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The Relationship among Prior Knowledge, Mathematical Reading, Mathematical Literacy, Mathematical Comprehension and Learning Achievement

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ABSTRACT: *The main objective of this study is to explore the relationship among, prior knowledge, mathematical reading, mathematical literacy, mathematical comprehension and learning achievement of students who have studied or are studying calculus in a college in Taiwan. Purposive sampling was used to sample the population, and the main subjects were the students who have studied or are studying calculus and teachers teaching calculus in a college in Taiwan. In addition, purposive sampling was used to sample the population in this study, and partial least squares structural equation modeling (PLS-SEM) was used to understand the goodness of fit of inner model and outer model of this study. Bayesian Estimation, and the significance of direct effect analyzed the path coefficients between each latent (unobservable) variable of the inner model for the effectiveness, mediate effect and total effect of the model were analyzed. The results showed that prior knowledge, mathematical reading, mathematical literacy, mathematical comprehension and learning achievement are related. These results can be provided to the teachers of technical colleges and educational decision-making authorities in Taiwan as a reference for teaching and development of educational policies, respectively.*

KEYWORDS - *Prior Knowledge, Mathematical Reading, Mathematical Literacy, Mathematical Comprehension, and Learning Achievement*

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I. INTRODUCTION

The introduction of the paper should explain the nature of the problem, previous work, purpose, and the contribution of the paper. The contents of each section may be provided to understand easily about the paper.

Cognitive studies regarding learning showed that students' prior knowledge affects their learning (【1】,【2】). Moreover, a teacher's sense of students' prior knowledge is part of the teacher's professional teaching knowledge, and is also an important factor that affects the teacher's teaching behavior. Therefore, teachers' understanding of students' prior knowledge is an indispensable part of teaching.

Prior knowledge is the knowledge a learner has, and it includes an individual's understanding of things, learning mode and way to construct cognition. Moreover, the knowledge required by a subject is also an important part of prior knowledge【3】.

In addition, in the era of varied and abundant sources of information, the importance of reading cannot be underestimated. In the school stage, part of thinking ability training is to be achieved through reading.

In recent years, the trend to promote scientific reading in society has become popular. With this trend, the importance of mathematics reading is increasing. The Programme for International Student Assessment (PISA) focuses on science, mathematics and reading of junior and senior high school students. This programme evaluates the ability and literacy among students of different nationalities through reading of life situation questions【4】. Therefore, with regard to the students' mathematics literacy, whether the students can apply the mathematics knowledge they have learned in real situation and whether they have the ability to effectively analyze, reason and communicate when they form, explain and solve different mathematics problems are one of the important issues worthy of discussion.

Moreover, students should have enough knowledge about their learning activities in the process of learning, and should know what kind of thinking methods, methods and techniques or activities to use to enhance learning achievement. This is called learning strategies. In the process of learning mathematics, students can understand mathematical formulas or calculation methods, reorganize and connect mathematical formulas and calculation examples, integrate new mathematical formulas with mathematical formulas learned or associate new examples with examples practiced to enhance their knowledge in order to apply the knowledge or techniques they have learned from examples practiced to new examples in order to solve mathematical problems smoothly and enhance the mathematical achievement【5】.

Furthermore, with the mathematicization of the society, language reading ability alone is not enough. Many students' ability to solve problems is weak because their reading ability is poor【6】.

Chin【7】believed that the particularity of mathematical reading includes the (1) symbolization, (2) logic, (3) rigor and (4) abstraction of mathematical language. In other words, mathematics itself is a language. Therefore, one should learn mathematical language before learning mathematics【8】.

In today's school education, mathematics has always been one of the areas of attention. Big international tests also consider mathematics. The education community has extensively discussed the use of the term "mathematics literacy" and the public since Taiwan participated in the PISA led by the Organization for Economic Co-operation and Development (OECD) in 2006. PISA focuses its assessment of key competencies on learning literacy. This also reflects the trend of the goal of global curriculum reform. The concept of literacy refers to the students' ability to apply the knowledge and ability they acquired to real situations as well as their ability to effectively analyze, reason and communicate when they form, explain and solve different mathematics problems【9】.

Summarizing from the above literature, whether prior knowledge, mathematical reading, mathematical literacy, mathematical comprehension and learning achievement have a considerable degree of relevance is one of the key issues worthy of study. Based on the above motivations, the objective of this study is to understand the relevance among prior knowledge, mathematical reading, mathematical literacy, mathematical comprehension and learning achievement. The population of this study was the students who have studied or are studying calculus and the teachers teaching calculus in a college in Taiwan. This study aimed to understand the relationship among prior knowledge, reading, literacy, comprehension and learning achievement of the students who have studied or are studying calculus in a college in Taiwan. Therefore, the specific objectives of the study are as follows: to understand

(1) Whether prior knowledge has significant positive impact on mathematical reading;
(2) Whether prior knowledge has significant positive impact on mathematical literacy;
(3) Whether prior knowledge has significant positive impact on reading comprehension;
(4) Whether mathematical reading has significant positive impact on mathematical comprehension;
(5) Whether mathematical literacy has significant positive impact on mathematical comprehension;
(6) Whether mathematical comprehension has positive impact on learning achievement;
(7) Whether mathematical literacy has positive impact on learning achievement; and
(8) Whether mathematical reading has positive impact on learning achievement.

II. LITERATURE REVIEW

Literature regarding key constructs

Below is a review of the literature in relation to key constructs in this study, i.e. prior knowledge, mathematical reading, mathematical literacy, mathematical comprehension and learning achievement.

Definition of prior knowledge

The prior knowledge in this study is conceptually defined as "the useful knowledge a student has before learning relevant courses, and the assessment on the student's prior knowledge is based on the subjective conception a teacher has according to the familiarity of the knowledge involved in the student's learning of natural unit." The above conceptual definition is summarized from the following literatures. Over the years, many scholars have different definitions of prior knowledge:

Glaser & De Corte【10】believed that prior knowledge is a well-structured and consistent knowledge base, which can enlighten indicial learning behaviors, such as reasoning, conceptualization and knowledge acquirement.

Dochy, Valcke and Wagemans【11】suggested that, from the perspectives of learning and assessment, prior knowledge may be classified into three categories and described as follows: (1) Subject-oriented prior knowledge: refers to the relevant information of a learning material that a learner already has before learning the material; (2) Essential prior knowledge: refers to the basic information a learner must have before learning a certain subject. The information provides learners the knowledge of how much they have already acquired concerning the subject and the decision of whether they should enter in the learning of the said subject; and (3) Domain-specific prior knowledge: refers to the extent of knowledge a learner has, relating to a specific domain, before the learner starts learning the subject.

Dochy【12】proposed that prior knowledge affects learning in two ways: direct effect, and indirect effect. Direct effect refers to the direct influence on learning through the priority of prior knowledge that leads to good learning achievement, for example, using recall, test results, quality comments and other methods to affect learning. Whereas, indirect impact refers to the effects on learning outcomes through correct learning skills, speed and learning behavior.

Dochy【12】defined prior knowledge more specifically as the actual knowledge of an individual, in which there are five features: (1)Prior knowledge itself is available for use before implementing a specific task of learning; (2) Prior knowledge is constructed inside of an individual's knowledge schemata; (3) Rrior knowledge may be declarative or procedural knowledge; (4) Prior knowledge is explicit and partly tacit; and (5) The nature of prior knowledge is dynamic to provide access for individuals, and is stored in an individual's knowledge infrastructure. Dochy【13】pointed out that the essence of prior knowledge is dynamic; it is the useful knowledge a learner has prior to learning; and its structure is diversified.

Chi【14】argued that, from a broad perspective, prior knowledge includes "domain-specific prior knowledge," "domain-related prior knowledge," "misconception prior knowledge" and "general field prior knowledge." Among which, Chi【14】argued that prior knowledge includes misconception. Although misconception is knowledge related to learning materials, relatively speaking, it is a wrong belief and hard to change. The stubborn and tough characteristics of misconception hinder learners from learning new things 【15】. Moreover, Alvermann & Hague【16】argued that if a learner's relevant prior knowledge is aroused in a reading process and the learner is not warned about his/her wrong concept, it may obstruct his/her own understanding of correct materials and form misconception 【17】.

Chen【18】argued that, from the point of view of teaching and learning, prior knowledge is knowledge necessary for learning a subject. Its impact on academic achievement is significant. Regardless of general subject or specialized subject, the role prior knowledge plays is significant.

Han【19】pointed out that prior knowledge is constructed from many aspects. Two main structures related to reading are domain knowledge and general knowledge. Domain knowledge is the knowledge a reader has regarding a specific subject, and the experience is from the relevant text the reader read before; on the other hand, general knowledge is the script of daily life or experience (【20】,【21】).

Definition of mathematical reading

In this study, mathematical reading is conceptually defined as "a process a reader transforms the meaning of the content he/she read through reading. When the content includes mathematical languages (words, symbols, terms, formulas and charts), the reader can judge and give examples and counterexamples based on the content he/she read. It is a cognitive process involving continuous hypothesis, proof, imagination and reasoning." The above conceptual definition is summarized from the following literatures. Over the years, many scholars have different definitions of mathematical reading:

Borasi & Siegel【22】defined reading as a process a reader transforms the meaning of the content he/she read through reading. Reading is a course of learning. When the content involves mathematical language (words, symbols, terms, formulas and charts), it can be regarded as mathematical reading.

Shao【23】argued that mathematics is the teaching of mathematical language. Mathematical reading is a process of constructing meanings through the understanding of mathematical language, and it should include words, symbols and graphics.

Wakefield【24】argued that mathematics has the following characteristics: communication of abstract ideas or images verbally or by words or symbols, with fixed symbols and rules, expressed in linear or serial, enhanced comprehension by practice, need to remember symbols and rules to be succeed, novice learners require translation and interpretation, the order of symbols affects the meaning, communication requires encoding and decoding, smooth reading requires intuition, insightfulness and speaking without thinking, childhood experience provides the foundation for future development, expression has infinite possibility. While language learning is inseparable from reading, mathematics learning is also unable to be separated from reading. This is the origin of mathematical reading (【7】,【25】).

Chin【26】pointed out that mathematical reading requires specific subject reading skills, including mathematical prior knowledge, comprehension of mathematical graphs, understanding of mathematical vocabulary and symbols, and knowledge of mathematical graphing procedures.

Wu【27】believed that mathematical reading includes three parts: (1) language transformation ability: mathematical materials are professional knowledge of mathematics expressed by words, symbols and graphs, and thus mathematical reading builds on the transformation of these three forms; (2) logical and abstract thinking ability, which can be divided into analytical ability and abstract and generalization ability. Analytical ability is the ability to explain the logical relationship among various parts of the material and clarify the overall train of thinking of mathematical materials. Abstract and generalization ability is to identify the most important thing from the mathematical materials and to identify the common points from different mathematical materials; (3) meta-reading ability, i.e., students' self-awareness and self-monitoring ability in the course of mathematical reading in mathematical learning.

Gao, Han and Tian【28】argued that mathematical reading is more difficult, complex and demanding than language reading, and, in reality, there are situations where language learning ability cannot effectively facilitate mathematical reading ability. Therefore, it is necessary to explore the condition that cultivates mathematical reading ability. The condition includes five aspects: (1) The ability to understand and apply mathematical language, i.e., the smooth mathematical reading is inseparable from awareness and understanding of proper nouns, terminologies, symbols and graphs; (2)Reading and reasoning ability, i.e., the ability to infer new knowledge; (3) The ability to associate and memorize, i.e., the effective connection between the mathematical materials and existing cognitive structure; (4) Generalization ability on mathematical subject matters, i.e., the ability to reorganize and adjust mathematical subject matters; and (5) Metacognitive reading ability, i.e., the ability to monitor reading comprehension.

Chen【29】thought that mathematical reading refers to the reading of mathematical text, including the strategy to read mathematical text, mathematical reading comprehension and mathematical reading literacy. Unlike general reading, mathematical reading requires certain reading technics. A reader requires a certain level of mathematical ability and knowledge. Words and graphs both contain certain extent of mathematical meaning. When the reader is reading, he/she needs to constantly connect the content and mathematical knowledge, find the mathematical knowledge in paragraphs, and then formulate a reading strategy to solve problems.

Definition of Mathematical Literacy

In this study, mathematical literacy is conceptually defined as "a student's ability to effectively analyze reason and communicate when he/she forms, explains and solves different mathematical problems in real situation by applying the mathematical knowledge he/she learned. Such ability includes describing, explaining and predicting mathematical phenomena by mathematical reasoning, mathematical concept, procedure, fact and use of tools." The conceptual definition is summarized from the following literatures. Over the years, many scholars have different definitions regarding mathematical literacy:

Skovsmose【30】argued that Matheracy is an important topic in connecting mathematics education and democracy and it is a kind of ability to be able to move in a world of mathematical structure. Skovsmose【30】also believed that when we discuss Matheracy, we should focus on reflection, which can be divided into four types: (1) mathematics-oriented reflection; (2) model-oriented reflection; (3) Context-oriented reflection and (4) lifeworld-oriented reflection. (【31】,【32】)

Adding it up: Helping children learn mathematics【37】written by the mathematical learning research team led by Kilpatrick, Swafford and Frndell, defined successful mathematical learning as having so-called mathematical literacy. Mathematical literacy is a mathematical learning indicator combining five mathematical abilities, which are (1) conceptual understanding; (2) procedural fluency; (3) strategic competence; (4) adaptive reasoning; (5) productive disposition. The five abilities are not independent from each other. They are more like five intertwined strings, dependent on each other and develop into a solid and sturdy rope of mathematical literacy【38】.

Niss【39】believed that there are eight indicators or characteristics of core mathematical literacy: (1) mathematical thinking and reasoning; (2) mathematical argument; (3) mathematical communication; (4) modeling; (5) problem formulation and problem solving (6) indicators; (7) use of symbolic, formal and technical language and calculation; and (8) use of auxiliary tools【40】.

Organization for Economic Cooperation and Development (OECD)【41】argued that an individual with mathematical literacy has the ability to form, apply and interpret mathematics under different contexts, and this includes using mathematical reasoning, mathematical concept, procedure, fact and use of tools to describe, explain and predict mathematical phenomena. Mathematical literacy helps individuals to identify the role mathematics plays in the world, and make exhaustive and evidence-based judgments and decisions that a constructive, inputable and reflective citizen can make.

Hwang【31】pointed out that Webster's New World Dictionary has three types of interpretation regarding literate: (1) well-educated, i.e., possessing or showing extensive knowledge, learning or culture; (2) versed in literature; and (3) knowledgeable or capable【32】.

Taiwan PISA National Research Center (December 2011) mentioned in the Taiwan PISA 2009 Report that "literacy refers the ability that students can apply the knowledge and skills they learned in actual situation and can effectively analyze, reason and communicate when they form, explain and solve different problems."【33】

PISA defines mathematical literacy as the ability an individual has to formulate, employ and interpret mathematics in different contexts, including mathematical reasoning, mathematical concept, procedure, fact and use of tools to describe, explain and predict mathematical phenomena. Mathematical literacy assists individuals to identify the role mathematics plays in the world and make exhaustive and evidence-based judgements and decisions that a constructive, imputable and reflective citizen can make (【34】,【35】,【36】).

Definition of Mathematical Reading Comprehension

In this study, mathematical reading comprehension is conceptually defined as "an ability to judge and give examples and counterexamples, compare the similarity or differences of similar concepts or analyze the steps for solving a problem, judge the merits and drawbacks of different problem-solving strategies and give reasons, and even use his/her own word to describe concepts, theorems and formulas based on the content the student read from mathematical text." The above conceptual definition is summarized from the following literature:

Hsieh【42】argued that reading is important to a person's learning growth; however, there are many definitions of reading. In a narrow sense, reading is a process to obtain meaning from literacy and decoding, and only text reading is within the scope of reading. Nevertheless, in a broader sense, reading refers to all attempts to understand the meaning through written languages or symbols in life.

Liu【43】also pointed out that reading is the core of education and learning. Reading comprehension ability relates to the performance of each learning course.

Duke, Pearson, Strachan & Billman【44】argued that there are ten basic elements in the teaching of mathematical reading comprehension, including building disciplinary and world knowledge, providing exposure to a volume and range of texts, providing motivating texts and contexts for reading, teaching strategies for comprehending, teaching text structures, engaging students in discussion, building vocabulary and language knowledge, integrating reading and writing, observation and assessment and different instructions. Teachers need to master these elements in the teaching process to achieve successful teaching of reading comprehension.

Hsu【8】argued that reading comprehension is an ability to judge and give examples and counterexamples, compare the similarity or differences of similar concepts or analyze the steps to solve a problem, judge the merits and drawbacks of different problem-solving strategies and give reasons, and even use his/her own word to describe concepts, theorems and formulas based on the content the student read.

Hsu【8】pointed out that the important strategies of teaching of mathematical reading comprehension are (1) give students enough reading time and opportunities; (2) guide the students to read and understand the structure of each small unit in a textbook; (3) give the students more opportunities to participate in discussion and presentation before, during and after reading; and (4) provide a variety of text to combine various teaching activities when the students' reading motivation drops.

Definition of learning achievement

In this study, learning achievement is conceptually defined as "the behavioral ability a learner shows after taking various possible forms of tests once a learning activity comes to an end. It is also an effect that only shows after a long period of school education." The above conceptual definition is summarized from the following literature:

Chang【45】argued that learning is a process of knowledge acquisition or behavior change. In other words, learning is a process not a result of knowledge acquisition or behavior change. Knowledge acquisition is knowledge learned and behavioral change is behavior learned.

Lin【46】and Wen【47】pointed out that education can train technical professionals and contribute to the professional achievement needed by a society. The professional achievement can be divided into three types: (1) knowledge achievement: the knowledge level of certain things after learning; (2) technical achievement: the operational skills learned after learning; and (3) attitude achievement: ambition and attitude of doing things after learning【48】.

The study of Gagné 【49】 showed that the factors that affect individual learning are very complex. Gagné【49】believed that learning achievement is affected by intrinsic and extrinsic conditions of learning. Intrinsic condition of leaning refers to learning attitude, intelligence, cognitive development, self-expectation, interest, and internal condition of an individual (【50】,【51】,【52】). Extrinsic condition refers to the teaching materials, teaching methods and approach an individual receives【53】.

Wang【54】believed that learning effectiveness is the impact and outcome that a learner acquires through learning, which includes instructor's teaching, learning environment, learning curriculum and learning outcomes.

Huang【55】pointed out that learning effectiveness is the accumulated ability and accomplishment a learner acquires after the course is completed, through active participation in the experience of the teaching process.

Wang【56】argued that learning effectiveness is associated with imitation, image of heritage and provision of technology and ability, from simple imitation to entrepreneurial sophistication and from the beginning to the end of the learning process. It is a self-integration between what one learned and what one can apply.

Literature Review on Pairwise Correlations of the Dimensions of this Study

Literature related to prior knowledge and mathematical reading

With regard to the relevance between prior knowledge and mathematical reading, Ozuru, Dempsey & McNamara【57】 pointed out the difference in the performance of answering questions when readers with different level of prior knowledge read text with various degrees of coherence. The results showed that reading comprehension was affected by the readers' prior knowledge, reading skills and coherence of text. Among which, individual prior knowledge showed the greatest variation.

To date, this study has found no literature discussing the relevance between mathematical comprehensions and learning achievement. However, this study subjectively argues that there is a correlation between mathematical comprehension and learning achievement. Therefore, this study proposes the following hypothesis:

Although the subject of the above literature is different from that of this study, this study proposed a hypothesis based on that literature. Hypothesis 1 (H_1): the prior knowledge of students who have studied calculus or are studying calculus in a college in Taiwan has significant positive impact on mathematical reading.

Literature related to prior knowledge and mathematical literacy

To date, this study has found no literature discussing the relevance between prior knowledge and mathematical literacy. However, this study subjectively argues that there is a correlation between prior knowledge and mathematical literacy. Therefore, this study proposes the following hypothesis:

Hypothesis 2 (H_2): the prior knowledge of students who have studied calculus or are studying calculus in a college in Taiwan has significant positive impact on mathematical literacy. However, interview questionnaire data and statistical methods are required to check whether the hypothesis is valid.

Literature related to prior knowledge and mathematical (reading) comprehension

With regard to the literature related to prior knowledge and mathematical (reading) comprehension, Cromley, Snyder-Hogan & Luciw-Dubas【58】used structural equations to analyze factors that affect reading comprehension, including prior knowledge, reasoning ability, reading skills, vocabulary, reading fluency, and confirmed the impact of prior knowledge on reading comprehension. According to the results of Cromley et al 【58】, the impact of prior knowledge, reasoning ability, reading skills and vocabulary on reading comprehension was significant. However, to confirm the degree of impact of prior knowledge on reading comprehension, Cromley et al. 【58】controlled the reasoning ability, reading skills and vocabulary and found that the impact of prior knowledge on reading comprehension was still significant.

Although the subject of the above literature is different from that of this study, this study proposed a hypothesis based on that literature. Hypothesis 3 (H_3): the prior knowledge of students who have studied calculus or are studying calculus in a college in Taiwan has significant positive impact on mathematical (reading) comprehension. However, interview questionnaire data and statistical methods are required to check whether the hypothesis is valid.

Literature related to mathematical reading and mathematical comprehension

With regard to the literature related to mathematical reading and mathematical comprehension, Su【59】pointed out that integration of reading strategies into teaching helps to enhance students' mathematical reading comprehension. However, such effect gradually disappeared with time.

Although the subject of the above literature is different from that of this study, this study proposed a hypothesis based on that literature. Hypothesis 4 (H_4): the mathematical reading of students who have studied calculus or are studying calculus in a college in Taiwan has significant positive impact on mathematical comprehension. However, interview questionnaire data and statistical methods are required to check whether the hypothesis is valid.

Literature related to mathematical literacy and mathematical comprehension

With regard to the literature related to mathematical literacy and mathematical comprehension, Chen 【60】pointed out that the relevance between mathematical literacy and mathematical reading comprehension is low. Both pretest and post-test of reading comprehension skill scale were moderately positively correlated to mathematical literacy. Moreover, both post-test of reading comprehension skill scale and post-test of mathematical literacy were moderately positively correlated to learning achievement. Although the subject of the above literature is different from that of this study, this study proposed a hypothesis based on that literature. Hypothesis 5 (H_5): the mathematical literacy of students who have studied calculus or are studying calculus in a college in Taiwan has significant positive impact on mathematical comprehension. However, interview questionnaire data and statistical methods are required to check whether the hypothesis is valid.

Literature related to mathematical comprehension and learning achievement

To date, this study has found no literature discussing the relevance between mathematical comprehensions and learning achievement. However, this study subjectively argues that there is a correlation between mathematical comprehension and learning achievement. Therefore, this study proposes the following hypothesis:

Hypothesis 6 (H_6): the mathematical comprehension of students who have studied calculus or are studying calculus in a college in Taiwan has significant positive impact on learning achievement. However, interview questionnaire data and statistical methods are required to check whether the hypothesis is valid.

Literature related to mathematical literacy and learning achievement

With regard to the literature related to mathematical literacy and learning achievement, the results of Chien【61】showed that mathematical achievement, mathematical literacy, mathematical anxiety and mathematical self-efficiency are moderately correlated.

In addition, Kuo【62】pointed out that the strategies used by students with high mathematical literacy were mostly fine strategies and control strategies, while the strategies used by the students with low mathematical literacy were mostly related to memory strategies. The higher the students' self-efficiency, internal motivation and instrumental motivation are, usually, the higher the mathematical literacy is.

With regard to the correlation between mathematical literacy and learning achievement, although the subjects of the above literatures are different from that of this study, this study proposed a hypothesis based on the literatures. Hypothesis 7 (H_7): the mathematical literacy of students who have studied calculus or are studying calculus in a college in Taiwan has significant positive impact on learning achievement. However, interview questionnaire data and statistical methods are required to check whether the hypothesis is valid.

Literature related to mathematical reading and learning outcomes

To date, this study has found no literature discussing the relevance between mathematical reading and learning achievement. However, this study subjectively argues that there is a correlation between mathematical reading and learning achievement. Therefore, this study proposes the following hypothesis:

Hypothesis 8 (H_8): the mathematical reading of students who have studied calculus or are studying calculus in a college in Taiwan has significant positive impact on learning achievement. However, interview questionnaire data and statistical methods are required to check whether the hypothesis is valid.

Research Structure

Based on the above research objectives, hypotheses and literature review, this study develops a research structure (Figure 1) as follows:

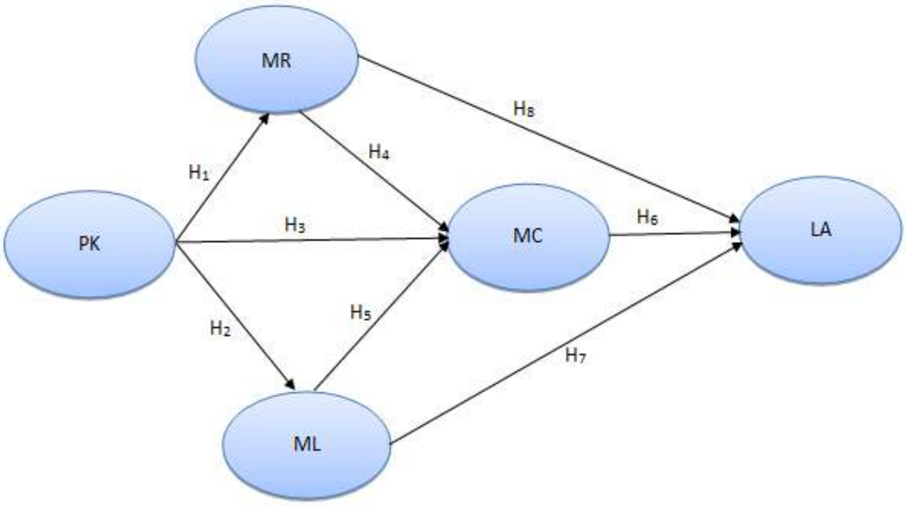

Figure1 Research Framework

III. RESEARCH METHODOLOGY

Research Subjects and Questionnaire Design

This study issues questionnaires to the students who have studied or are studying calculus and teachers teaching calculus in a college in Taiwan via Purposive Random sampling. To enhance the content validity and reliability of the questionnaire, this study conducts an expert questionnaire survey in the design phase and performs a pilot test to modify or eliminate unsuitable questions. A post-test is then administered with a total of 150 questionnaires issued. The number of recovered effective questionnaires is 78, at an effective recovery rate of 52%.

Table 1 summarizes the question allocations to different variables in the main construct (conceptual) and sub-constructs (operational measurement).

Main construct	No. of questions	Reference
Prior Knowledge	3	Chen【18】, Han【19】
Mathematical Reading	3	Chin【26】, Wu【27】, Chen【29】
Mathematical Literacy	5	Hwang【31】
Mathematical Comprehension	8	Hsu【8】

Learning Achievement	3	Wang【56】

Partial Least Squares Regression- Lineal Structural Model (PLS-SEM)

There are two SEM families: covariance-based SEM (CBSEM) and variance-based SEM, a.k.a. partial least square SEM (PLS-SEM). Table 2 shows the differences of these two models. This study uses PLS-SEM due to its following advantages: (1) model complexity; (2) exploratory research; (3) non-normal data; (4) focus on prediction; (5) theory development; (6) convergence ensured; (7) use of categorical variables; (8) theory testing etc.【63】. Meanwhile, the PLS-SEM model is employed to understand the goodness of fit in the inner model and the outer model 【64】.

Table 2 Differences between CBSEM and PLS-SEM

	CBSEM	PLS-SEM
Goal	Sample matrix closest to expected co-variances	Greatest explanatory power for dependent variables
Data source	Raw data, covariance matrix or correlation matrix with standard deviation	raw data (format: .csv or .txt)
Software	AMOS, LISREL, EQS, MPLUS etc.	Smart PLS, PLS-Graph, Visual PLS etc.

Source: Hair et al【63】& this study

Questionnaire Data Processing and Measurement System

This study sets up five inner (latent) variables, i.e. prior knowledge, mathematical reading, mathematical literacy, mathematical comprehension and learning achievement. Each latent variable can be further divided into outer (observable) variables, and a number of questions are allocated to each observable variable. The original surveyed data is processed into data files. To understand the goodness of fit of the inner model and the outer model, this study employs the PLS-SEM model to examine the path coefficients of individual latent (unobservable) variables in the inner model. This study uses the Bayesian estimation to analyze the path effects of the structural models and then conducts the Sobel tests, to gauge the significance of direct effects, mediating effects and total effects.

Common Method Variance Test (CMV Test)

Using Latent Marker Variable with PLS and One Marker Variable for control, to test common-method bias, the research finds that the common method variance does not exist in the questionnaire designed by this study as shown in Figure 2.

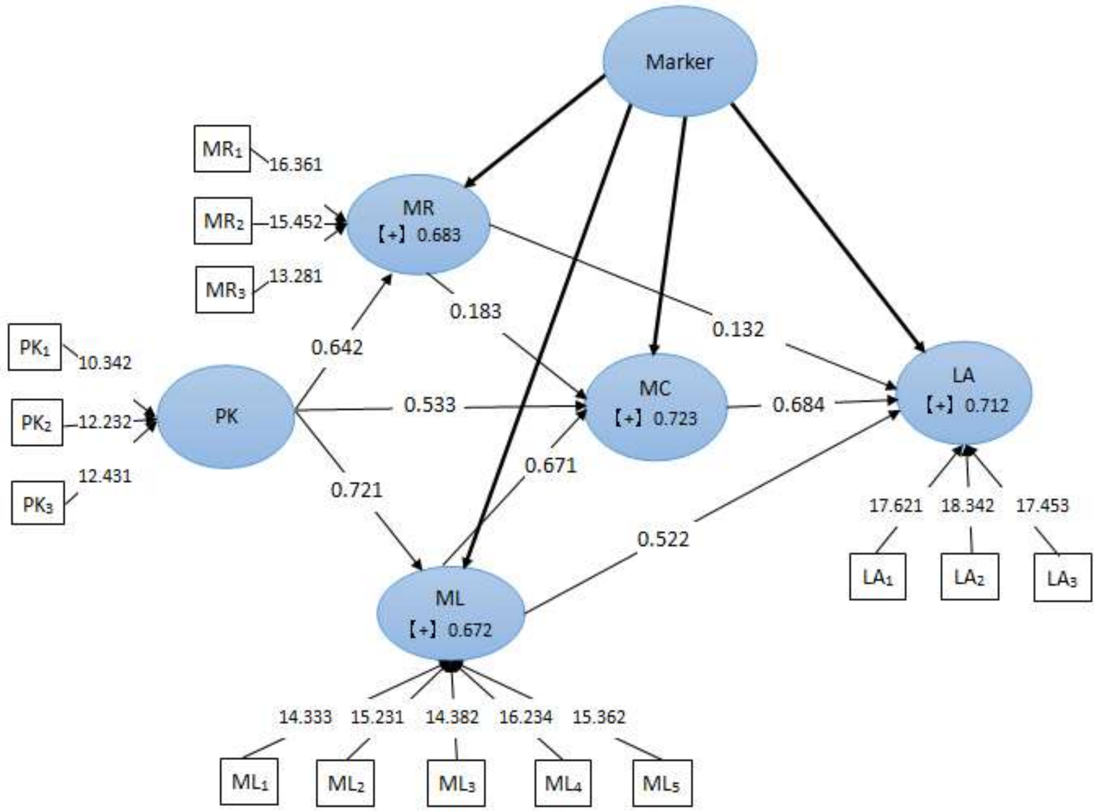

Figure 2 Latent marker variable with PLS

IV. RESEARCH ANALYSIS & FINDINGS

Outer Model

The outer model in this study is a reflective one. Table 3 shows the assessment of this reflective model. The Cronbach's α is greater than 0.8, Composite Reliability (CR) greater than 0.5, Average Variance Extracted (AVE) greater than 0.5. Hence, the outer model has convergence validity. Meanwhile, the AVE is larger than square of constructs correlation, indicative of the discriminate validity in the outer model. Table 4 indicates that the factor loading is higher than low cross-loading, another indication of the discriminate validity in the outer model (【65】,【64】).

Tables 3 Assessment Indicators of Convergence Validity & AVE Discriminate Validity in Outer Model

	AVE	Composite Reliability	Cronbach's α	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
PK→MR	0.638	0.917	0.891	0.821							
PK→ML	0.642	0.933	0.901	0.721	0.843						
PK→MC	0.624	0.870	0.823	0.712	0.623	0.762					
MR→MC	0.632	0.914	0.881	0.722	0.732	0.681	0.832				
ML→MC	0.634	0.905	0.864	0.712	0.724	0.682	0.654	0.821			
MC→LA	0.683	0.932	0.912	0.823	0.842	0.811	0.832	0.804	0.892		
ML→LA	0.621	0.872	0.820	0.682	0.662	0.642	0.663	0.661	0.693	0.732	
MR→LA	0.623	0.893	0.824	0.672	0.663	0.654	0.634	0.642	0.632	0.631	0.742

Table 4 Discriminate Validity

	PK	MR	ML	MC	LA

PK 1	0.42	***0.86***	0.45	0.44	0.33
PK 2	0.48	***0.94***	0.46	0.47	0.34
PK 3	0.45	***0.91***	0.44	0.47	0.33
MR1	0.25	0.41	0.36	***0.75***	0.27
MR2	0.35	0.36	0.55	***0.70***	0.20
MR3	0.36	0.36	0.46	***0.80***	0.28
ML1	***0.91***	0.45	0.42	0.39	0.15
ML2	***0.94***	0.46	0.42	0.39	0.18
ML3	***0.87***	0.45	0.43	0.37	0.25
ML4	***0.86***	0.47	0.43	0.38	0.24
ML5	***0.85***	0.45	0.42	0.36	0.23
MC1	0.21	0.34	0.41	0.32	***0.89***
MC2	0.22	0.34	0.40	0.31	***0.89***
MC3	0.13	0.35	0.32	0.25	***0.81***
MC4	0.17	0.28	0.28	0.23	***0.85***
MC5	0.17	0.30	0.30	0.31	***0.80***
MC6	0.21	0.34	0.41	0.32	***0.89***
MC7	0.22	0.34	0.40	0.31	***0.89***
MC8	0.13	0.35	0.32	0.25	***0.81***
MC9	0.17	0.28	0.28	0.23	***0.85***
MC10	0.17	0.30	0.30	0.31	***0.80***
LA1	0.34	0.42	***0.84***	0.50	0.37
LA2	0.33	0.43	***0.74***	0.44	0.36
LA3	0.42	0.43	***0.86***	0.54	0.36

Remarks:
(1) Factor loadings are in Bold font
(2) Cross loadings are in Serif font

Inner Model

The validity indicators of the inner model are as follows: (1) Coefficient of determination (R^2): According to Hair et al【63】, if R^2 of the dependent inner variables are greater than 0.67, they are of practical value; if R^2=0.33, they are of a medium level of explanatory power; if R^2=0.19, they are of a weak level of explanatory power; (2) Path Coefficient; (3) Effect size (f^2): this indicator represents the influence of independent variables on dependent variable. According to Cohen【66】, if f^2>0.35, it suggests strong influence of the independent variables on dependent variable; if f^2=0.15, it suggests medium influence and if f^2=0.02, it suggests weak influence. Meanwhile, if predictive relevance (Q^2) >0, it indicates the influence of independent variables on dependent variable. The greater the Q^2, the stronger the predictive relevance is. This is derived with the blindfolding function; (4) Goodness of fit (GOF): the equation is $\sqrt{\ } R^2 * AVE = \sqrt{\ }$ redundancy. If GOF small=0.1, GOF medium=0.25, GOF large=0.36. Table 5 shows the path coefficients of the inner model. The p-values of all the path coefficients are smaller than 0.001, and are statistically significant. Additionally, according to Table 6, the R^2 of dependent variables (MR, ML, MC, LA) are 0.683, 0.672, 0.723 and 0.712, respectively, and all greater than 0.67. The redundancy value is 0.615, indicative of goodness of fit in the inner model.

Table 5 Path Coefficients (Mean, STDEV, T-Values)

	Original Sample(O)	Standard Deviation (STDEV)	T Statistics (IO/STERRI)	P Values
PK→MR	0.642	0.083	7.735	0.000
PK→ML	0.721	0.081	8.901	0.000
PK→MC	0.533	0.072	7.403	0.000
MR→MC	0.583	0.074	7.878	0.000
ML→MC	0.671	0.079	8.494	0.000
MC→LA	0.684	0.081	8.444	0.000
ML→LA	0.522	0.063	8.286	0.000
MR→LA	0.532	0.067	7.940	0.000

Table 6

R^2	Communality	AVE	Redundancy

PK		0.643	0.643	**0.650**
MR	0.683	0.632	0.632	
ML	0.672	0.631	0.631	
MC	0.723	0.683	0.683	
LA	0.712	0.662	0.662	

Overall Model Estimates
Figure 3 shows the standardized model estimates, regression path coefficients and R squares of the dependent variables.

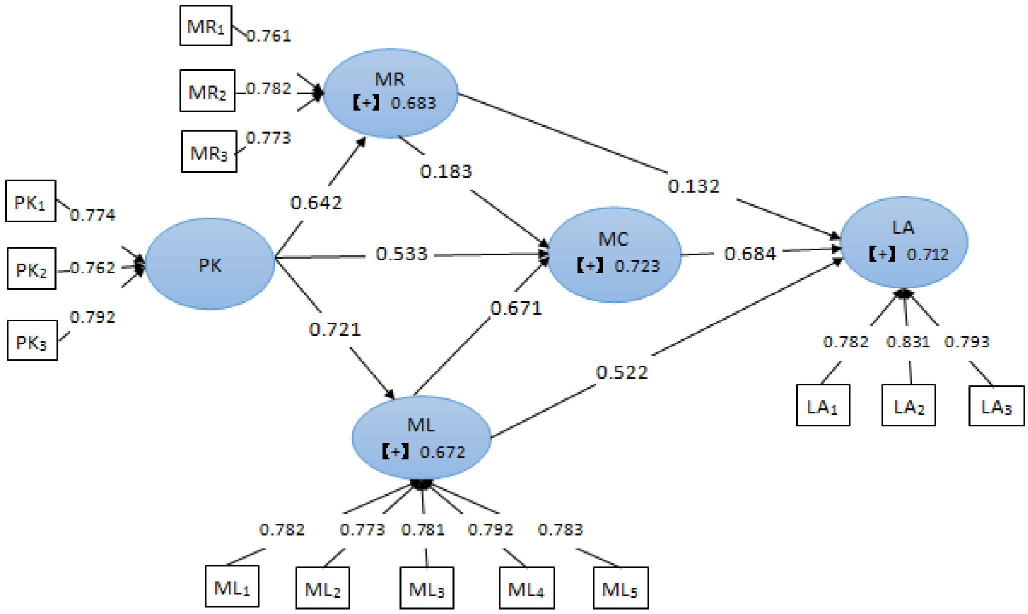

Figure 3 The Standardized Model Estimates

Significance Tests
Figure 4 shows that the significance tests on the model by using Smart PLS. The numbers on the line of the inner model indicate t values. The t values of greater than 1.96 indicate statistical significance. The unstandardized numbers in the outer model indicate measurement coefficients.

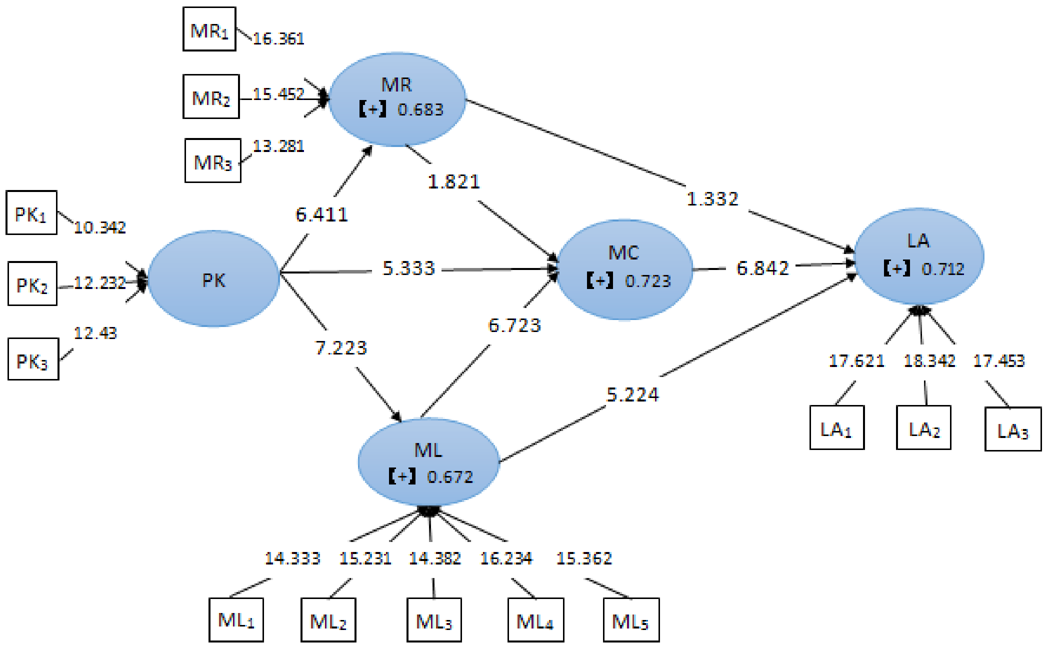

Figure 4 Significance Tests using Smart PLS

Analysis & Tests on Path Effects of Inner Model

Table7 Sobel Test: Bootstrapping→ Path Coefficients (Mean, STDEV, t-Values)

	Original Sample (O)	Sample Mean (M)	Standard Deviation (STDEV)	Standard Error (STERR)	T Statistics (O/STERR)	
PK→MR	6.411	0.642	1.051	1.051	6.099	A1
PK→ML	7.223	0.721	1.032	1.032	6.999	A2
PK→MC	5.333	0.533	1.041	1.041	5.123	C1&C2
MR→MC	1.821	0.183	1.031	1.031	1.766	B1
ML→MC	6.723	0.671	1.121	1.121	5.997	B2
MC→LA	6.842	0.684	1.122	1.122	6.098	B3
ML→LA	5.224	0.522	1.001	1.001	5.219	C3
MR→LA	1.332	0.132	1.002	1.002	1.329	C4

Remark:

(1) PK→MC, ML→LA and MR→LA (Direct Effect); PK→MR, PK→ML, MR→MC, ML→MC and MC→LA (Indirect Effect)

Table 8 Total Indirect Effect

	PK→MR	PK→ML	MR→MC	ML→MC	MC→LA	VAF
Indirect Effect(IE)	0.103	0.104	0.122	0.121	0.123	0.573

Remarks:

(1)Total Effect (TE) = Direct Effect+ Indirect Effect

(2) VAF>80% indicates complete mediating effects.

This study uses Bayesian estimations to examine the path coefficients of latent (unobservable) variables in the structural model. This is followed with the Sobel tests to gauge the significance of the direct effects, mediating effects and total effects. Table 8 shows that when the VAF of the model equals 0.573, mathematical reading, mathematical literacy and mathematical comprehension only have partial mediation effect. However, mathematical reading and mathematical literacy are dual mediators, and mathematical comprehension is a triple mediator.

Moreover, Tables 7 and 8 show that:

(1) T statistics of PK to MR (O/STERR) 6.099>1.96, indicative of significant indirect effects.

(2) T statistics of PK to ML (O/STERR) 6.999>1.96, indicative of significant indirect effects.

(3) T statistics of PK to MC (O/STERR) 5.123>1.96, indicative of significant direct effects.

(4) T statistics of MR to MC (O/STERR) 1.766<1.96, indicative of no significant indirect effects.
(5) T statistics of ML to MC (O/STERR) 5.997>1.96, indicative of significant indirect effects.
(6) T statistics of MC to LA (O/STERR) 6.098>1.96, indicative of significant indirect effects.
(7) T statistics of ML to LA (O/STERR) 5.219>1.96, indicative of significant direct effects.
(8) T statistics of MR to LA (O/STERR) 1.329<1.96, indicative of no significant direct effects.

The VAF=IE/TE in this model is equal to 0.573, less than 80%, indicative of partial mediating effects to a certain degree for the constructs of mathematical reading, mathematical literacy and mathematical comprehension.

Based on Figures 3 & 4, this study derives the following research results:
(1) H_1: Prior knowledge has positive and significant influence on mathematical reading (supported, with a regression path coefficient of 0.642 and a t value of 6.099).
(2) H_2: Prior knowledge has positive and significant influence on mathematical literacy (supported, with a regression path coefficient of 0.721 and a t value of 6.999).
(3) H_3: Prior knowledge has positive and significant influence on mathematical reading and comprehension (supported, with a regression path coefficient of 0.533 and a t value of 5.123).
(4) H_4: Mathematical reading has positive but no significant influence on mathematical comprehension (partially supported, with a regression path coefficient of 0.183 and a t value of 1.766).
(5) H_5: Mathematical literacy has positive and significant influence on mathematical comprehension (supported, with a regression path coefficient of 0.671 and a t value of 5.997).
(6) H_6: Mathematical comprehension has positive influence on learning achievement (supported, with a regression path coefficient of 0.684 and a t value of 6.098).
(7) H_7: Mathematical literacy has positive influence on learning achievement (supported, with a regression path coefficient of 0.522 and a t value of 5.219).
(8) H_8: Mathematical reading has positive but no significant influence on learning achievement (partially supported, with a regression path coefficient of 0.132 and a t value of 1.329).

V. CONCLUSIONS AND SUGGESTIONS

Based on the above analysis and findings, this study presents the following conclusions as its contributions, and then articulates the research limitations and suggestions to future studies.

Conclusions

This study conducts a survey on the students who have studied or are studying calculus and teachers teaching calculus in a college in Taiwan, and employs the partial-least-square structural equation model (PLS-SEM) to explore the relationship among prior knowledge, mathematical reading, mathematical literacy, mathematical comprehension and learning achievement. Below is a summary of the conclusions:

Influence of prior knowledge on mathematical reading

The research findings support H1: Prior knowledge has positive and significant influence effect on mathematical reading. This is consistent with Ozuru, Dempsey & McNamara【57】.

Influence of prior knowledge on mathematical literacy

The research findings support H2: prior knowledge has positive and significant influence and effect on mathematical literacy.

Influence of prior knowledge on mathematical reading comprehension

The research findings support H3: prior knowledge has positive and significant influence on mathematical reading comprehension. This is consistent with Cromley et al【58】.

Influence of mathematical reading on mathematical comprehension

The research findings support H4: Mathematical reading has positive but no significant influence on mathematical comprehension. This is the same as the conclusion by Su【59】.

Influence of mathematical literacy on mathematical comprehension

The research findings support H5: Mathematical literacy has positive and significant influence on mathematical comprehension. This is consistent with Chen【60】.

Influence of mathematical comprehension on learning achievement

The research findings support H6: Mathematical comprehension has positive and significant influence on learning achievement.

Influence of mathematical literacy on learning achievement

The research findings support H7: Mathematical literacy has positive and significant influence on learning achievement. This result is consistent with the results of Chien【61】and Kuo【62】.

Influence of mathematical reading on learning achievement

The research findings support H8: Mathematical reading has positive and significant influence on learning achievement. However, it was not significant.

In conclusion, from the above eight points, we can see that the main constructs of this study are correlated, and the good goodness of fit of inner and outer models are good. Mathematical reading, mathematical literacy and mathematical comprehension only have partial mediation effect. However, mathematical reading and mathematical literacy are dual mediators, and mathematical comprehension is a triple mediator.

Research Contributions

This study used Smart PLS to explore the correlation among several constructs. It is an innovative application in the field of mathematics education. These results can be provided to the teachers of technical colleges and educational decision-making authorities in Taiwan as a reference for teaching and development of educational policies, respectively.

Research Limitations

Given the limited resources, this study seeks to accomplish the research tasks as robustly as possible. However, there are certain limitations. This study uses purposive sampling to achieve a higher effective recovery rate. However, there may be a bias if the effective sample is not representative of the population. Moreover, the subject of this study was limited to the students who have studied or are studying calculus and teachers teaching calculus in a college in Taiwan. The results of this study might not be sufficient to represent the population, i.e., all freshmen taking calculus in all technical colleges in Taiwan.

Suggestions to Future Studies

(1) Subsequent researchers are recommended to sample the population with the Stratified Random Sampling method.

(2) Because of the limitation of research resources, the subject of this study was limited to the students who have studied or are studying calculus and teachers teaching calculus in a college in Taiwan. For data extensiveness or innovation, the follow-up researchers can try to extend the scope of the study or change other research constructs to understand the correlation of other constructs.

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