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Predictive analysis of cognitive skills achievements in mathematics along seven logical operations among elementary pre-service teachers

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Abstract: The study aimed to examine the predictors of cognitive skill achievement along seven logical operations in mathematics based on academic aspects and social learning domains among 328 elementary preservice teachers at Central Luzon State University during the second semester. This study utilized a quantitative method with descriptive and correlational approaches. A total of 328 pre service elementary teachers at Central Luzon State University participated in a study that aimed to assess their academic elements, social learning domains, and cognitive skills achievements. To collect the data, a standardized research instrument taken from the National Assessment of Educational Progress (NAEP) based on the Scenario-Based Task (SBT) was adapted to measure academic and social learning domains, while the Test on Logical Operations (TLO) was used to determine their cognitive skills achievement in mathematics along seven logical operations (classification, seriation, logical multiplication, compensation, ratio and proportional thinking, probability thinking, and correlational thinking). The results revealed that year level, preferred subject to teach, cognitive aspects, affective domain, and cognitive development practice as components of the social learning domain were found to influence cognitive skills achievement in mathematics. Further assessment is recommended on two distinct variables to find the connection between cognitive skills achievement applicable to elementary preservice teachers and metacognitive skills achievement for secondary prospective teachers. Cognitive development practice shows that one is capable of using the brain to comprehend various numerical concept processes, and it is more prospective to affect his or her capability to adjust to a particular environmental condition for learning the logic operations of numeracy.

Keywords: *Academic domains, Cognitive skills achievement, Logical reasoning, Mathematics education, seven logical operations, Social learning domains.*

1. Introduction

The attainment of cognitive skills is a fundamental factor in achieving academic success, as these skills are influenced by one's cognitive abilities. This input-output process defines one's brain's ability to accumulate and process information, including those related to attention, logical reasoning, thinking, and transformation in particular. It is likewise believed as a key element that research can constantly forecast academic performance, in this case, cognitive skills achievement. According to Zhao [1], scholastic success defines individual actual performance relative to mastery of academic knowledge and skills demonstrated through assessment after a tedious but systematic learning process. In the Philippine educational system, for instance, state universities and colleges commonly classify students by academic achievements through college entrance examinations. Thus, this research strongly argues that cognitive skills achievement, especially among pre-service teachers in teacher education programs' classification examinations, may determine students' future transformation; thereby, examining the elements that

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would assist each student's cognitive skills achievement and development would be imperative mathematics education. Liu [2] emphasized that academic achievement is the measure of student scholastic performance in broad areas of discipline, including numeracy, and is one of the most significant reference factors for admission to universities and colleges.

Both academic factors and social learning domains have been identified as key factors that greatly contribute to student's cognitive skills achievement [3]. Academic domains, including self-discipline, have been identified as crucial elements governing one's cognitive skills achievement, especially since the educational system adopted virtual instruction following the outbreak of the global pandemic. Conversely, there seemed to be opposing ideas about how academic factors and social learning domains work together to influence their cognitive skills and achievement. Likewise, the components of individual academic practice and social learning approaches have rarely been examined alongside cognitive skills achievement in mathematics for their impact on academic performance in general.

This study aimed to investigate the cognitive skills achievement, academic factors, and social learning domains of elementary pre-service teachers. Additionally, a structural categorization of cognitive skills in mathematics achievements was utilized as a moderating mediating variable to explore the factors that influence these constructs.

Predictors of academic achievements, which are referred to in this study as cognitive skills achievement, have been linked to memory, processing, and extraction of information, which involve attention and logical reasoning [4]. Previous research focused on the direct impact of the personal cognitive abilities of students on their academic achievement Miriam, et al. [5]. Rohde and Thompson [6] determined that cognitive factors and skills had direct contributions to academic achievement, as these were found to have a highly significant relationship.

By forecasting the factors associated with cognitive skills achievement, it would be inevitable to link constructivism theory, which situates relevance and continuity on the theory of cognitive development [7], that theorized aptitude skill as the rudimentary mechanism of ensuring symmetry in the relationships between an individual and his environment. Piaget further emphasized that the mechanism connected with this process of increasing abstraction, interiorization, and coordination symbolizes concept development in abstract form. Kraft [8] noted that these abilities assist students in classifying new concepts into cognitive loads and transmitting content and procedural knowledge from recognized schemas to new challenges. Edens, et al. [9] likewise emphasized that cognitive growth gains would occur within the first two years at the college level. This phenomenon has significance for college administrators and educational leaders with four-year college degrees. Thus, in the context of this study, teaching and learning the seven logical operations in mathematics would have far-reaching implications in order to assist the preservice teachers in attaining the ideal level of cognitive skills that would match their biological age and capacity. This researcher believes that the present situation of pre-service teachers' cognitive skills achievement in mathematics in the local teacher education programmes is quite alarming. By looking at Piaget's seven logical operations, it would be likewise debatable to discern pre-service teachers' cognitive skills achievement according to socio-demographic characteristics, academic aspects, and social learning domains, which would offer new insights for a deeper understanding of the process.

Certainly, there may be certain predictors that may support individual differences in cognitive skills achievement in mathematics as well as determine the predictors of elementary pre-service teachers' cognitive skills achievement.

Thus, this study sought to find out the significant predictors of cognitive skill achievement in the seven logical operations in mathematics among elementary pre-service teachers. The study's main goal was to find out which of the student's socio-demographic traits, academic factors such as cognitive, affective, psychomotor, and social learning domains, as well as their health and physical condition, could predict how well they would do in learning the seven logical operations in mathematics. This study hypothesized that socio-demographic profile, academic domain, and social learning domain do not predict elementary pre-service teachers' cognitive skills achievement in mathematics.

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2. Methodology

2.1. Materials and Methods

2.1.1. Research Design

The study used a descriptive research design utilizing a questionnaire to describe the cognitive skills achievement in basic mathematics of elementary pre-service teachers at CLSU. Descriptive research design is a purposive process of gathering, analyzing, classifying, and tabulating data about prevailing conditions, practices, beliefs, processes, trends, and cause-and-effect relationships and then-making an adequate and accurate interpretation of such data with or without the aid of statistical methods. In addition, the study used a correlational research design (1) to investigate the difference in cognitive skills achievement in the mathematics group of respondents according to personal, social, and academic domains, (2) to find relationships between independent and dependent variables, and the researcher's goal is to determine whether the independent variable affected the outcome, or dependent variable, by comparing two or more groups of individuals, and (3) to measure and describe the degree of association among independent and dependent variables.

2.1.2. Locale and Study Site

The study was conducted at the College of Education, Central Luzon State University (CLSU) during the second semester, academic year 2022-2023, located in Science City of Muñoz, Nueva Ecija. CLSU. Considered one of the most renowned and prestigious teacher education state-institutions, it is recognized as a center of excellence in Teacher Education.

2.1.3. Respondents to the Study

This study utilized a total enumeration sampling design in selecting the respondents. There were 328 elementary pre-service teachers (Bachelor of Elementary Education) who participated in the study. Total enumeration was considered since they represented the entire population of the study.

2.1.4. Instrumentation

The study used a questionnaire with four sections: a) socio-demographic information; b) academic information (cognitive, affective, and psychomotor aspects); and c) social learning information (approaches to learning, cognitive development practice, language acquisition and communication, health and physical development, and emotional–social development). Each section had about six to eight statements, and people could answer them with a number from 5 (strongly agree) to 10 (strongly disagree).

To determine the instrument's validity and reliability, the researchers asked experts to examine the test, which was administered to randomly select pre-service students. The results of the test were item-analyzed to identify its discrimination and difficulty indices, which were used as the basis for item classifications as good, marginal, and/or poor items. While marginal items were modified and improved in line with the scope of the study, good items were retained. Further, the reliability of the instrument was determined using the split–half method, and the reliability coefficient was computed with a Cronbach's alpha or coefficient alpha of $\alpha > 0.87$, which means that the research instrument was reliable.

The respondents were asked to place a check (/) for each characteristic that described them in the first part of the instrument. Respondents answered part two, the TLO, based on what is being asked for its sub-parts. On the items for classification, the respondents encircled their answer among the choices, while on the items for seriation, the respondents supplied the missing term(s) as the answer for each item. For logical multiplication, compensation, ratio and proportional thinking, and probability thinking, respondents were asked to solve each problem in each logical operation. On the items for correlational thinking, respondents logically analyzed and determined the relationship between two variables. All items were problem solving-based; thus, a solution for each problem was required to be shown, which served as the basis for scoring.

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2.1.5. Methods of Data Gathering

The instrument was administered by the requested faculty, who acted as the facilitator, and four (4) of his math major students, who served as the research enumerators. To observe proper protocol, letters of request and permission to administer the questionnaire were addressed to the concerned office. Prior to answering the questionnaire, the research facilitator and the assigned enumerators clarified the instructions to the respondents and permitted them to independently work on their own phase for a time duration of one (1) hour or so. Prior to data gathering, ethics approval was sought to protect the privacy of the respondents. During the course of the study, their real names were not disclosed, and all the data being gathered was kept with the utmost confidentiality and only utilized for the purpose of this study.

2.1.6. Methods of Data Analysis

The answers to the questionnaires provided were analyzed by descriptive and inferential analyses using Statistical Package for Social Sciences (SPSS) and MS Excel Worksheets to make the computations easier in treating collected data. The collected data were tabulated and summarized through Microsoft Excel, after which the Statistical Package for Social Sciences (SPSS) was applied for the treatment of the data.

We used frequency distribution, percentages, means, and standard deviation to show the respondents' socio-demographic details, as well as their academic and social learning factors, cognitive skill achievement, and how they categorized their cognitive skill achievement. Moreover, to find out the significant difference in the elementary pre-service teachers' cognitive skills achievement in mathematics when grouped according to socio-demographic characteristics, inferential statistics and a series of One-way ANOVA with post hoc analysis were utilized while Pearson r-moment correlation was applied in determining the significant relationship, which is the mandatory requirement for multiple regression analysis.

3. Results and Discussion

3.1. Predictors of Cognitive Skills Achievement in Mathematics

Table 1 illustrates the predictive analysis of elementary pre-service teachers' cognitive skills achievement in mathematics along seven logical operations. A multiple linear regression analysis was performed to determine whether socio-demographic profile, academic domains such as cognitive aspects, affective aspects, and psychomotor aspects, and social learning and development in terms of approaches to learning, cognitive development practice, language acquisition and communication, health and physical development, and emotional and social development could predict the cognitive skills achievement of the elementary pre-service teachers in mathematics. The results revealed that the model is significant; $R^2 = 0.417$, $Adj.R^2 = 0.393$, $F_{(14,313)} = 12.941$, $p < 0.05$. The coefficient of determination R^2 means that about 41.70 % of the variance in the cognitive skills achievement of the elementary pre-service teachers is explained or accounted for by the related independent variables combined. The result of the ANOVA also indicates that the model is significant, that the regression model is significant, or that the model fits the data.

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Table 1.
Multiple regression analysis predicting the respondents' cognitive skills achievement in mathematics.

Predictors	*B*	Standard error	t	P-value
Constant	3.11	1.20	1.01	0.000
Sex	4.21	9.08	1.44	0.153
Place of residence	-1.40	2.11	-0.83	0.409
Mother's educational attainment (MEA)	1.31	3.12	0.63	0.529
Father's educational attainment	-3.20	2.59	-2.01	0.058
Year level	1.58	1.85	0.61	0.047
Preferred subject to teach	-2.23	1.67	-4.33	0.033
Cognitive aspect	3.84	2.46	2.37	0.002
Affective aspect	1.34	2.08	1.23	0.021
Psychomotor aspect	2.40	2.00	0.83	0.409
Approaches to learning	1.97	1.12	0.31	0.529
Cognitive development practice	3.20	2.59	2.01	0.048
Language acquisition & communication	-1.22	1.02	-2.63	0.547
Health & physical development	4.23	1.34	1.33	0.070
Emotional & social development	1.84	0.46	1.37	0.120

Note: $R^2 = 0.417$, Adj.$R^2 = 0.393$, $F_{(14,313)} = 12.941$, $p < 0.05$
Sex (1-male, 2-female), Place of Residence (1-Rural, 2-Urban), MEA-(1-w/o degree, 2-w/ degree), FEA-(1-w/o degree, 2-w/ degree), Preferred Subject to Teach-(1-Science,2-non-science).

3.2. Year Level and Cognitive Skills Achievement

Specifically, *Year Level* is a positive predictor of *Cognitive Skills Achievement*, $\beta = 1.58$, Std.error = 1.85, $t = 0.61$, $p < 0.05$, indicating that year level in college which corresponds to age, has been identified to have influenced cognitive skills achievement among prospective teachers in teacher education program. As the result suggests, academic achievement is significantly inclined to one's class group, represented by a particular year both homogenous and heterogenous groups. Thus, respondents in higher years are more likely to manifest higher cognitive skills achievement as compared to freshmen students in mathematics class.

The finding concurred with previous studies in this context. The study conducted by Gamit [10] using teacher-made tests on logical operations in mathematics revealed that cognitive skills achievement among students is influenced by year level, which comprises heterogeneous groupings. However, the results showed that lower year levels were categorized as late concrete, while few of the higher year level were found to have early formal or late formal categories. Similarly, according to the findings of Domingo, et al. [11], year level was found to have influenced cognitive skills achievement in mathematics. Students in higher years tend to perform the logical operations better as compared to student in lower years. Compared to the former, the latter, considering their age, is expected to be in the formal operational stage based on Piaget's stages of cognitive development. Both Gamit [10] and Domingo, et al. [11] concluded that weak mathematical foundations among lower years level compared to higher year levels had been chronicled. Though year level is found to have an influence on cognitive skills achievement in mathematics among pre-service teachers, this realization must be recognized by educational leaders when planning curriculum and other instructional decision-making.

Furthermore, existing empirical studies have analyzed the significant influence of socio-demographic characteristics, including cognitive variables in various grade levels, on mathematics cognitive skills achievement [12-16]. These researchers have paid attention to the role of the year level of class groupings with similar ages in relation to their mathematics achievements. Considering the year level of heterogenous and homogenous age-grouped students, both transversal and longitudinal inquiries have systematically reported that academic achievement in mathematics showed a gradual increase throughout schooling. Moreso, the studies of Dowker, et al. [12] and Mata, et al. [13] indicated that motivational and emotional competencies tend to increase as students undergo the process of logical mathematics

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instruction from one year level to the next; thus, their cognitive skills achievement likewise tends to change over time, including math anxiety, which diminishes as students go through their years of schooling. However, in the conclusion of Namkung, et al. [14], as occurs with gender variables, the predictive power of year level to cognitive skills achievement or the affective variables in mathematics achievement needs further investigation with a larger representative sampling.

3.3. Preferred Subject to Teach and Cognitive Skills Achievement

One of the independent variables, *Preferred Subject to Teach*, is a negative predictor of *Cognitive Skills Achievement*, $\beta = -2.23$, Std.error = 1.67, $t = -4.33$, $p < 0.05$, indicating that respondents who are inclined to use applied science subjects as their preferred course of instruction are more likely to manifest higher cognitive skills achievement. As indicated in this study, the unique sequential nature of mathematics courses in connection with other applied science courses may suggest significant impacts on students' opportunities to learn concepts. Furthermore, the applied science courses preferred by the students during their years of schooling can have far-reaching effects on their cognitive skills and achievement in mathematics.

This result coincided with McCue [17], who studied preferred course placement criteria and mathematics achievements among students and teachers and found that individuals who preferred to teach and learn advanced applied science courses were more likely to have a greater chance of experiencing increased mathematics success. Furthermore, current research continues to validate the previous findings in this context (e.g., [18, 19]) regarding the significant connections between preferred applied science courses and future cognitive skills achievement in mathematics.

3.4. Cognitive Aspects of Academic Domain and Cognitive Skills Achievement

The *cognitive aspect of the academic domain* is a positive predictor of *cognitive skill achievement*. $\beta = 3.84$, Std.error = 2.46, $t = 2.37$, $p < 0.05$ indicating that cognitive variables such as those associated with intellectual abilities, along with the motivational constructs as to perceived competence, utility, successful motivations, verbal fluency, selective focus attention, and positive work memory, more likely function as potential predictive elements of cognitive skills achievement. To aptly put it, this significant predictor of cognitive skills achievement defines an individual's independence level of their memory and capacity. Furthermore, the cognitive aspects of mathematics delineate how one's mathematical insights function inside his or her brain, demarcating their interconnectivity with other faculties related to associated processes.

One of the cognitive aspects of the academic domain widely and constantly identified as predictors of cognitive skill achievement is the cognitive element of style chronicled by Cargnelutti, et al. [20] and Juniati and Budayasa [21]. The cognitive skill of an individual is defined in the context of self-consistency in the form of perceptive function, as an individual's distinct characteristic and tendency to remember, think, and solve processes of information logically. Thus, the significant role of cognitive aspects would be their influencing capacity to enhance cognitive skills achievement and other related mathematical performance.

Furthermore, the result similarly coincided with other empirical studies that showed consistent findings on cognitive aspects of the academic domain as a significant predictive construct of cognitive skills achievement. Duru and Okeke [22] and Shi and Qu [23]. Shi and Qu [23] concluded that cognitive aspects, specifically those centered on one's mental ability, were found to be positive predictors of cognitive skill achievement. The intersection of cognitive aspects and cognitive achievements was likewise found to have a predictive correlation. This indicates that the direct connection between cognitive aspects and mathematical cognitive skills tends to influence the latter. More so, Duru and Okeke [22] concluded that one's regulated skills, which also define cognitive aspects, had a significant influence on cognitive skill achievement in mathematics.

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3.5. Affective Aspect of Academic Domain and Cognitive Skills Achievement

Under the academic domain, the *affective aspect* of the academic domain is a positive predictor of *cognitive skills achievement.* $\beta = 1.34$, Std.error = 2.08, $t = 1.23$, $p < 0.05$ indicating that certain emotions in numeracy skills are vital for decision-making, thus affective aspects of the academic domain are more likely to positively influence pre-service teachers' academic achievement, including their pedagogical performances such as their learning mechanisms, teaching methods and strategies, instructional preparations, and other ways of explaining numerical concepts. The finding might suggest that positive emotions about numerical tasks play a pivotal role in one's academic achievement.

The finding of this study on affective aspects as predictors of cognitive skills achievement has likewise been confirmed with several empirical studies in this area, Al Mutawah [24] underscoring the negative or positive effect of emotion on cognitive skills achievement with prospective teachers. More so, Gürefe and Bakalım [25] found that affective factors like that of optimistic emotion, which is typically termed constructive emotion, could contribute greatly to cognitive skill achievement. This positive influence can cause students to think logically when taking the test, which would provide good results and enable them communicate ideas in their minds successively and logically. Thus, it is highlighted that teachers' affective factors, specifically those that define positive emotions, are vital aspects of their experiences as future teachers, as well as influencing their students' meaningful learning experiences in the classroom. Among the affective factors teachers encountered, both positive and negative emotions had been identified as potential elements to consider, as Juniati and Budayasa [21] found that the mathematics positive level of emotion among prospective teachers was quite lower than expected.

3.6. Cognitive Development Practice and Cognitive Skills Achievement

Lastly, the *cognitive development practice* of social learning and development is a positive predictor of *cognitive skills achievement* $\beta = 3.20$, Std.error = 2.59, $t = 2.01$, $p < 0.05$ indicating that one's capability to use the brain in comprehending various numerical concept processes is more likely to influence his or her ability to adjust to a particular environmental situation for learning the logic operations of numeracy.

Consistent with the chronicled evidence studied by Duru and Okeke [22], one of the cognitive development practices of an individual pertains to how self-regulated learning skills function in understanding numerical tasks or problem-solving. It was noted that high- and low-achieving students in mathematics are products of cognitive development practice. This means that the more the students utilize and apply their self-regulated learning as one component of cognitive development practice, the higher their chances of acquiring high cognitive skills in mathematics. This prediction is significant in a way, as attested by the regression analysis used in their study. Therefore, both students in secondary schools and teacher education institutions should constantly regulate their cognitive development skills to enhance their mathematics achievement.

More so, Rolison, et al. [26] conducted a linear regression analysis to explore the mediated association of cognitive development practice that centers on numerical ability with the mathematics achievement of prospective teachers. Linear regression analysis revealed that individuals with higher numerical ability were more likely to respond correctly to risk comprehension questions than those with higher subjective numeracy skills. Thus, numerical ability is most likely to influence one's capability to acquire high cognitive skills and achievement in mathematics.

In summary, respondents predicted cognitive skills achievement in Mathematics is equal to 3.11 + 1.58 (Year Level) − 2.23 (Preferred Subject to Teach) + 3.84 (Cognitive Aspect) + 1.34 (Affective Aspect) + 3.20 (Cognitive Development Practice).

Meanwhile, other variables like sex, place of residence, mother's educational attainment, father's educational attainment, psychomotor aspect, approaches to learning, language acquisition and communication, and health and physical development do not predict the elementary pre-service teacher's cognitive skills achievement. Based on the R^2, the results most likely implied that the remaining 59.30 percent could be accounted maybe for by variables not included in this study.

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As a result, the null hypothesis that socio-demographic profile, academic domain practise, and social learning domains do not predict elementary school pre-service teachers' cognitive skills achievement is thrown out.

4. Conclusion

Examining the predictors of cognitive skills achievement, the variables on year level, preferred subject to teach, cognitive aspects and development practice, and affective aspects offered substantive insights on this research area. As the result suggests, academic achievement is significantly inclined to one's class group, represented by a particular year both homogenous and heterogeneous groups. Thus, respondents in higher years are more likely to manifest higher cognitive skills achievement as compared to freshmen students in mathematics class. In the context of preferred subjects to teach, individuals who are inclined to use applied science subjects as their preferred course of instruction are more likely to manifest higher cognitive skills achievement. As indicated in this study, the unique sequential nature of mathematics courses in connection with other applied science courses may suggest significant impacts on students' opportunities to learn concepts. Furthermore, the applied science courses preferred by the students during their years of schooling can have far-reaching effects on their cognitive skills and achievement in mathematics.

In addition, cognitive variables such as those associated with intellectual abilities, along with the motivational constructs as to perceived competence, utility, successful motivations, verbal fluency, selective focus attention, and positive work memory, are more likely to function as potential predictive elements of cognitive skill achievement. To aptly put it, this significant predictor of cognitive skills achievement defines an individual's independence level of their memory and capacity. More so, the cognitive aspects of mathematics delineate how one's mathematical insights function inside his or her brain, demarcating how their interconnectivity with other faculties related to associated processes.

The implication of affective factors indicates certain emotions on numeracy skills are vital for decision-making; thus, affective aspects of the academic domain are more likely to positively influence pre-service teachers' academic achievement, including their pedagogical performances such as their learning mechanisms, teaching methods and strategies, instructional preparations, and other ways of explaining numerical concepts. They might suggest that positive emotions about numerical tasks would play a pivotal role in one's academic achievement.

Finally, cognitive development practice indicates one's capability to use the brain in comprehending various numerical concept processes, which is more likely to influence his or her ability to adjust to a particular environmental situation for learning the logic operations of numeracy.

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Institutional Review Board Statement:

The Ethical Committee of the Central Luzon State University, Philippines has granted approval for this study on 17 April 2023 (Ref. No. 2023-286).

Transparency:

The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

Competing Interests:

The authors declare that they have no competing interests.

Authors' Contributions:

All authors contributed equally to the conception and design of the study. All authors have read and agreed to the published version of the manuscript.

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