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Procedural Knowledge-to-Conceptual Knowledge or Conceptual Knowledge-to-Procedural Knowledge: Which Order of Knowledge is Better for Conceptual Understanding and Procedural Fluency

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Abstract This study explored the effectiveness of the two orders of instruction (conceptual-to-procedural knowledge and conceptual-to-procedural knowledge) to grade 10 students' conceptual understanding and procedural fluency. A quasi-experimental control-group pretest-posttest design was used. The control group experienced a conceptual-to-procedural order of instruction which is the usual practice in the school while the experimental group experienced a procedural-to-conceptual order of instruction. Quade's ANCOVA, a non-parametric statistical tool, was used to examine if there is a significant difference between the student's conceptual understanding and procedural fluency when grouped according to order of instruction. A non-parametric statistical tool was utilized because the data was found to be not normally distributed. The pretest scores serve as a covariate in Quade's ANCOVA to reduce the error variance and to eliminate systematic bias. Results showed that, there is no significant difference in the students' conceptual understanding and procedural fluency in measures of central tendency, measures of dispersion, and measures of position when grouped according to the order of instruction. Moreover, students under the conceptual-to-procedural knowledge and procedural-to-conceptual knowledge performed similarly. Thus, the researchers recommend the interchangeable use of order of instruction. Since there is a bidirectional relationship between conceptual and procedural knowledge, the teachers are recommended not to stick with just one order of instruction but to use it iteratively.

Keywords: *conceptual knowledge, procedural knowledge, conceptual understanding, procedural fluency, Quade's ANCOVA*

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1. Introduction

The Philippines has been performing low on international assessments in mathematics, a dilemma that the Department of Education has been strongly rectifying through the introduction of new techniques and teaching strategies. During the 2022 Programme for International Student Assessment (PISA), Filipino students ranked among the lowest-performing students among all participating countries. In mathematics, results revealed that only 16% of Filipino students exhibited a minimum proficiency level (Level 2); 84% demonstrated low proficiency (Level 1) and no student from the Philippines is a top performer in Mathematics [1]. This result from the 2022 PISA only solidifies the fact that Filipino students have the lowest level of proficiency among their peers in the other parts of the world with a huge gap in terms of mathematics education and skills.

Additionally, in the 2019 edition of the Trends in International Mathematics and Science Study (TIMSS), the Philippines scored 297 in Mathematics, the lowest among the 58 countries that participated in the study [2].

To address the low performance among students on Mathematics, the National Research Council identified five strands of mathematical proficiency that are essential for developing math skills in students. Among the five strands, conceptual understanding and procedural fluency are two components [3].

In developing conceptual understanding and procedural fluency, two types of knowledge are involved—conceptual knowledge and procedural knowledge. Conceptual knowledge is essential to understand the basic concepts in mathematics and procedural knowledge is required to point out the steps to solve problems [4]. This aligns with principles and standards for school mathematics, that understanding mathematical concepts and fluency in procedures is very significant for students in the learning process [5].

Conceptual and procedural knowledge in mathematics have generated much discussion over the years. The concept-driven vs. skills-oriented perspectives have led to a series of arguments and discussions between researchers. Speculations about whether this sort of knowledge is more significant or what may be an adequate balance between them are at the heart of questions concerning how students should learn mathematics, and particularly how they should be taught [6].

In the study of Hurrell (2021) [7], he concluded that both conceptual and procedural knowledge are crucial, and they complement one another. Furthermore, if students begin with conceptual information before moving on to procedural knowledge, there is a greater probability that they will build a conceptual understanding. Going the other way runs the risk of discouraging learners from pursuing conceptual understanding first. These results were supported by Rittle-Johnson & Alibali (1999) [8] which suggests that conceptual knowledge may influence procedural knowledge more strongly than the reverse.

However, in the study of Cheung, Kulasegaram et al. (2019) [9] where they compared groups with procedural-only and integrating conceptual knowledge, the results indicate that incorporating conceptual knowledge improves skill transfer but not skill retention. Additionally, Sweller, van Merrienboer, and Paas (1998), [10] studied evidence that suggests that learning a procedural skill can reduce the cognitive demands on working memory. This demand decrease can free the working memory to concentrate on developing conceptual information.

Uncertainty exists regarding the developmental relationships between procedural knowledge and conceptual knowledge [11]. Understanding how the two types of knowledge interact is crucial to comprehending how learning takes place.

In Corpus Christi School, where the study takes place, the standard practice of delivering a mathematical lesson starts with conceptual knowledge building and is followed by procedural knowledge mastery. The school follows the mathematics framework for Philippine basic education where the order of instructions starts with conceptual knowledge followed by procedural knowledge [12]. Although, there are bidirectional relationships between conceptual and procedural knowledge, there may be a certain sequence that is best for instruction. According to the widely accepted conceptual-to-procedural knowledge paradigm, instruction should first establish conceptual knowledge in great detail before concentrating on procedural knowledge [13,14].

Considering this, this study provides more empirical data regarding the efficacy of the conceptual-to-procedural and procedural-to-conceptual orders of instruction. The researcher compared the impact of the two orders of instruction on students' procedural fluency and conceptual understanding.

2. Methodology

2.1. Research Design

The researcher used a quasi-experimental pretest-posttest control group design. According to Thomas [15], a quasi-experimental design aims to establish a cause-and-effect relationship between an independent and dependent variable. For this study, this design was used to determine if there is a significant difference in the student's conceptual understanding and procedural fluency proficiency level as influenced by the order of instruction. The treatment (X) represented by the order of instruction using procedural knowledge first followed by conceptual knowledge follows the design below:

Control	O_1	O_2
Experimental	O_1	$X\left(P-to-C\right)\ O_2$

As shown in the figure above, the study is composed of two intact groups assigned as the control and experimental group. These groups were given a pretest (O_1) and a posttest (O_2). The experimental group was given treatment (X), which is the procedural-to-conceptual order of instruction.

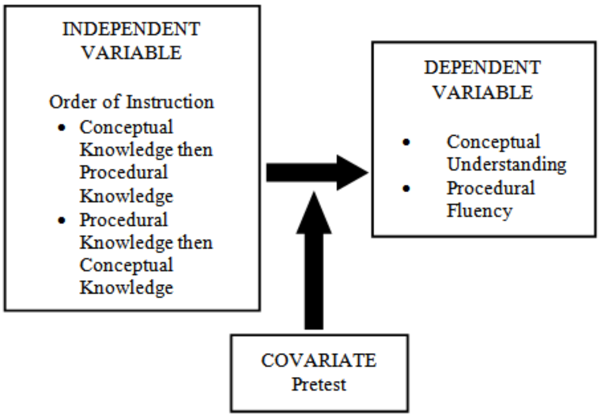

Figure 1. Interplay of the Independent Variable and Dependent Variable

2.2. Participants

The study was conducted at Corpus Christi School – Macasandig Campus. Corpus Christi School is a school that offers pre-school, grade school, junior high school, and senior high school education in Cagayan de Oro City with two campuses. The participants of the study are Junior High School students, specifically, Grade 10 students for the school year 2022 - 2023. A total of 81 participants were taken from four (4) intact sections with an average number of 20 students per section. Since the school is still adjusting to the new educational setup, the participants were undergoing 5 days of face-to-face classes and 5 days of online classes using the Silid Learning Management System (LMS), the school's official LMS. Out of the 4 sections, the researcher randomly picked 2 sections as the control group and 2 sections as the experimental group. These groups were handled by the researcher.

2.3. Research Instrument

The research instrument that was used in this study is a 10-item researcher-made questionnaire. This questionnaire covers topics from the Fourth Quarter of Grade 10 Mathematics which are measures of central tendency, measures of dispersion, and measures of position. The questions stipulated in the questionnaire were aligned with the Grade 10 Mathematics Curriculum Guide prescribed by the Department of Education.

Since the questionnaire was researcher-made, the validity and reliability of this instrument are very important. The questionnaire designed for this study was subjected to a validation process for face, construct, and content validity. The constructed questions were checked to ensure that all questions were aligned in the table of specification (TOS). Lastly, for the content validity, the questionnaire was checked to ensure that the instrument would address all the research problems. For the reliability of the instrument, Cronbach's coefficient alpha was used by the researchers to measure the internal consistency. The goal in designing a reliable instrument is for scores on similar items not only to be related (internally consistent) but also for each to contribute some unique information as well. The instrument gave a result of $\alpha = 0.76$ which signifies that the items have high internal consistency, and the instrument is good for classroom tests.

2.4. Data Analysis

Data were collected by means of 8-item open-ended questions pretest-posttest on mean, median, mode, standard deviation, deciles, and percentiles for grouped and ungrouped data. Both control and experimental groups answered the pretest on the same day. The treatment process was conducted immediately the next day after the pretest. Each group was met by the same teacher 3 times a week for 50 minutes. A total of 8 weeks were used for this study.

In the control group, students were taught starting with conceptual knowledge like the definition of mean, median, and mode followed by their characteristics and when it is best used. After mastering the conceptual knowledge of the measures of central tendency, students were then taught procedural knowledge like how to use the formula, and the steps to follow in solving measures of central tendency.

On the other hand, the students in the experimental group were taught using procedural knowledge first. Students were taught the steps of solving the measures of central tendency and how to use the formula.

After achieving mastery in procedural knowledge, students were then taught conceptual knowledge about the topic like the definition of mean, median, and mode followed by their characteristics and when it is best used. The post-tests were administered right after the end of the quarter.

The researcher employed descriptive and inferential statistics to interpret the gathered data. To determine the proficiency of the conceptual understanding and procedural fluency of the students, the mean and standard deviation will be utilized. A scoring guideline was used in interpreting a student's level of proficiency. Meanwhile, to determine the effect of the intervention, the researcher supposedly used ANCOVA. According to Rosenstein (2019) [16], ANCOVA is a parametric test with the following assumptions: normality distribution of the residuals, homogeneity of variance (or homoscedasticity), linear relationship between the covariate and the dependent variable at each level of the independent variable, and homogeneity of regression slopes (no interaction effect between the covariate and the independent variable). These assumptions were tested, and the results showed that only the experimental group is normally distributed, homogeneity of variance was displayed by the conceptual understanding data only, and there is no interaction effect between the covariate and the independent variable therefore, homogeneity of regression slopes is achieved for. Additionally, using the boxplots, it was found out that there are no outliers from the data. Since not all assumptions were met, the researcher employed non-parametric Quade's analysis of covariance (ANCOVA). The pretest scores serve as a covariate in ANCOVA to reduce the error variance and eliminate systematic bias.

3. Results and Discussion

Table 1 presents the descriptive analysis of the mean scores and standard deviation of the student's conceptual understanding before and after the intervention. The mean score reveals that the groups exhibited a beginning level of conceptual understanding for the pretest. It is noticeable that the control group's mean score is greater than the experimental group, implying that the control group's prior knowledge about the topic is higher than the experimental group's. Additionally, the standard deviation of the pretest score for both the control and experimental groups is included in the table. It can be observed that the amount of variation in test scores in the control group is more than that in the experimental group, indicating that the test scores in the experimental group fluctuated closer to the mean than in the control group. This means that their performance score before the treatment is marginally different.

Table 1. Performance of the Experimental and Control Groups on the Conceptual Understanding Test

Groups	N	Pretest		Posttest		Adjusted Means
		Mean	SD	Mean	SD	
Control	41	14.73	8.34	43.54	20.63	41.571
		Beginning		***Moderately Strong***		
Experimental	40	10.38	6.98	43.27	17.80	45.290
		Beginning		***Moderately Strong***		

Legend: *Perfect Score: 76.00*

Mean Interval	Description
65 - 76	*Very Strong*
51 - 64	*Strong*
37 - 50	*Moderately Strong*
23 - 36	*Developing*
0 - 22	*Beginning*

The posttest showed that both groups improved from the beginning level to a moderately strong level. The control group showed a higher mean compared to the experimental group but the difference is quite small (0.27).

In terms of standard deviation, the control groups' posttest is more spread out with a standard deviation of 20.63 compared to the experimental group with a standard deviation of 17.80. This explains the different levels of variance of the experimental and control groups. Specifically, the control group posttest scores vary by ±20.63, indicating a wide spread in scores toward the mean, compared to the experimental group posttest scores, which vary by ±17.80, indicating a close variation in scores toward the mean. It is quite noticeable that the experimental group had a close variation of scores towards the mean, implying that participants' test scores are closely similar.

The analysis of covariance findings for the participants' degree of conceptual understanding is summarized in Table 2. The data indicate no significant difference in post-test scores between groups (1,79) = 1.296, *p* = .258, supporting the null hypothesis that the degree of conceptual understanding was similar between groups.

Table 2. Quade's ANCOVA Summary of Students' Conceptual Understanding

Source	Df	Sum of Squares (SS)	Mean Squares (MS)	F	p-value
Treatment between groups	1	639.652	639.652	1.296	.258
Error	79	39005.614	493.742		
Total	81	39645.266			

The results indicate that the experimental group exposed to procedural-to-conceptual knowledge becomes moderately strong as the control group. Although there is an amount of increase in the control group, this increase is comparable to the experimental group, as evidence was a non-significant result in the analysis of covariance. This indicates that both groups' level of conceptual understanding was almost similar after the intervention period. These results explain why the studies of Valmoria and Tan (2019) [17] and Haapsalo (2003) [18] have different or conflicting results. Both of their studies resulted in one dominating order of instruction. In Balmoria's study, students under the conceptual-to-procedural order of instruction performed better in conceptual understanding than those who were under the procedural-to-conceptual order. In Haapsalo's study, he concluded that procedural knowledge enables the development of conceptual knowledge using his MODEM utilizing Java Technologies.

The finding of this current study affirmed the complementary importance of these two main components of instruction and that the order of instruction is not that significant in terms of developing conceptual understanding. Both conceptual and procedural knowledge are crucial, and they complement one another well [7]. The results above aligned with the study's findings of Rittle-Johnson, Schneider, and Star (2015) [19]. They found that the development of procedural knowledge promotes the development of conceptual knowledge, on the other hand, conceptual knowledge supports the development of procedural knowledge. Students can better recall and use procedures when linked to underlying concepts [20]. Both orders of instruction increased the student's conceptual understanding. Greater learning resulted from switching back and forth between conceptual and procedural knowledge lessons [21].

Table 3. Performance of the Experimental and Control Groups on the Conceptual Understanding Test

Groups	N	Pretest		Posttest		Adjusted Means
		Mean	SD	Mean	SD	
Control	41	5.88	3.43	17.71	7.69	17.115
		Beginner		***Developing***		
Experimental	40	3.90	2.78	18.40	5.67	19.007
		Beginner		***Developing***		

Legend: *Perfect Score: 28.00*

Mean Interval	**Description**
26 – 28	*Exemplary*
20 – 25	*Proficient*
14 – 19	*Developing*
8 – 13	*Emerging*
0 – 7	*Beginner*

Table 3 shows the mean, standard deviation, and adjusted means of the control and experimental group on the procedural fluency test. The table shows that the control group has a higher pretest mean of 5.88 than the experimental group with a pretest mean 3.09. However, both the control and experimental group are under the beginner level as evidenced by their means. This indicates that both groups do not have prior skills for the procedural fluency test. Also, the standard deviation of the control group has a higher value compared to the experimental group (3.43 vs 2.78). This indicates that the test score of the experimental group is closer to the mean compared to the control group.

The posttest reveals that after the intervention, both groups have an increase in their procedural fluency skills. The mean of the experimental group's posttest 18.40 is higher compared to the control group's posttest 17.71. However, the difference is small and both groups have developing levels in the procedural fluency test. The standard deviation of the experimental group 7.69 is higher compared to the standard deviation of the control group 5.67 leading to an analysis that the experimental group's posttest result has closer variation towards the mean compared to the control group with a wider variation.

Table 4. Quade's ANCOVA Summary of Students' Procedural Fluency

Source	Df	Sum of Squares (SS)	Mean Squares (MS)	F	p-value
Treatment between groups	1	617.813	617.813	1.210	.275
Error	79	40322.662	510.413		
Total	81	40940.475			

The analysis of covariance findings for the participants' degree of procedural fluency is summarized in Table 4. The data indicate no significant difference in post-test scores between groups (1,79) = 1.210, *p* = .275, supporting the null hypothesis that the degree of procedural fluency was similar between groups.

The results indicate that the experimental group exposed to procedural-to-conceptual knowledge increased from beginner to developing with the same results as the control group. Although there is an increase in the amount of the control group, as shown in the previous table, this increase is comparable to the experimental group. As evidence, there was a non-significant result in the analysis of covariance. This indicates that both groups' level of procedural fluency was almost similar after the intervention period.

Procedural fluency requires procedural knowledge (knowledge of the steps taken to accomplish a goal), conceptual knowledge (knowledge of concepts that reflect abstract ideas or general principles), and a dynamic relationship between both [22]. The result of this paper agrees with the results of Rittle-Johnson and Koedinger's study in 2009 [21] which concluded that it has been demonstrated that an iterative link between procedural and conceptual knowledge facilitates the application of procedures to new contexts and fosters procedural flexibility and adaptivity. [23]. These results are consistent with a number of recent research that, using diverse methods and mathematical domains, revealed indirect evidence for the existence of bidirectional relationships between conceptual and procedural knowledge. Specifically, in fourth and fifth graders' study of equivalence problems, direct instruction on one type of information improved the other type of knowledge [24], and iterating between sessions on concepts and procedures on decimals helped a sample of sixth graders learn more procedural knowledge than when concept lessons came first [21].

Conceptual knowledge may aid in the creation, selection, and effective application of problem-solving techniques. Inversely, as students practice employing processes, their conceptual comprehension may also grow and deepen. Both types of knowledge are interconnected and might eventually reinforce one another. The architecture of the human information processing system is fundamentally characterized by the bidirectional relationships between conceptual and procedural knowledge. [9]

However, this study contradicts the findings of Valmoria and Tan (2019) [17], whose research found that procedural-to-conceptual instruction had less of an impact on Grade 7 students' procedural fluency with number operations than did conceptual-to-procedural instruction.

To support the quantitative finding, the researcher also conducted a qualitative examination of student work. The researcher compared the students' use of concepts, principles, and techniques in formulating and defending their solutions. The responses of some students are displayed below:

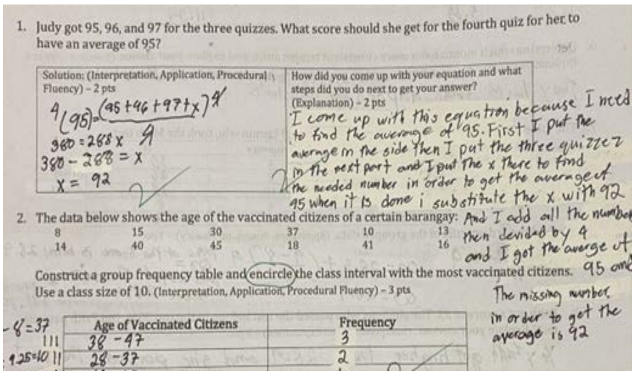

Figure 2. Answer on item number 1 written by a student from the experimental group (ES14) exposed under procedural-to-conceptual knowledge order of instruction

The student in the experimental group started his solution using his conceptual knowledge about the mean. He knew that the mean is a result of adding the scores divided by the total number of scores. The student then proceeded to apply his procedural knowledge to the problem. Since he knew the formula to use, he integrated his algebra skills to solve for the missing term. After solving for the missing term, the student once again used his conceptual knowledge and used the formula to find the mean. He substituted the solved number in the formula and used his procedural knowledge to conclude that the missing number is really 95.

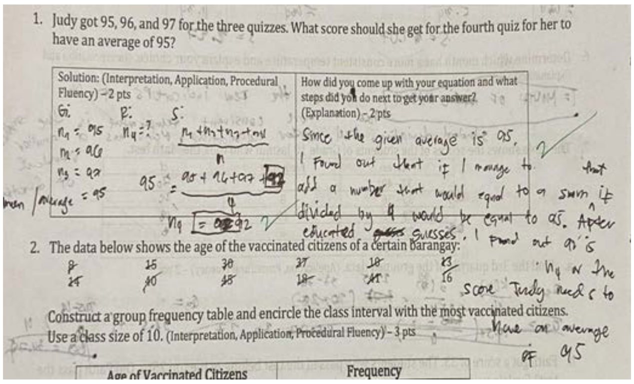

Figure 3. Answer on item number 1 written by a student from the control group (CS23) exposed under conceptual-to-procedural knowledge order of instruction

On the other hand, the student from the control group started his solution using his conceptual knowledge about the mean. After determining what formula is appropriate to use, the student uses procedural knowledge to determine the missing number using trial and error. The student kept on substituting any number until he got a mean of 95.

As evident in both groups, the use of conceptual knowledge and procedural knowledge was interchangeable. Both groups were able to arrive at the correct answer even though they used different ways. Therefore, this supports the result that both the experimental and control groups have comparable results.

4. Conclusion

This study seeks to determine which order of instruction is most effective in developing conceptual understanding and procedural fluency. This study concludes that both orders of instruction (conceptual-to-procedural and procedural-to-conceptual) were effective, and no certain order is better than the other. This study affirmed the complementary importance of these two main components of instruction and that the order of instruction is not that significant in terms of developing conceptual understanding and procedural fluency.

Recommendation

Based on the findings and conclusions of the study, the researcher recommends the interchangeable use of order of instruction. Since there is a bidirectional relationship between conceptual and procedural knowledge, the teachers are recommended not to stick with just one order of instruction but to use it iteratively. Also, given that the experimentation period occurred during blended learning with a combination of face-to-face and online classes, it would be interesting to conduct additional research on full face-to-face instruction incorporating both orders of instruction. This study is also not just limited to Mathematics; therefore, future studies are encouraged to check relationships across other grade levels and other subject matters.

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