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SOLO Taxonomy and Newman Error Analysis: Understanding the Difficulties of Students in Solving Word Problems in Pre-Calculus

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ABSTRACT

Error analysis in mathematics education has a long history. For the past years, many researchers used error analysis to better understand students' incorrect solutions and/or answers when given mathematical word problems. This study is aimed at exploring the SOLO Taxonomy and Newman Error Analysis as means of understanding the difficulties of students from STEM track programs when solving word problems in Conic Sections in the senior high school setting. A descriptive-qualitative design was used to investigate the different errors committed by the students using the Newman Error Analysis and then describe how learners' understanding builds while solving word problems in Conic Sections using SOLO Taxonomy. The participants of the study were STEM students from Higher School ng UMak of the University of Makati. Validated open-ended questions were used to identify the level of understanding and errors committed by the students when solving the problems in Conic Sections. The study revealed that most students commit errors under the transformation level when their level of understanding is between multi-structural and relational. Implications and future research were discussed.

Keywords:: SOLO Taxonomy, Newman Error Analysis, Word Problems

Introduction

Mathematics is a powerful tool and a doorkeeper for success in life. It is believed to be the mother of all subjects. Exposure to mathematics can help students develop various skills. For instance, it helps students to acquire better organization of ideas. Also, it enhances accuracy in expressing their thoughts. It mainly offers a lot of 21st-century skills such as critical thinking, problem-solving, collaboration, agility, adaptability, effective communicating, accessing and analyzing, curiosity and imagination, and Information Technology and Communication literacy. Despite the importance of mathematics in all human endeavors, the poor performance of students, nowadays, is becoming alarming. In the recent report of PISA 2018, the Philippines ranked second to last than any other Southeast Asian country in mathematics (OECD, 2019; Villegas, 2021; Gravemeijer et al., 2017; Adegun & Adegun, 2013; National Research Council et al., 2001). The low ranking of the Philippines in the recent PISA 2018 can be attributed to the learning difficulties of the students in mathematics.

Difficulties in learning mathematics can be rooted in different factors. Some research reported that difficulties in learning mathematics include mathematical terms and their related concepts, qualification of teachers, the experience of teachers, low commitment on the part of teachers, and the attitude of students towards mathematics. Many topics and concepts in mathematics were found to be difficult as perceived by teachers and students. In addition, students also lacked in many mathematical skills such as number-fact, visual-spatial, and information skills which hinder mathematical problem-solving (Mulwa, 2015; Adegun & Adegun, 2013; Yusha'u, M. (2013); Tambychik & Meerah, 2010; Holton, 2009).

Polya's problem-solving is finding a way around a difficulty, around an obstacle, and finding a solution to a problem that is unknown. To completely solve the problem, the students must undergo different steps: (1) the students should understand the problem, (2) the students should devise a plan to solve the problem, (3) the students should execute the plan to solve the problem, and (4) the students should make sure that their solution and answer are correct or make sense to the given problem. The students should explore what the problems tell them to find out. The exploration involved using a different range of strategies to solve

unfamiliar problems, as well as the process of analyzing, reasoning, generalizing, and abstracting. In the exploration process, students can make errors (Atteh, et al., 2017).

Errors of students in solving problems in mathematics are always the quandaries of most mathematics teachers in the classroom. Several authors and researchers have conducted studies on why students commit errors in solving different kinds of problems and categorized these errors committed by the students. Some of them established well-defined and distinct theories and categorizations to describe why such errors occur when a student attempts to solve mathematical word problems. Different theories about how students commit errors in solving mathematical problems were started from the research of JS Brown and Kurt VanLehn in 1980-the Repair Theory, Anne Newman of Australia in 1977, and 1983-the Newman Error Analysis, to Clement and Ellerton from 1980 to 1996-the modification of Newman Error Analysis.

One of the theories of errors in Mathematics that has been increasingly used in analyzing errors in solving word problems is the Newman error analysis or NEA. It was developed by Anne Newman in Australia in 1977 and was used on elementary pupils who were solving basic word problems in Mathematics. According to Anne Newman, when students try or attempt to solve a problem that is unfamiliar to them, the error occurs on different levels: reading error, comprehension error, transformation error, process skill error, and an encoding error. But in 1980 and 1997, Ellerton and Clement modified the NEA model. They said that when students attempt a second time to solve problems and commit one of the errors in the hierarchy of Newman, other errors can occur: carelessness and motivation errors. One of these errors may occur at any stage of Newman's analysis of errors in solving problems in mathematics. In this study, the original classification of NEA was also used to identify the type of errors committed by students in solving word problems in mathematics.

Errors of students in solving mathematical problems are not simply a result of situational accidents but the product of previous experience in the classroom. One of the causes of errors in students is the failure to understand certain concepts, techniques, and problems in a "scientific" way. Many researchers have tried to use the NEA to identify errors committed by students involving mathematical word problems and tried to describe how each error occurs while some researchers used NEA to recommend remedial classes and interventions as their basis to minimize errors in solving word problems in mathematics. NEA spreads widely in different regions and countries in Asia-Pacific such as in Brunei (Mohidin, 1991), Malaysia (Marinas and Clement, 1990; Clements and Ellerton, 1992), Thailand (Prakitipong and Nakamura, 2006), Papua New Guinea (Clarkson, 1983 and 1991), Iran (Haghverdi, 2012; Sajadi, 2013), and Philippines (San Gabriel, 2011; Siducon, 2013). From these studies, the common errors committed by the students when solving word problems in mathematics were either Transformation error or Process error with a percentage ranging from almost 50% to 70%.

The use of NEA can be beneficial to the different stakeholders specifically the teachers and students. But, research studies on understanding the level of thinking in mathematics problem-solving using Structure of Observed Learning Outcomes (SOLO) Taxonomy by Biggs and Collis (1982) have been increasing (e.g. Amar, et al., 2017; Mardiyana, et al., 2017; Upu & Bangatau, 2018; Saputra, Nurjanah, & Retnawati, 2019, Mukuka, Balimuttajjo, & Mutarutinya, 2020). These studies used SOLO taxonomy for the identification of abilities of students in solving problems in mathematics, assessment, and instruction in a mathematics curriculum. The studies found out that: (1) SOLO taxonomy can very useful to influence mathematics assessment and instructions, (2) students' levels of thinking skills in solving mathematical problems are different because each student has also a different level of self-efficacy and cognitive style, (3) based on SOLO taxonomy students lack cognitive abilities and different mathematical skills such as readiness, planning, and process in solving word problems, and (4) students' thinking ability to solve problems is either pre-structural or uni structural and few to none reach the extended abstract. In SOLO Taxonomy, there are five distinct ways in which a learner might structure responses. The SOLO Taxonomy was created by carefully analyzing student responses to assess tasks and has been validated for use in a wide range of disciplines (Biggs & Collis, 1986 as cited by Potter & Kustra, 2012). The SOLO Taxonomy can be represented in the table below.

Table 1

The Description of Each Level in SOLO Taxonomy

Level of Understanding	Biggs Description
Pre-structural	Students do not understand the topic/problem.
Unistructural	Students learn one relevant aspect of the topic/problem.
Multi-structural	Students learn several independent aspects of the topic/problem but cannot link them together.
Relational	Students learn to link several independent aspects of the topic/problem into a structure.
Extended – Abstract	Students can generalize what they learn into new areas of knowledge.

The description of each level in SOLO taxonomy is the guide of this study to identify the ability of the

students in solving mathematical word problems but will be modified to fit in this study using indicators (see table 2) developed by Chick (1998) and was used in the study of Mulbar, Rahman, and Ahmar (2017) and Suptra, Nurjanah, and Retnawati (2018). These indicators were the guide of this study to analyze students' responses.

Table 2

The Indicators of Each Level in SOLO Taxonomy

Level of Understanding	Biggs Description
Pre-structural	• The student uses incorrect data or processes so that his/her conclusion obtained is incorrect or irrelevant • The student only has little information that is not even related, so it does not form a unified concept at all and does not have any meaning.
Unistructural	• The student can use at least one piece of information and use one concept or process. • The student uses a process based on selected data to solve the word problem but the conclusion obtained is not relevant.
Multi-structural	• Students use multiple data/information, but find no relationship between the data, so they cannot draw relevant conclusions. • Students can make some connections between several data/ information sources, but these relationships are not appropriate so the conclusions obtained are irrelevant.
Relational	• Students use multiple data/information to the applied concept/process and provide interim results then connect the data or other processes so that they can draw relevant conclusions. • Students associate the concept/process so that all relevant information is connected and relevant conclusions are obtained.
Extended – Abstract	• Students use multiple data/information, then, apply the concept/ process and provide interim results and, then, connect the data or other processes, so that they can draw conclusions that are relevant and can generalize about the results obtained. • Students think conceptually and can generalize in a domain/area of knowledge and experience of others.

Since there are little empirical data on the study of Newman error analysis and SOLO taxonomy in understanding the responses of the students when they solve mathematical word problems, this study aimed to explore the SOLO Taxonomy and Newman Error Analysis as means of understanding the difficulties of students from STEM track program when solving word problems in Conic Sections in a senior high school setting in the University of Makati

Methodology

The study used a descriptive-quantitative method of research as it intended to describe and classify the errors of the students in solving problems involving Conic Sections.

The researcher used a purposive sampling technique to select the respondents of the study to answer the eight open-ended word problems since the purpose of the study is to look for common errors of senior high school students in solving word problems. The respondents of the study were senior high school students of the University of Makati who were enrolled in a Pre-Calculus specialized subject. Only 49 students out of 70 from the two sections, G12-02STM and G12-05STM, participated in the study.

There were two instruments used in the study namely, the diagnostic test, and the rubric-score guide. The diagnostic test and the rubric were developed by the researcher. In this study, the researcher developed a diagnostic test composed of eight mathematical word problems in Pre-Calculus specifically in word problems involving Parabolas, Circles, Ellipses, and Hyperbolas. These mathematical word problems were used to identify the common errors committed by the students in solving word problems.

The diagnostic test was validated using rubrics developed by the researcher. The experts rated the diagnostic test and rubric using a 3-point scale. Based on the collected data, it was revealed that all the mathematical word problems involving the application of conic sections are acceptable with a grand mean of 2.86. Only eight out of thirteen validated moderate and difficult mathematical word problems were chosen in this study. The answer sheets for solving word problems involving conic sections were also provided. Each answer sheet is composed of the steps to solve the word problem involving the application of conic sections.

The rubric for scoring the students' solutions was also an instrument. It was composed of 5 indicators and a 5-point level of performance. Each point represents the type of error that attempted to solve each of the mathematical word problems. For example, if a student answered one of the mathematical word problems and meets all the indicators, he/she will receive five points. The rubric was also validated by the same experts. The data revealed that the rubric for scoring the students' solutions was acceptable with a grand mean of 3.00. It also includes indicators to identify the level of understanding of students in solving the word problem involving Conic Sections.

The conduct of the study underwent two stages. The first stage of the study involved the writing of items for the diagnostics test in word problems involving the application of conic sections. Writing of items was based on the competencies in the Pre-Calculus curriculum guide that was given by the Department of Education. After the writing of items, the diagnostic test was validated by the experts and then revised and finalized based on the expert's comments and recommendations. This was followed by the development of rubrics for the interpretation of students' solutions to the word problems in the application of conic sections. This was again content validated by the experts and modified the content of the rubrics using the expert's recommendation or suggestions. The second stage of the conduct of the study was the administration of the diagnostic test involving the application of conic sections (Parabola, Circle, Ellipse, Hyperbola) to the selected groups of participants who volunteered and gave their consent to participate in the study.

The percentage is used to summarize the common errors committed by students in solving word problems in Pre-Calculus and identify the level of understanding using SOLO Taxonomy. After the

students attempted to solve problems involving the application of conic sections, the researcher checked the solutions of the students using the indicators written in the rubric. In checking the students' solutions, the researcher used indicators to score each word problem. After the researcher gave the score for each word problem solved by the students, he interpreted the score to the type of error committed by the students and identify the level of understanding using the SOLO Taxonomy.

Results and Discussion

Tables 3 to 6 showed the descriptive analysis of the level of understanding using SOLO Taxonomy and types of error committed by the Grade 11 students in solving word problems involving conic sections: circle, parabola, ellipse, and hyperbola using the Newman Error analysis (NEA)

Table 3

Descriptive Analysis on Level of Understanding using SOLO Taxonomy and the Errors Committed by the Grade 11 Students in Solving Word Problems in Conic Sections (Circle) Using the NEA

PROBLEM SET	Level of Understanding Using SOLO Taxonomy	TYPES OF ERROR USING NEWMAN ERROR ANALYSIS											
		RE		CE		TE		PE		EE		NE	
		f	%	f	%	f	%	f	%	f	%	f	%
Circle 1* (N=46)	Pre-Structural												
	Unistructural			7	15.22								
	Multi-structural					39	84.78						
	Relational												
	Extended Abstract												
Circle 5** (N=41)	Pre-Structural	3	7.32										
	Unistructural												
	Multi-structural					16	39.02						
	Relational									1	2.44		
	Extended Abstract											21	51.22

Note: RE - Reading Error, CE - Comprehension Error, TE - Transformation Error, PE - Process Error, EE - Encoding Error, NE - No Error
**Moderate Level, **Difficult Level*

The data showed that out of 47 students, 46 solved problem 1, 39 (84.78%) students committed errors that are classified as Transformation error with multi-structural as their level of understanding, and 7 (25.22%) students committed errors that are classified as Comprehension error with uni structural as their level of understanding. However, one student did not answer problem 1. In addition, 41 students solved word problem 5, 16 (39.02%) students committed errors that are classified as Transformation error with multi-structural as their level of understanding, 3 (7.32%) students committed errors that are classified as Reading error with pre-structural as their level of understanding, and only 1 (2.44%) student committed error which is classified as Encoding error with relational as his level of understanding. It can be interpreted that almost 85% of the students who solved moderate word problems committed a Transformation error with multi-structural as their level of understanding while more than 39% committed a Transformation error with multi-structural as their level of understanding in the difficult word problem involving circle. Moreover, 21 (51.22%) students did not commit errors in difficult problems, and their level of understanding is under the extended abstract. This confirms the results of the study by Abdullah et al. (2015) that students commit Transformation error in word problems involving Higher Order Thinking Skills. In addition, more than 25% of the students who committed errors are classified as Comprehension error. San Gabriel (2011) found that students working with the higher levels committed most errors in Comprehension.

Table 4

Descriptive Analysis on Level of Understanding using SOLO Taxonomy and the Errors Committed by the Grade 11 Students in Solving Word Problems in Conic Sections (Ellipse) Using the NEA

PROBLEM SET	Level of Understanding Using SOLO Taxonomy	TYPES OF ERROR USING NEWMAN ERROR ANALYSIS											
		RE		CE		TE		PE		EE		NE	
		f	%	f	%	f	%	f	%	f	%	f	%
Ellipse 2** (N=47)	Pre-Structural												
	Unistructural			2	4.26								
	Multi-structural					11	23.40						
	Relational							15	31.91				
	Extended Abstract											19	40.43
Ellipse 8* (N=39)	Pre-Structural												
	Unistructural												
	Multi-structural					16	41.03						
	Relational							1	2.56			22	56.41
	Extended Abstract												

Note: RE - Reading Error, CE - Comprehension Error, TE - Transformation Error, PE - Process Error, EE - Encoding Error, NE - No Error
**Moderate Level, **Difficult Level*

The data showed that out of 47 students who solved problem 2, 15 (31.91%) students committed errors that are classified as Process error with a relational level of understanding, 11 (23.40%) students committed errors that are classified as Transformation error with multi-structural as their level of understanding, and 2 (4.26%) students committed errors that are classified as Comprehension error with uni structural as their level of understanding. Only 39 students solved problem 8. In this problem, 16 (41.03%) students committed errors that are classified as Transformation error with a multi-structural level of understanding, and only 1 (2.56%) student committed an error which is classified as Process Skill error with relational as their level of understanding. It can be seen that more than 40% of the students who answered moderate and difficult problems did not commit error and their level of understanding is under the extended abstract. Furthermore, 22 (56.41%) students and 19 (40.43%) students did not commit errors in moderate problems and difficult problems,

respectively, with extended abstract as their level of understanding. It can be interpreted that the majority of the students who committed errors solving difficult problems involving ellipses committed a Process skill error with relational as their level of understanding while the majority of the students who committed errors in solving moderate problems involving ellipses committed a Transformation error with multi-structural as their level of understanding. The result is similar to the study of Zakaria and Maat (2010) that the students who made errors in solving word problems in quadratic equations committed Transformation and Process Skill errors.

Table 5

Descriptive Analysis on Level of Understanding using SOLO Taxonomy and the Errors Committed by the Grade 11 Students in Solving Word Problems in Conic Sections (Hyperbola) Using the NEA

PROBLEM SET	Level of Understanding Using SOLO Taxonomy	TYPES OF ERROR USING NEWMAN ERROR ANALYSIS											
		RE		CE		TE		PE		EE		NE	
		f	%	f	%	f	%	f	%	f	%	f	%
Hyperbola 3** (N=43)	Pre-Structural												
	Unistructural												
	Multi-structural					41	95.35					2	4.65
	Relational												
	Extended Abstract												
Hyperbola 6* (N=43)	Pre-Structural												
	Unistructural					19	44.19						
	Multi-structural							4	9.30				
	Relational												
	Extended Abstract											20	46.51

Note: RE - Reading Error, CE - Comprehension Error, TE - Transformation Error, PE - Process Error, EE - Encoding Error, NE - No Error
**Moderate Level, **Difficult Level*

The data showed that out of 47 students, only 43 solved problem 3, 41 (95.35%) students committed errors that are classified as Transformation error with multi-structural as their level of understanding. Also, only 43 out of 47 students solved problem 6, 19 (44.19%) students committed errors that are classified as Transformation error with multi-structural as their level of understanding, and 4 (9.30%) students committed errors that are classified as Process error with relational as their level of understanding. Also, it can be seen that 20 (46.51%) students in solving moderate problems did not commit error with extended abstract as their level of understanding. The results can be interpreted that more than 95% of the students who committed errors when solving a difficult problem involving hyperbola committed a Transformation error with multi-structural as their level of understanding while less than 45% of the students who committed errors when solving a moderate problem involving hyperbola committed a Transformation error with uni structural as their level of understanding. These results concur with the findings of San Gabriel (2011) that students committed most errors in Transformation.

Table 6

Descriptive Analysis on Level of Understanding using SOLO Taxonomy and the Errors Committed by the Grade 11 Students in Solving Word Problems in Conic Sections (Parabola) Using the NEA

PROBLEM SET	Level of Understanding Using SOLO Taxonomy	TYPES OF ERROR USING NEWMAN ERROR ANALYSIS											
		RE		CE		TE		PE		EE		NE	
		f	%	f	%	f	%	f	%	f	%	f	%
Parabola 4* (N=47)	Pre-Structural	2	4.26										
	Unistructural												
	Multi-structural					22	46.81						
	Relational									2	4.26		
	Extended Abstract											21	44.68
Parabola 7** (N=43)	Pre-Structural	3	7.89										
	Unistructural												
	Multi-structural					35	81.4						
	Relational							2	4.65				
	Extended Abstract											3	6.98

Note: RE - Reading Error, CE - Comprehension Error, TE - Transformation Error, PE - Process Error, EE - Encoding Error, NE - No Error
**Moderate Level, **Difficult Level*

The data showed that out of 47 students who solved problem 4, 22 (46.81%) students committed errors that are classified as Transformation error with multi-structural as their level of understanding, 2 (4.26%) students committed errors that are classified as Reading error with pre-structural as their level of understanding, and 2 (4.26%) students committed errors that are classified as Encoding error with relational as their level of understanding. Only 43 out of 47 students solved problem 7. In problem 7, 35 (81.40%) students committed errors that are classified as Transformation error with multi-structural as their level of understanding, 3 (7.89%) students committed errors that are classified as Reading error with pre-structural as their level of understanding, and 2 (4.65%) students committed errors that are classified as Process Skill error with relational as their level of understanding. In addition, 21 (44.68%) students did not commit error with extended-abstract as their level of understanding. The results can be interpreted that almost 50% of the students who solved a moderate problem involving a parabola committed a Transformation error with multi-structural as their level of understanding while more than 80% of the students who solved a difficult problem involving a parabola committed a Transformation error with multi-structural as their level of understanding, and only a few students (~8%) committed a Reading error with a pre-structural level of understanding. This is similar to the findings of Trance (2013) that students frequently made errors in Transformation and very few students committed a Reading error.

Conclusion and Recommendations

Most of the Grade 11 students who solved the moderate and difficult word problems involving the applications of Conic Sections have learning difficulties when they committed a Transformation error with multi-structural as their level of understanding. Applying appropriate methods and transforming the word problem into conic sections are the most difficult procedures for students in solving the word problems involving the applications of Conic Sections. Furthermore, the use of error analysis and SOLO Taxonomy can be beneficial in the learning process for teachers to understand the mathematical difficulties of their students since a large number of errors in solving the applications of conic sections can be reflected in the PISA results.

A more comprehensible study of error analysis in Conic Sections with a larger sample may be conducted for a more conclusive and accurate result. SOLO Taxonomy and Error analysis on students' solutions to word problems may be done by teachers to identify and understand the difficulties of students in learning mathematics. Remedial intervention programs must be done to minimize the different errors committed by students under the Transformation level and improve students' level of understanding.

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