conducting an interview with several calculus and physics teachers to get a teacher's perspective of the students' difficulties in solving calculus problems and calculus-based physics problems. Also, exploring how teachers addressed the difficulties of the students can make the research more meaningful.

The results of the study revealed that students' physics performance is positively correlated with the students' calculus performance which means the possibility that students were able to connect the two subjects. However, students experience many difficulties in solving calculus-based physics problems as described in part IV of the study. These difficulties are rooted in the fact that students have little experience applying calculus in word problems, especially in the physics context. This is also perceived by the students and was revealed in other studies (Cui et al, 2006 and Nguyen et al, 2011). The researcher believes that word problems in calculus are helpful to prepare students in calculus-based physics subjects. Putting more effort in giving word-problem exercises in both physics and mathematics instruction would also help students to understand the physical meaning of the equations that they are deriving and the application of calculus in real-life situations. Moreover, the majority of the students recognize the connection between the two subjects and the need to integrate them. This is contrary to the result of the study of Cui (2006), and Roorda (2015). Several studies (Dunn et al, 2000; Tyson, 2011; and Dominguez et al, 2016;) are proposing instructional models that integrated the two subjects to establish to the students how calculus is used and applied in Physics. However, many schools are still teaching calculus and physics as two separate subjects. The researcher believes that establishing the connection between the two subjects by integrating it as early as the senior high school will address some of the difficulties they experience. This would also help future college science students prepare to solve calculus-based physics problems that require complex calculations.

ACKNOWLEDGEMENT

I would like to extend my warmest and sincerest appreciation and gratitude to my statistics professor, Dr. Frederick Talaue of De La Salle University, who continuously guide and support me in writing and improving this study. I am also thankful for my colleagues' feedback and the cooperation of the respondents to make this study possible.

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