Causal Effects of Cognitive and Affective Factors on Students' Mathematical Problem Solving Performance

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Abstract- *Learning to solve problems is one of the primary objectives in teaching and learning mathematics. However, results of the different achievement tests continued to show that problem solving is still one of the least learned skills in mathematics which is attributed to several cognitive and affective factors. This study investigated the direct and indirect effects of the identified cognitive and affective factors on the mathematical problem solving performance (MPSP) of Grade 8 students. The sample consisted of 446 students of whom 196 (44%) were males and 250 (56%) were females. Data were gathered using achievement tests and survey questionnaires. Pearson r, regression and path analyses were used to determine which of the identified factors has/have direct and/or indirect effects on MPSP. Findings revealed that reading comprehension and computational skill have causal effects on MPSP which together explained 29.20% of its variance. Furthermore, results showed that reading comprehension had direct and indirect effects on MPSP while computational skill had only a direct effect. The rest of the variables such as academic motivation, reading attitude, mathematical attitude and mathematical belief had no direct effects on MPSP but only showed indirect effects revealing that these variables acted only as mediators of the effects of one variable to other variables including MPSP.*

Index Terms- mathematical problem solving performance, cognitive factors, affective factors

I. Introduction

Mathematics plays an important role not only in an individual's full development, but it plays an essential role in both national and global development as well (Musasia, Nakhanu & Wekesa, 2012). In fact, one will find it difficult to imagine a life and a world apart from mathematics since all human efforts from the simplest one to the most sophisticated are in one way or another connected to and influenced by the subject.

Despite the importance of mathematics and the role it plays in our daily lives, it is still considered by students as one of the most difficult subjects to learn, boring, not very practical and requires a special ability that is not always within everyone's reach (Ignacio, Nieto & Barona, 2006) due to its symbolic and abstract nature in addition to the fact that it involves problem solving.

Problem solving is one of the necessary skills to be successful in the study of mathematics. In fact, three decades ago, it has been recommended by the US National Council of Teachers of Mathematics to be the focus and one of the major objectives in teaching and learning the subject. Considered as one of the most complex intellectual functions, it is defined as a higher order cognitive process that has been refined and systematized to address the different challenges people encounter in their daily lives (Microsoft Student 2009).

However, results of the different achievement tests (both local and national) continued to show that problem solving is still one of the least learned skills in mathematics which is attributed to several cognitive and affective factors. For this reason, the researcher would like to determine which of the identified cognitive and affective factors influence students' mathematical problem solving performance viewing positively that in the light of coming up valuable results, some improvement could be done along with the hypothesized student variables.

Conceptualization of the hypothetical path model

The role of cognitive and affective factors has long been recognized in the area of human learning (Mendoza, 2015). In fact, several theories have already been made to explain how learning and problem solving occur some of which served as basis for conducting this study. For instance, advocates of cognitive psychology considered problem solving as a cognitive process that includes introspection, observation and the development of heuristics (Hardin, 2002). This is due to the fact that problem solving involves several cognitive skills which include but not limited to reading comprehension, translating verbal phrases to mathematical phrases and simplifying and evaluating algebraic expressions.

However, Larsen (2013) in her thematic literature review on attitude in mathematics, said that though learning mathematics (problem solving included) may be considered as a cognitive challenge, it is also an affective one. In fact, several studies have been conducted investigating the role of the affective dimension in mathematics achievement and problem solving which are clear manifestations that humans are not only cognitive individuals, but also social persons with beliefs, emotions and views that could somehow influence their learning styles and learning outcomes (Nicolaidou & Philippou, 2002).

In this connection, Mendoza (2015) highlighted that while it is true that cognitive factors are important in improving students' achievement in general and problem solving in particular, we should not take for granted the affective factors that play an equally important role in learning. Cognitive factors considered in this study include reading comprehension and computational skill while the affective factors include academic motivation, reading attitude, mathematical attitude and mathematical belief.

In this study, it was hypothesized that students with higher levels of reading comprehension and computational skill will have better performance in mathematical problem solving (Orhun, 2003; Vilenius-Tuohimaa, Aunola & Nurmi, 2008; Hite, 2009; Ajogbeje, 2012; Fuchs, Fuchs, Hamlett, Lambert, Stuebing & Fletcher, 2008; Krawec, 2010; Nizoloman, 2013). Similarly, students with positive reading attitude, positive mathematical attitude and positive mathematical belief were assumed to perform better in reading comprehension, computational skill and mathematical problem solving than their counterparts with negative attitudes (Nicolaidou & Philippou, 2002; Bassette, 2004; Parker, 2004; Steiner, 2007; Zan and Di Martino, 2007; Pimta, Tayruakham & Nuangchalem, 2009; Sangcap, 2010; Michelli, 2013). Furthermore, students who have good reasons to go to school and are motivated to participate in the teaching-learning process were assumed to demonstrate better computational skill, higher reading comprehension level and better mathematical problem solving performance (Middleton and Spanias, 1999). Thus, the researcher developed the following hypothetical path model showing the different relationships to be explored and examined.

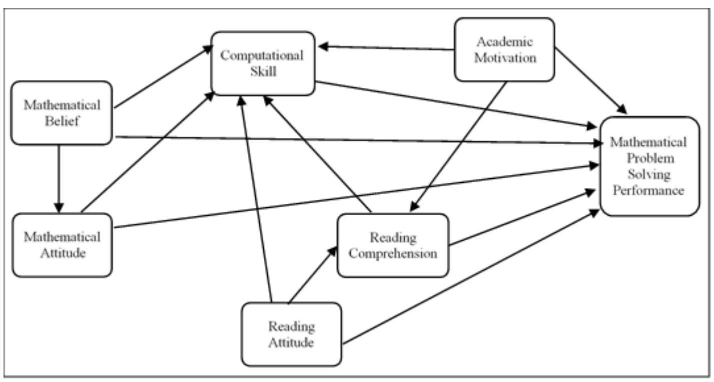

Fig. 1. Hypothesized path model of mathematical problem solving performance.

Objectives of the study

This study investigated the effects of the hypothesized cognitive and affective factors on students' mathematical problem solving performance, which served as a basis in coming up with the theoretical path model of MPSP. Specifically, it sought to determine the performance level of students in mathematical problem solving, test if significant relationships exist between MPSP and the hypothesized causal factors, identify the direct and /or indirect effects of these hypothesized factors on students' MPSP and develop a path model relating MPSP to the significant factors.

II. METHODOLOGY

This study used the descriptive-correlational research design. The respondents of this study were the 446 grade 8 students which were selected using universal sampling technique. Achievement tests were given to students to determine their levels in computational skill, problem solving and reading comprehension. Students' computational skill was measured using the Basic Mathematics Quiz (Johnson and Kuennen, 2006). Their problem solving performance was determined using the Mathematics Processing Instrument (Suwarsono as cited in Krawec, 2010) while their reading comprehension level was measured using items taken from a national standardized test. Pilot study was conducted and extreme group method item analysis was made on these instruments in order to test the suitability and clarity of these questionnaires to the respondents which resulted to discarding some of the items in basic mathematics quiz and mathematics processing instrument.

Other variables involved in the conduct of this study were measured using survey questionnaires. The researcher used a 5-point Likert-type scale with values ranging from 1 "strongly disagree" to 5 "strongly agree". These questionnaires included: 1) Reading Attitude Survey (Sani and Zain, 2011); 2) Mathematics Attitude Scale (Yasar, 2014); 3) Mathematics Belief Scale (Lazim, Abu Osman & Wan Salihin, 2004); and 4) Academic Motivation Scale (Vallerand, Pelletier, Blais, Briere, Senecal & Vallieres, 1992). These survey questionnaires were also subjected to a pilot study and Cronbach's alpha was used to estimate the internal consistency reliability of each instrument. Results revealed that Cronbach's alpha values of these instruments were within the acceptable range.

Students' questionnaire score was in a score-sum format, that is, their total score was determined by adding all their responses to the items given (per variable) which was used to determine their level of measurement for that specific variable. Prior to the analysis, the data collected were entered, coded and some were reversed coded using a spreadsheet program. The researcher then used a statistical software as a device for computation with the following employed statistical tools: frequency count and simple percentage, mean and standard deviation, Pearson r and regression analysis.

Ethical Consideration

In order to protect respondents' privacy, identity and anonymity, information given by them was treated with utmost confidentiality through various confidentiality procedures. Respondents' informed consent was sought first and they were given the right to refuse if they do not want to be involved in the study. Participants of the study provided their answers voluntarily thus no financial compensation or any other incentive was given to them. Likewise, no monetary cost was involved on the part of the students.

III. RESULTS AND DISCUSSION

Data Normality

Prior to any multivariate analysis, certain assumptions about the gathered data have to be considered and addressed, one of which is data normality. This is because deviation from normality to a significant degree when not resolved can greatly affect the results of the data analysis (Nasser as cited in Mendoza, 2015). Results revealed that skewness and kurtosis values for all variables were all below 1 suggesting an approximately normal distribution (Brown as cited in Mendoza, 2015).

Profile of the Respondents

Table 1 presents the profile of the respondents along the different exogenous and endogenous variables. As presented, it can be observed that generally, the study population (Grade 8 students) showed positive reading attitude (mean = 42.43). However, as to reading comprehension, the students indicated below average performance level (mean = 3.74). Meanwhile, the table further revealed that the students' academic motivation was on average level as indicated by its mean score of 109.63.

Furthermore, results also showed that while students indicated positive mathematical attitude (mean = 67.88) and positive mathematical belief (mean = 71.06) however they have demonstrated below average performances both in computational skill (mean = 3.44) and mathematical problem solving (mean = 3.54).

Table 1: Profile / Level of the respondents along the different variables

Predictor Variables / Factors	Mean	SD	Description
Reading Attitude	42.43	6.34	Positive
Reading Comprehension	3.74	1.56	Below Average
Academic Motivation	109.63	12.52	Average
Mathematical Attitude	67.88	8.52	Positive
Mathematical Belief	71.06	8.20	Positive
Computational Skill	3.44	1.95	Below Average
Mathematical Problem Solving Performance	3.54	1.60	Below Average

Correlation Between Mathematical Problem Solving Performance and Predictor Variables

Table 2 reflects the Pearson Product Moment Correlation coefficients between each pair of variables involved in the study. As reflected, two sets of observations can be extracted and these are: 1) correlation coefficient values between each pair of the hypothesized causal factors (both exogenous and endogenous variables) and 2) correlation coefficients between MPSP and each of the hypothesized causal factors.

Table 2: Correlation between mathematical problem solving performance and predictor variables

Predictor Variables	2	3	4	5	6	Mathematical Problem Solving Performance
1.Reading Attitude	.35*	.32*	.45*	.34*	.27*	.17*
2. Reading Comprehension	-	.35*	.32*	.26*	.56*	.47*
3. Academic Motivation		-	.48*	.57*	.43*	.24*
4. Mathematical Attitude			-	.62*	.36*	.19*
5. Mathematical Belief				-	.26*	.15*
6. Computational Skill					-	.49*

*Note. *p-value < .01*

Taking into consideration the correlation coefficients between exogenous and endogenous variables, it can be observed that all of the relationships between each pair of these variables were statistically significant. Generally speaking, in the correlation analysis presented, r – values which were greater than or equal to 0.15 were considered statistically significant.

As to which of the hypothesized causal factors were significantly related to MPSP, the data revealed a significant relationship between MPSP and each of the following variables: reading attitude $(r = .17, p < .01)$, reading comprehension $(r = .47, p < .01)$, academic motivation $(r = .24, p < .01)$, mathematical attitude $(r = .19, p < .01)$, mathematical belief $(r = .15, p < .01)$ and computational skill $(r = .49, p < .01)$.

Regression Analyses of the Endogenous Variables and their Respective Hypothesized Causal Factors

In the present study, four regression analyses were performed to determine the path coefficients of the hypothesized causal factors in the proposed model, and later on, the impact of each of the hypothesized causal factors on the mathematical problem solving performance of the students. The analyses included four endogenous variables, namely: mathematical attitude, reading comprehension, computational skill and mathematical problem solving performance, each of which served as a dependent variable one at a time, with their corresponding hypothesized exogenous variables.

Mathematical Attitude. In the proposed path model, mathematical belief was assumed to affect students' mathematical attitude. As presented in Table 3, the model significantly predicted students' mathematical attitude $[F\ (1{,}444) = 277.297, p < .001]$. Furthermore, it indicates that 38.30 % of the variation in students' mathematical attitude can be attributed to their mathematical belief $(t = 16.652, p < .001)$.

Table 3. Regression Analysis on Mathematical Attitude and Its Identified Causal Factor

Variables	Unstandardized Coefficients		Standardized Coefficients (Beta)	t	p
	B	Standard Error			
(Constant)	22.124	2.766	-	7.999	.000
Mathematical Belief	.64	.039	.62	16.652	.000

$R = .620;\ Adjusted\ R^2 = .383;\ F\ (1, 444) = 277.297;\ p < .001$

Reading Comprehension. In this analysis, two independent variables were assumed to affect students' reading comprehension level (reading attitude and academic motivation)**.** Table 4 reveals that the model significantly predicted students' reading comprehension level $[F(2{,}443) = 49.680, p < .001]$. It also shows that academic motivation $(t = 5.901, p < .001)$ and reading attitude $(t = 5.741, p < .001)$ significantly predicted students' reading comprehension which together explained 18% of its variance.

Table 4. Stepwise Regression Analysis on Reading Comprehension and Its Identified Causal Factors

Variables	Unstandardized Coefficients		Standardized Coefficients (Beta)	*t*	*p*
	B	Standard Error			
(Constant)	-2.60	.65	-	-4.006	.000
Academic Motivation	.03	.01	.27	5.901	.000
Reading Attitude	.06	.01	.26	5.741	.000

$R = .428$; $Adjusted\ R^2 = .180$; $F\,(2, 443) = 49.680$; $p < .001$

Computational Skill. In the present study, five independent variables were believed to affect students' computational skill (reading attitude, reading comprehension, academic motivation, mathematical attitude and mathematical belief). Table 5 shows that the model significantly predicted students' computational skill $[F(3, 442) = 91.938; p < .001]$. It can also be observed that reading comprehension $(t = 10.95, p < .001)$, academic motivation $(t = 5.09, p < .001)$ and mathematical attitude $(t = 2.56, p < .05)$ significantly predicted students' computational skill which together explained 38% of the variation of the students' computational skill.

Table 5. Stepwise Regression Analysis on Computational Skill and Its Identified Causal Factors

Variables	Unstandardized Coefficients		Standardized Coefficients (Beta)	*t*	*p*
	B	Standard Error			
(Constant)	-4.18	.72	-	-5.77	.000
Reading Comprehension	.56	.05	.44	10.95	.000
Academic Motivation	.04	.01	.22	5.09	.000
Mathematical Attitude	.025	.01	.11	2.56	.011

$R = .620$; $Adjusted\ R^2 = .380$; $F\,(3, 442) = 91.938$; $p < .001$

Mathematical Problem Solving Performance. Finally, all independent variables which were found to be significantly correlated with students' mathematical problem solving performance were included in the analysis. As reflected in Table 6, the model significantly predicted students' mathematical problem solving performance $[F(2, 443) = 92.806, p < .05]$. Similarly, it can be observed that reading comprehension $(t = 6.06, p < .05)$ and computational skill $(t = 6.74, p < .05)$ significantly predicted students' mathematical problem solving performance. These two variables together accounted for 29.20% of the total variation of the dependent variable (mathematical problem solving performance).

Table 6. Stepwise Regression Analysis on Mathematical problem solving performance and Its Identified Causal Factors

Variables	Unstandardized Coefficients		Standardized Coefficients (Beta)	*t*	*p*
	B	Standard Error			
(Constant)	1.5	.17	-	8.86	.000
Computational Skill	.27	.04	.32	6.74	.000
Reading Comprehension	.30	.05	.29	6.06	.000

$R = .543$; $Adjusted\ R^2 = .292$; $F\,(2, 443) = 92.806$; $p < .001$

The Final Path Model

After a series of stepwise regression analyses, both significant and insignificant path coefficient values (standardized coefficients) were observed. Variables with insignificant values were considered non-causal variables on students' mathematical problem solving performance (MPSP) which means that no link or connection had been observed between those variables and MPSP.

Overall, on the basis of the preceding analysis, it led the researcher to finalize the proposed theoretical path model of MPSP, indicating clearly that both reading comprehension and computational skill influence MPSP. That is, reading comprehension has both direct and indirect effects on MPSP while computational skill has only direct effect on MPSP. The rest of the variables such as academic motivation, reading attitude, mathematical attitude and mathematical belief may have no direct effect on MPSP but they have indicated indirect effects, revealing that these variables acted only as mediators of the effects of one variable to other variables, including MPSP.

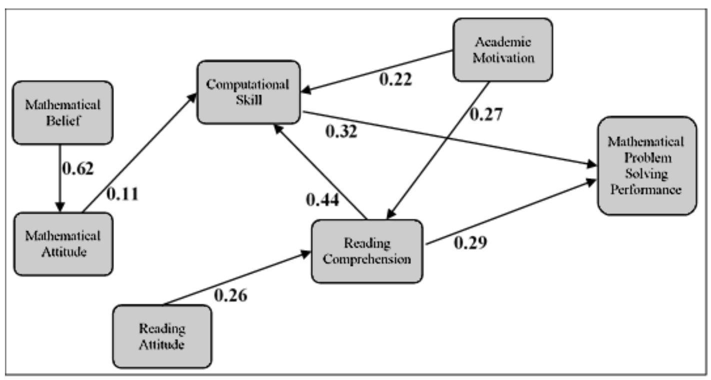

Fig. 2. Final path model of mathematical problem solving performance.

Direct, Indirect and Total Effects of Causal Variables on Mathematical problem solving performance

Table 7 summarizes the results of the path analysis indicating separately the direct, indirect and total effects of each significant variable on students' mathematical problem solving performance. As shown in the table, among the six significant variables, only two came up to have significant direct effects on students' MPSP which were reading comprehension $(\beta = .29;\ t = 6.06, p < .001)$ and computational skill $(\beta = .32;\ t = 6.74, p < .001)$. The other factors such as academic motivation, reading attitude, mathematical attitude and mathematical belief do not have significant direct effects on MPSP. However, these factors may not have direct effects on MPSP, nevertheless, they have indicated indirect effects (.15, .11, .04, .02, respectively) revealing that these variables acted only as mediators of the effects of one variable to other variables including MPSP.

Table 7. Direct, indirect and total effects of causal variables on mathematical problem solving performance.

Predictor Variables / Factors	Effects			Description
	Direct	Indirect	Total	
Computational Skill	.32	-	.32	Large
Reading Comprehension	.29	.14	.43	Large
Academic Motivation	-	.15	.15	Small
Reading Attitude	-	.11	.11	Small
Mathematical Attitude	-	.04	.04	Very Small
Mathematical Belief	-	.02	.02	Very Small

Discussions

As presented in the previous section, findings of this investigation mostly agree with the findings and conclusions of other similar studies conducted. Specifically, with regards to reading attitude and reading comprehension, it was observed that a significant relationship existed between them and each of the following variables: academic motivation, mathematical attitude, mathematical belief and mathematical problem solving performance. Such findings were consistent with the claim that reading attitude and reading comprehension affect students' level of achievement through its influence on factors such as engagement and practice (Parker, 2004). This means that students with positive reading attitude displayed higher achievement than their peers with negative attitude (MacQuillan, 2013).

Similarly, since reading is important in the development of several academic and intellectual skills like problem solving and critical thinking (Koroglu and Guzel, 2014), attitude towards reading must have played an essential role in the development of those skills. In fact, it was found out in some studies that reading attitude played a fundamental role in forming, developing and using lifelong reading skills (Parker, 2004) which later on will enable individuals develop their creativity, abilities, thoughts, imaginations, cognitive and motor skills (Ayhan, Simsek & Bicer, 2013).

Furthermore, several studies had also shown that reading comprehension was significantly and consistently related to mathematical problem solving performance (Orhun, 2003; Vilenius-Tuohimaa, Aunola & Nurmi, 2008; Hite, 2009) which means that failure to comprehend what the problem is trying to communicate will hinder students from solving the problem correctly (Yeo, 2005). This is due to the fact that problem solving requires students to use the given text to identify what are known and what are unknown which will then be used to construct a number sentence that relates them to derive the calculation problem in finding the missing information (Fuchs et al, 2008).

As to academic motivation, significant relationships were observed with each of the following variables: mathematical attitude, mathematical belief, computational skill and problem solving performance. It is quite a valid argument that students who had good reasons to go to school and were motivated to actively participate in the teaching – learning process will have better computational skill and better mathematical problem solving performance (Middleton and Spanias, 1999).

Moreover, improved attitudes and motivation in mathematics will lead to greater effort which later on will result to enhanced mathematics achievement (De Paolo and McLaren, 2006). However, students who may have considered schooling and learning a burden and at the same time a demanding task will most likely result to poor computational skill and poor mathematical problem solving performance.

It was also found out that mathematical attitude, mathematical belief, computational skill and mathematical problem solving performance are significantly correlated with each other which to some extent proved that learning mathematics is not only a cognitive challenge but also an affective one (Nicolaidou and Philippou, 2002; Pimta, Tayruakham and Nuangchalem, 2009; Larsen, 2013; Michelli, 2013). This finding suggested that what students think about mathematics influences their feelings and predisposition toward the subject (Blanco, Barona & Carrasco, 2013). They pointed out that students' negative beliefs about mathematics would likely result to unfavorable mathematical attitude which can then be made manifested in their avoidance or rejection of any mathematics related tasks. This finding further implied that positive mathematical attitude and mathematical belief will likely result to better computational skill and mathematical problem solving performance (Zan and Di Martino, 2007; Grootenboer and Hemmings, 2007). Likewise, it also confirmed the idea that superior computational skill can have direct (positive) effect on mathematical problem solving performance (Krawec, 2010; Ajogbeje, 2012; Nizoloman, 2013).

IV. CONCLUSION AND RECOMMENDATION

Due to the importance of mathematics in everybody's lives and the role it plays in both national and global development, learning the subject should be considered as a necessity rather than an option. For over three decades now, teaching and learning the subject have been directed to and focused on problem solving. Despite new efforts to address students' deteriorating performances in mathematics and problem solving, the same scenario persisted to appear deserving earnest and immediate attention.

Results of the present investigation revealed that mathematical problem solving performance is generally cognitive in nature, however, affective factors such as academic motivation, reading attitude, mathematical attitude and mathematical belief indicated indirect effects making it an affective challenge as well.

Furthermore, certain corrective measures / interventions may be done in enhancing students' mathematical problem solving performance by taking into consideration the different significant factors. In the light of recent developments, the researcher came to a conclusion that students' computational skill and reading comprehension played an essential role in their mathematical problem solving performance and that enhancing the former will eventually improve the latter. However, variables such as academic motivation, reading attitude, mathematical attitude and mathematical belief should not be taken for granted as they demonstrate indirect effects on mathematical problem solving performance.

Although findings of this study may provide valuable information which can be used as basis to improve students' mathematical problem solving performance, however, one has to take note of some of its limitations which could possibly affect the outcomes of the investigation. One such limitation is that this study is confined to one grade level (grade 8) only which means that what is true to grade 8 might not be true to other grade levels. Another limitation this study has is the modification of some of the instruments used in the investigation resulting to a change in the scoring information. Thus, similar or parallel study may be conducted in another area with a wider scope, greater number of respondents and / or another set of hypothesized causal factors to validate the findings of this investigation.

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