The Causal Relationship between Mathematical Creativity, Mathematical Aptitude and Mathematical Problem-Solving Performance

A Cross-Lagged Panel Analysis

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Abstract

The Cross-lagged Panel Analysis (CLPA) was used to investigate the causal relationship between mathematical creativity, mathematical aptitude and mathematical problem-solving performance. 480 students studying in Class VIII were selected through a random cluster technique from nine Intermediate and High Schools of Varanasi District, India. Mathematical creativity, mathematical aptitude and mathematical problem-solving performance tests were administered three times, at intervals of four months. The CLPA uncovered a significant relationship and revealed that mathematical creativity was found to be causally predominant over mathematical aptitude (i.e., higher mathematical creativity leads to higher mathematical aptitude). Furthermore, mathematical problem-solving performance was found to be the cause of mathematical aptitude and mathematical creativity both (i.e., higher mathematical problem-solving performance leads to higher mathematical aptitude and mathematical creativity).

Keywords*: Mathematical Creativity, Mathematical Aptitude, Mathematical Problem-Solving Performance.*

Introduction

The concept of mathematical creativity originated in France in 1902 when an extensive questionnaire was published in French

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periodical *L' Enseignement Mathématique* to study mathematical creativity. This questionnaire and a lecture on creativity delivered by the distinguished mathematician Henri Poincaré to the '*Societé de Psychologie'* inspired Hadamard, to investigate the psychology of mathematical creativity (Hadamard, 1945). Poincaré and Hadamard are the key persons who have done commendable work in the area of mathematical creativity and highlighted that discovery in mathematics are the combination of ideas. Mathematical creativity cannot occur in a vacuum and needs a context in which the individual moves forward through previous experiences. The ability to create novel ideas/objects in mathematics is an example of mathematical creativity.

Several definitions of mathematical creativity have been put forward but no acceptable definition has been found yet. Poincaré (1948) defined mathematical creativity as the ability to discern, or choose. Hadmard (1945) described that the roots of creativity lie in the long unconscious work of incubation, and in the unconscious aesthetic selection of ideas that thereby pass into consciousness. Mathematical creativity was considered to be the most important ingredient for solving problems divergently. Mathematical creativity plays a vital role in the full cycle of advanced mathematical thinking (Ervynck, 1991). Guilford (1968) has pointed out that creativity is the key to education in its fullest sense and the solution to mankind's most serious problems. For the development of a nation there is a great need to identify creative doctors, mathematicians etc. A creative mind is imaginative, full of hypothesis, theories and dreams (Dunn, 1976). It seeks to discover the facts, generalisations, and understanding that may appear to be widely accepted. Empirical evidences have shown that factors such as lack of interest, negative attitude towards mathematics, self concept in mathematics, mathematical intelligence, use of traditional methods of teaching and so on (Jhony, 2008; Mann, 2005; Singh, 1985; Sriraman, 2004) affect the performance convergently and divergently both in mathematics.

The recent upsurge in the research conducted on problem-solving performance in mathematics stems from the apparent belief that children's feelings about themselves are the key factors in problem-solving performance which helps in the development of mathematical creativity. Mathematical problem-solving performance appears to a certain extent to be as complex and subtle as to defy description and analysis. Polya (1957) defined mathematical problem-solving as a process that involved four dynamic activities: understanding the problem, making a plan, carrying out the plan and looking back. Problem solving involves the acquisition and application of mathematical concepts and skills in a wide range of situations, including non-routine, open-ended and real world problems. Torrance (1960) and Parnes (1967) found the close conceptual link between problem solving and creativity. Toynbee (1964) stated that creative problem solvers are the history making talents in any area of human endeavour, nevertheless, the causal relationship between these two constructs is yet to be clearly defined. Due to the optimum utilisation of human and natural resources, there is always a necessity of potential human resources. Bingham (1937) defined that aptitude is a condition symptomatic of a person's relative fitness, of which one essential aspect is his readiness to acquire proficiency—his potential ability—and the other is his readiness to develop an interest in exercising that ability (p. 18). According to the theory of aptitude, individuals differ in their readiness to profit from a particular treatment and individuals may adapt their situations to fit their own characteristics; therefore, the learners' aptitudes help to create an environment to achieve optimal learning.

Research in the field of mathematical creativity and mathematical ability has been reported by Katoou, Kontoyianni, Pitta-Pantazi, and Christou, (2013) who concluded that mathematical creativity is the subcomponent of mathematical ability. The relationship of mathematical creativity has been studied with problem-solving performance in mathematics (Tyagi, 2015; Somashekhar, 1998; Singh, 1993); interest patterns (Singh, 1988), general creativity (Singh, 1990). Manchanda and Prakash (2000) found a significant relationship between problem-solving ability and mathematical creativity. Johny (2008) studied the effect of some environmental factors on mathematical creativity and reported that mathematical creativity is significantly related with intelligence, attitude towards mathematics and self-concept in mathematics. A significant relationship was found between mathematical creativity and mathematical achievement (Singh, 1986; Walia, 2012; Sethi, 2012; Bahar and Maker, 2011). Somashekhar (1998) and Singh (1993) reported that mathematical creativity does not contribute significantly in the development of problem-solving performance in mathematics. On the other hand, Khichi (1994) reported that problem-solving in mathematics is the most important method to develop mathematical creativity among children and adults.

In addition, mathematical creativity was found to be significantly related to mathematical aptitude (Jensen, 1973; Tuli, 1979; Tyagi, 2014) as well as scientific aptitude (Verma, 1994; Srivastava, 1992). Aptitude was found to be a significant explanatory variable of elementary statistical performance (Woodward and Galagedera, 2006). Akpan (1991) reported that student's attributional factors (motivation, creativity and attitude towards mathematics) have no direct effect on their ability to solve mathematical problems.

The foregoing discussion shows about the paucity of research about the relationship between mathematical creativity, mathematical aptitude and mathematical problem-solving performance. As it is a known fact that simple correlation is not proof of causation. Further, it is not established that which variable is the cause of the other and if so, what is the direction of causation. This issue assumes significance for the development of effective mathematics teaching-learning strategies. The present study examines the directionality of the causal relationship between mathematical creativity, mathematical aptitude and mathematical problem-solving performance.

For establishing causal relationship, one needs to conduct experimental studies. But due to ethical reasons, in an experiment, a 'true' experimental design in the natural settings is formidable. Cross-lagged panel analysis is a quasi-experimental design (Campbell and Stanley, 1963) that indicates causal relation between the two variables measured at two or more time points simultaneously. Therefore, cross-lagged panel analysis was used to analyse the data.

Method

Sample

Data for the present study were collected from 480 participants (83 urban males, 107 urban females, 118 rural males, and 172 rural females), studying in class eight, in nine Intermediate and High Schools located in Varanasi District, India. The sample was selected employing random cluster technique. The mean age of the selected sample was 13 years.

Tools

The following tools were administered to the participants in the study.

1. *Mathematical Creativity Test*

The Mathematical Creativity Test developed by Singh (1985) was used to measure mathematical creativity. There were eight items related to creativity in mathematics in the test with an open range of possible test scores. Five types of activities, such as patterns in mathematics, new relationship test activity, nine dot areas, subsets and similarities, have been included in the test. Test-retest reliability of the total mathematical creativity test was found to be 0.81. The inter-item correlation technique was used to establish the validity of the test. The correlation of the total activity scores with grand total was found in the range between 0.63 to 0.84 for urban sample and 0.49 to 0.78 for the rural sample. The raw scores of each dimension, i.e., fluency, flexibility, and originality, were converted into 'T' scores with a Mean = 50 and SD = 10. The 'T' scores of each dimension were added to get the composite scores of mathematical creativity of each student.

2. *Mathematical Aptitude Test*

Braswell's (1978) Mathematical Aptitude Test was adapted in Hindi by the investigator and was used to measure the mathematical aptitude among middle school students. The test included 40 items related to the different branches of mathematics, i.e., Arithmetic, Algebra, and Geometry. The items of mathematical aptitude test were based on knowledge, comprehension and application dimension of Blooms Taxonomy (Bloom, 1956). The reliability of this test was found to be 0.88 on 200 urban and 200 rural students by using rational equivalence method. The multidimensional analysis was performed on 160 (83 boys and 77 girls) participants to establish the validity of the test. All the correlations were found in the range of 0.64 to 0.91.

3. *Mathematical Problem-Solving Performance Test*

To measure problem-solving performance in mathematics, the investigator used the Hindi adaptation of Krutetskii's Problem-Solving Test developed by Singh (1993). The test consisted of 15 items and was classified into two parts. Part–I consists of eight mathematical problems which are not based on content but related to the use of mathematical concepts in solving real life situations. Part–II consists of seven problems. Out of which one problem is of puzzle type and remains problems are situational problems. The test-retest reliability of the test was found to be 0.70. It indicates moderate consistency of the test. Validity of mathematical problem-solving test was calculated with the help of item-total correlation technique and found to be significant.

Procedure

The data were collected in three measurements phases with a lag of four months. All the instructions were adhered to clearly before the administration of each test for establishing rapport among students. In the first phase, there were 850 students. In the second and third phases some students left out and new joined. Because of the use of cross-lagged panel analysis, complete data was required to be presented for all time periods (Kenny, 1975). Finally, 480 of VIII standard students participated in this study, which were found common in three measurement waves (T_1, T_2, and T_3). Back translation procedure was used to ensure accuracy and equivalence to understand the problems.

Cross-Lagged Panel Analysis

In the absence of control of extraneous variables as well as the absence of theoretical relationship between mathematical creativity, mathematical aptitude and mathematical problem-solving performance upon which path analysis and regression analysis depends, the cross-lagged panel analysis (CLPA) is the most appropriate statistical procedure to detect the direction of causality. It is primarily an exploratory procedure designed to uncover 'the preponderance of causation' (Crano and Mellon, 1972) by eliminating alternative explanations owing to the spuriousness (Kenny, 1975). It requires at least two variables, each measured at two points in time. If one variable (e.g., mathematical creativity) measured at time 1, is consistently followed by a change in the other variable (e.g., mathematical aptitude) measured at time 2, and if the converse relationship is not true, then one can infer a direction of causality. This technique was independently suggested by Campbell (1963), and extensively reviewed (Kenny, 1979). This method utilises 'panel data', as indication from Figure 1.

As can be seen from Figure 1 that two variables X (Mathematical Creativity) and Y (Mathematical Aptitude) and three lags (time 1, time 2 and time 3) generate six variables (X_1, X_2, X_3 ,Y_1, Y_2, and Y_3) and the six variables generate fifteen correlations: six autocorrelations (rx_1x_2, rY_1Y_2, rx_2x_2, rY_2Y_3; and rx_1x_3, rY_1Y_3) three synchronous correlations (rx_1Y_1, rx_2Y_2 and rx_3Y_3) and (cross-section' or static); and

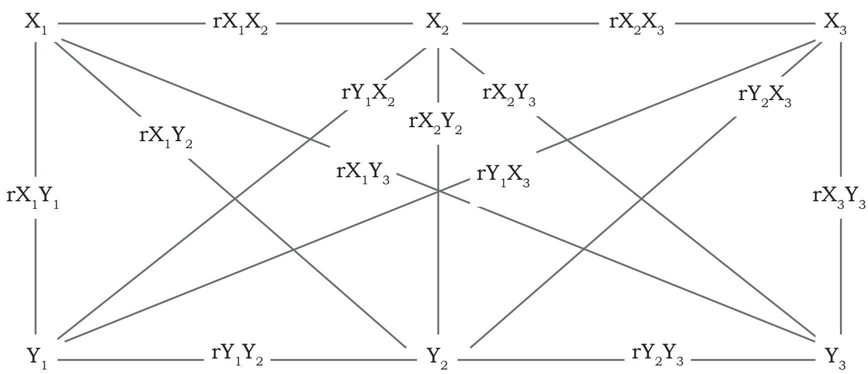

Figure 1. Cross-lagged Panel Correlation Paradigm (X and Y are variables and 1, 2, and 3 are time)

six cross-lagged correlations (rx_1Y_2, rY_1x_2, rx_2Y_3, rY_2x_3; and rx_1Y_3, rY_1x_3). A CLPC is a method for testing spurious relationships by comparing the cross-lagged differential: $rx_1Y_2 - rY_1x_2$ ($rx_1Y_2 - rY_1x_2$) and similarly ($rx_2Y_3 - rY_2x_3$) and ($rx_1Y_3 - rY_1x_3$). If the data indicates a 2w2v (two wave two variables) model, the cross-lagged differential is positive, concluding the causal predominance to be that of *X* causing *Y*, and if the cross-lagged differential is negative, concluding causal predominance to be that of *Y* causing *X*. No significant difference in the cross-lags suggests that the correlation between the variables is spurious. The synchronous correlations should be moderate to high (0.30 or above) for the effective use of cross-lagged analysis and a large sample size is generally important because of the expected difficulty in obtaining statistically significant differences between the cross-lag correlations.

The null hypothesis of CLPC is that the two variables are not causally related (Ho: $rx_1Y_2 = rY_1x_2$) but seem to be affected by some other set of common causes of 'third variable' (Simon, 1954). In order to interpret the results of cross-lagged analysis, two assumptions must be satisfied: synchronicity and stationarity (Kenny, 1975; Kenny and Harackiewicz, 1979). Synchronicity means that the variables involved are measured at the same point in time, a condition which is satisfied in this study. Stationarity, tested by comparing the synchronous correlations, means that there is no change over time in the strength, direction, or composition of the causes of a variable or the causal structure of the variables does not change over time. No significant differences between the synchronous correlations indicate that variables are stationary. If quasi-stationarity exists, Pearson-Filon (PF) test may be effectively used to test the significance of the difference between two dependent/correlated correlations.

Results

Data appeared as neither perfectly stable nor stationary due to abnormal changes in autocorrelation and synchronous correlation. In this situation, quasi-stationarity exists, therefore, communality/reliability ratios are used to correct the cross-lagged correlations. The implication of quasi-stationarity is that the synchronous correlations would be equal if corrected for attenuation due to measurement unreliability (Kenny and Harackiewicz, 1979). Otherwise, variables that decrease in reliability would erroneously appear to be the causes, while those that increase would erroneously appear to be the effects (Kahle and Berman, 1979; Campbell, 1963). The reliability ratio for mathematical aptitude was found fairly low, i.e., (0.79), indicating decreasing reliability, whereas the reliability of the mathematical creativity and mathematical problem-solving performance measures were found 1.08 and 1.07 respectively. Consequently, the difference in unadjusted cross-lagged correlations was caused primarily by the decreasing reliability of the mathematical aptitude measure. After the reliability adjustments the real cross-lagged difference appeared.

Table 1
Corrected Cross-lagged Correlations between Mathematical Creativity (MC), Mathematical Aptitude (MA) and Mathematical Problem-Solving Performance (MP) at Time–1 to Time–3 (N=480)

Sources	Time-1 to time–2 Cross-lags		z	p	Time-1 to time–3 Cross-lags		z	p
Mathematical Creativity – Mathematical Aptitude	MC_1MA_2 MA_1MC_2	0.58 0.54	–1.01	NS	MA_1MC_3 MC_1MA_3	0.52 0.61	-2.61	≤0.05
Mathematical Aptitude– Mathematical Problem-Solving Performance	MA_1MP_2 MP_1MA_2	0.49 0.56	–1.82	NS	MA_1MP_3 MP_1MA_3	0.57 0.63	-1.80	NS
Mathematical Problem-Solving Performance– Mathematical Creativity	MP_1MC_2 MC_1MP_2	0.63 0.59	1.25	NS	MP_1MC_3 MC_1MP_3	0.69 0.60	2.99	≤0.05

z is based on Pearson-Filon. If z ≥ 1.96, difference in cross-lags at 0.05 level (two-tailed)

As can be seen from the Table 1 that the obtained cross-lagged correlations between $r_{MC_1MA_3}$ and $r_{MA_1MC_3}$ were found significant but moderate. It shows that one variable may be the cause of other but from the results, the direction of causation is not clear, i.e., which one is cause and other is effect. Further to examine the direction of causation the Pearson-Filon *z* value of the differences between $r_{MC_1MA_3}$ and $r_{MA_1MC_3}$ was reported and found to be significant but negative. The minus sign of *z* value indicates the opposite directional support of the significant difference between cross-lagged correlations. Therefore, it means that mathematical creativity was found to be the cause of mathematical aptitude.

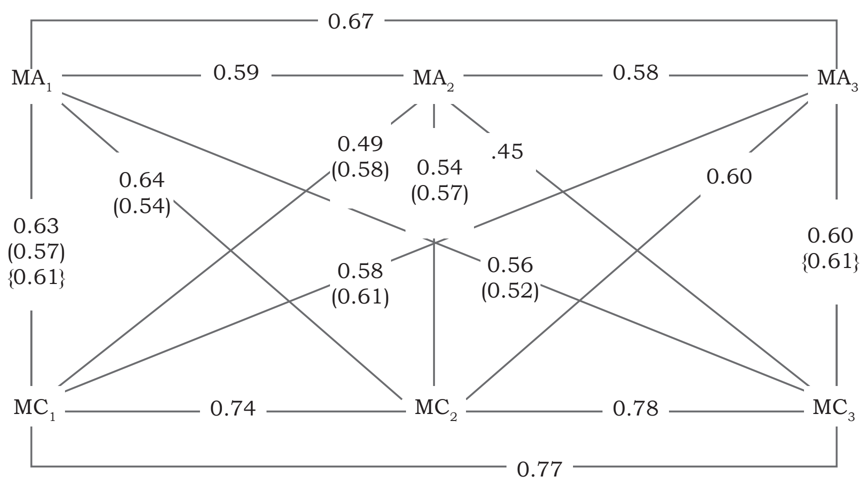

Figure 2: Cross-lagged Panel Paradigm of the Relationship between Mathematical Creativity and Mathematical Aptitude

( ) *Correction in Synchronous and Cross-lagged Correlation at time 1, 2, and 3*

{ } *Correction in Synchronous and Cross-lagged Correlation at time 1, 2, and 3*

All of the autocorrelations in Figure 2 are substantively high and statistically significant, thus, suggesting stability and reliability in variables over time but mathematical creativity appears to be a more stable construct over time than mathematical aptitude. The synchronous correlations reflect on the consistency of relationship between two variables. An abnormal change in the correlations between mathematical creativity and mathematical aptitude from time T_1 to T_2 may indicate the possible influence of a third factor.

Table 1 presents that the Pearson-Filon *z* value of the differences between $r_{MA_1 MP_3}$ and $r_{MP_1 MA_3}$ was not found to be significant, however, it also highlights the direction of the causal relationship that mathematical problem-solving performance was found to be a cause of mathematical aptitude at 0.10 level.

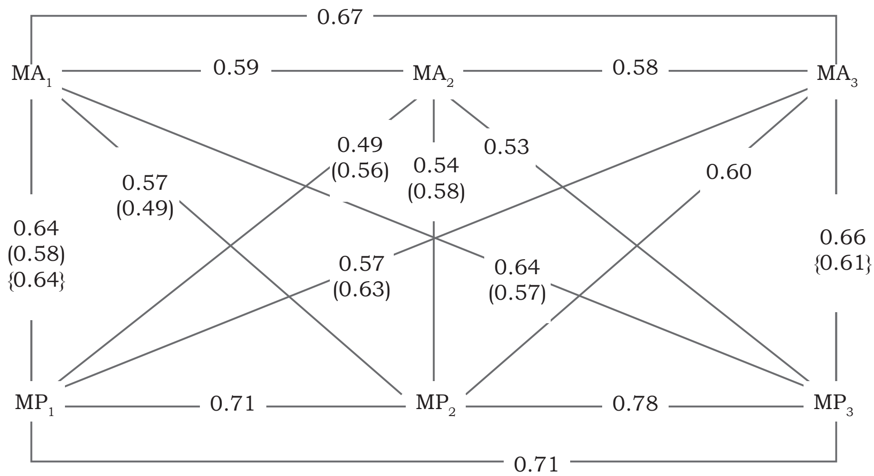

Figure 3: Cross-lagged Panel Paradigm of the Relationship between Mathematical Aptitude and Mathematical Problem-Solving Performance

( ) *Correction in Synchronous and Cross-lagged Correlation at time 1, 2, and 3*
{ } *Correction in Synchronous and Cross-lagged Correlation at time 1, 2, and 3*

Figure 3 shows that auto-correlations were of large magnitude, indicating high consistency of mathematical problem-solving performance over time than mathematical aptitude. Synchronous correlations were found to be significant and revealed a statistical relationship between mathematical aptitude and mathematical problem-solving performance (a priori relationship exists), nevertheless, a significant difference between the synchronous correlation of mathematical aptitude and mathematical problem-solving performance from Time–1 to Time–2 may indicate the possible influence of a third extraneous factor.

Table 1 shows that the Pearson-Filon *z* value of the differences between and was found to be significant. It indicates that mathematical problem-solving performance was found to be a cause of mathematical creativity.

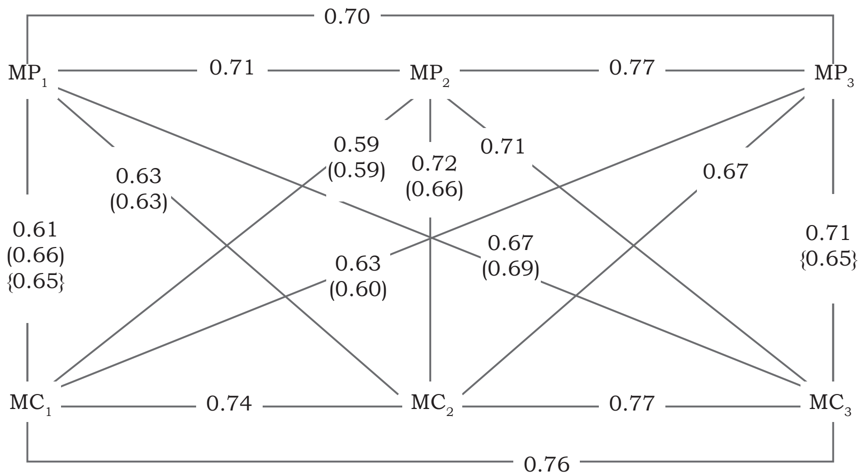

Figure 4. Cross-lagged Panel Paradigm of the Relationship between Mathematical Creativity and Mathematical Problem-Solving Performance

( ) *Correction in Synchronous and Cross-lagged Correlation at time 1, 2, and 3*
{ } *Correction in Synchronous and Cross-lagged Correlation at time 1, 2, and 3*

As can be seen from Figure 4, the auto-correlations were found to be highly significant and also indicate stability within variables over time. Both variables appear to have similar stability over time. The difference between synchronous correlations at time T_1 and T_2 were found to be significant; hence, some moderating variables may be influencing over time and may affecting the relationship between the same variables.

Discussion and Conclusion

The main purpose of this study was to uncover the strength and direction of causality between mathematical creativity, mathematical aptitude and mathematical problem-solving performance. For this CLPA was applied to analyse the panel data in three waves and three variable (3w3v) model. The results are very promising and interesting. In two lag procedures, causal relationship was not found, however, in three lag procedures, mathematical creativity was found to be a stronger cause of mathematical aptitude. Similarly, mathematical problem-solving performance was found to be the cause of mathematical creativity and mathematical aptitude both.

No significant difference (not equal to zero) between the significant cross-lagged correlations indicates that both variables equally cause each other in positive feedback loop making the cross-lag equal (as for mathematical aptitude and mathematical problem-solving performance). But the magnitude of the effect is too small to be detected. One important reason of the equal relationship between mathematical aptitude and mathematical problem-solving performance may be that the development of mathematical aptitude takes longer route by the application of mathematical problem-solving performance. In this study, the time lag was only four months, therefore, such results were obtained. If time lag was one or two years then clear results of the cause of may be obtained. The second reason may be the effect of gender, culture or socio-cultural and educational background differences etc., on the selected variables. Significant differences between the unequal corrected cross-lagged correlations indicate that the relationship between concerned variables was found to be asymmetrical, i.e., they were not influencing each other equally. In addition, non-zero cross-lag difference indicates that the relationship between mathematical creativity, mathematical aptitude and mathematical problem solving performance was found to be not spurious i.e., caused by undesirable third variable. Finally, it may be concluded that mathematical problem-solving performance was found to be the cause of mathematical creativity and mathematical aptitude both.

Synchronous correlations were found to be positive and significant. An abnormal change in the synchronous correlation (i.e., a significantly large difference) may indicate the possible influence of a third factor (Tyagi and Wotruba, 1993). On the basis of two wave analysis, a generalisable statement may not be made about the causal relationship for concerned variables.

Despite the methodological strengths, the present study has also some limitations. First, the present study was conducted in a relatively short time span, i.e., four months only, a long time interval may help in drawing a clear picture of the causal relationship. Second, although evidence was found for causal relationship between them, however, the effect sizes of the cross-lagged paths are generally small. Furthermore, the abnormal changes in auto-correlations were not considered in the correction method. To eliminate the above limitations, the third lag of longer duration should be used. Future research on this topic might consider other variables such as mathematical intelligence, self-concept in mathematics and mathematical curiosity that may have a significant role in causal relationship which provides the contribution to the theory and practice. Future longitudinal and laboratory research should be conducted to explicitly investigate the relationship between mathematical creativity, mathematical aptitude and mathematical problem-solving performance. The implications of these research findings suggest that a conducive environment needs to be created for solving mathematics problem in the classroom as well as in home.

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