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Sains Humanika

Mathematical Thinking and Physics Achievement of Secondary School Students

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Abstract

The present paper aims to identify mathematical thinking and physics achievement of secondary school students in Johor Bahru Malaysia. A total of 127 Form 4 students were selected from 3 Cluster Schools in Johor Bahru by using cluster sampling. This quantitative study used both test items and questionnaire for data collection. Cronbach's alpha was run on a sample of 12 students and the overall reliability coefficient for both mathematical thinking and physics test was 0.865 and 0.867 respectively. Descriptive analysis was used to obtain data on students' demographic information while inferential analysis was used to examine the relationship between mathematical thinking and physics achievement of the respondents. Findings showed significant relationship between all mathematical thinking skills and physics achievement. However, findings indicated that there was no significant difference in mathematical thinking and physics achievement by gender. In addition, the influence of mathematical thinking skills on students' physics achievement was statistically significant with $F(4,122) = 18.678$, $p < 0.001$. In future study, it is suggested to have more sub-constructs of mathematical thinking and a heterogeneous sample with larger size to gain meaningful knowledge about mathematical thinking and physics achievement, thus paving the way for effective instructional activities.

Keywords: Mathematical thinking; Physics achievement; gender

Abstrak

Kajian ini bertujuan untuk mengenal pasti pemikiran matematik dan pencapaian Fizik dalam kalangan pelajar sekolah menengah di Johor Baharu. Sebanyak 127 orang pelajar Tingkatan 4 dari tiga buah sekolah kluster di Johor Bahru diambil sebagai responden kajian ini melalui persampelan kluster. Kajian kuantitatif ini menggunakan instrumen berbentuk ujian dan soal selidik untuk mengumpul data. Statistik Cronbach alpha digunakan terhadap 12 orang pelajar dalam kajian rintis tentang pemikiran matematik dan ujian Fizik dan memperoleh nilai koefisien kepercayaan sebanyak 0.865 and 0.867 masing-masing. Analisis diskriptif digunakan untuk mendapat maklumat demografi pelajar manakala analisis inferensi pula digunakan untuk mengenal pasti hubungan antara pemikiran matematik dengan pencapaian Fizik respoden. Dapatan kajian menunjukkan bahawa terdapat hubungan yang signifikan antara semua kemahiran pemikiran matematik dengan pencapaian Fizik. Walau bagaimanapun, dapatan kajian menunjukkan tidak terdapat perbezaan yang signifikan antara pemikiran matematik dengan pencapaian Fizik merentas jantina. Selain itu, pengaruh pemikiran matematik terhadap pencapaian fizik adalah signifikan dengan $F(4,122) = 18.678$, $p < 0.001$. Dicadangkan dalam kajian masa depan, pemikiran matematik wajar mempunyai subkonstruk dan saiz sampel ditambah untuk mendaptkan pengetahuan lanjut tentang pemikiran matematik dan pencapaian Fizik, justeru menyumbang ke arah aktiviti pengajaran yang efektif.

Kata kunci: Pemikiran matematik; pencapaian Fizik, jantina

1.0 INTRODUCTION

As the world had slowly turned into an advance technological era, the government of Malaysia has a long term plan of turning the country into a developed nation by 2020 using with the resources that we have. In the context of the Tenth Malaysia Plan, the Prime Minister of Malaysia, Dato' Sri Mohd Najib Bin Tun Abdul Razak vowed to raise the standards of living of our nation and make Malaysia to become a high income nation (RMK-10, 2010). This so called talent base and workforce of high-income nations include a number of key characteristics which look more on to higher education qualifications to promote a knowledgeable generation with high innovation, high skill-levels in both technical and professional fields and strong levels of productivity (RMK-10, 2010). By looking into Malaysia's vision of becoming a developed country, it is unavoidable to admit that the foundation to become a nation which is industrialized is science and technology. Due to the mass necessities in our era, the Malaysian Mathematics Curriculum's aims are striving to develop human capitals that are able to think mathematically and apply mathematics in the real life situation (KBSM, 2004).

Mathematical thinking is a term that is used in most mathematics curriculum. However, the term "Mathematical Thinking" is not used in the Malaysian mathematics curriculum. Instead of using mathematical thinking, similarly, "to think mathematically" is used in the Malaysian secondary school mathematics curriculum. People from different fields and education levels defined that mathematical thinking differently (Lutfiyya, 1998). Furthermore, the educators developed the definition of mathematical thinking based on their own country's

curriculum (Isoda, 2006). This resulted in the diversity of different definitions of the term "mathematical thinking". He stated that mathematical thinking requires higher thinking skills with a blend of mathematics to understand the ideas, to identify and prove the relationship between the differences in ideas and connect these differences together to solve the existing problem. Meanwhile, Lim and Hwa (2006) defined mathematical thinking as a mental operation used in solving problem affirmed by the mathematical knowledge and dispositions.

Currently, mathematics curriculum aims to develop individuals who are able to think mathematically, apply mathematical knowledge effectively and responsibly during problems solving period while in the meantime facing the challenges in everyday life brought upon by the advancement of science and technology (KBSM, 2004). On the other hand, the aim of Physics Curriculum in Malaysia is to provide students with the right knowledge and skills in physics and technology to enable them to solve problems and make decisions in a daily basis based on scientific attitudes and noble values (KBSM, 2004). Based on the above statement, physics curriculum had similar aims with mathematics curriculum since as both emphasize skills in decision making and problem solving. This statement pointed out the hidden relationship between both mathematics and physics. Mathematics is an intrinsic component of science and serves as a universal language and indispensable source of intellectual tools (Chorin and Wright, 1999).

Mathematics and physics pose a threat to some students where mathematics may be regarded as a fearful subject which involves massive use of symbols and mathematical proofs (Mubark, 2005) whereas physics is a subject which involves a lot of abstract formulas for them to visualize (Bektasli, 2006). The study of Liu and Liu (2011) had investigated the students' epistemological beliefs of physics and mathematics and revealed that there was a strong interrelationship between mathematics and physics in historical views. The lack of understanding of development in mathematics and physics among the students had narrowed down their views in these two fields and further affected their preference in mathematics and physics (Liu and Liu, 2011). There is also a notion that these two subjects are interrelated where ability in mathematics is positively correlated with physics (Delialioglu & Askhar, 1999). In other word, mathematical thinking acts as the problem solving tool in physics (Tuminaro, 2004). A student who is excellent in mathematics is expected to be excellent in physics as well. Empirical evidence must be obtained so that measures can be taken to improve teaching strategies in these subjects. Therefore, this study aims to identify the current situation in Malaysia by focus on students' mathematical thinking skills and then related to their gender and physics performance.

2.0 RESEARCH OBJECTIVES

The objective of this research was to identify the relationship between mathematical thinking and physics achievement of the secondary students. Specifically, the research objectives are to identify the:

1) Relationship between intellectual skills and physics achievement of the students.
2) Relationship between verbal information and physics achievement of the students.
3) Relationship between cognitive strategy and physics achievement of the students.
4) Relationship between attitudes towards mathematics and physics achievement of the students.
5) Level of mathematical thinking of the students by gender.
6) Physics achievements of the students by gender.
7) Influence of mathematical thinking on physics achievement of the students.

3.0 RESEARCH HYPOTHESES

The following research hypotheses are formed according to the research objectives and questions that had been conducted.

HO1: There is no significant relationship between intellectual skills and physics achievement of the students.
HO2: There is no significant relationship between verbal information and physics achievement of the students.
HO3: There is no significant relationship between cognitive strategy and physics achievement of the students.
HO4: There is no significant relationship between attitudes towards mathematics and physics achievement of the students.
HO5: There is no significant difference between the level of mathematical thinking among male and female students.
HO6: There is no significant difference between the physics achievement among male and female students.
HO7: Mathematical thinking has no significant influence on the physics achievement of the students.

was approximately 100 nm, and their diameters were ca. 9 nm (depth ca. 1 nm).

4.0 CONCEPTUAL FRAMEWORK

Figure 1 shows the conceptual framework for this study. Gagne's Model of Learning (Gagne, 1972) was used as a guideline in this study since it had fulfilled most of the conditions of mathematical thinking. This study aimed to investigate mathematical thinking and physics achievement of secondary school students and the influence of mathematical thinking on physics achievement.

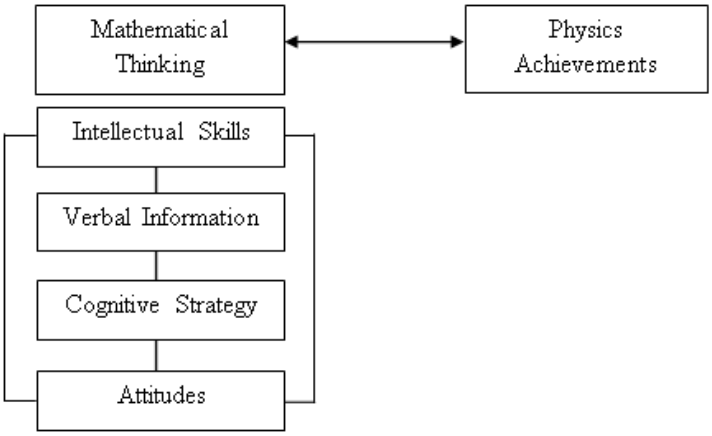

Figure 1 Conceptual framework

In this study, mathematical thinking was consisted of four components, which are intellectual skills, verbal information, cognitive strategy, and attitudes. Test and questionnaire were used to identify students' mathematical thinking. Test was used to identify students' intellectual skills and verbal information while questionnaire was used to identify students' cognitive strategy and attitudes towards mathematics. Each of the mathematical thinking skills was ranked in five levels. Meanwhile, test also used to determine the students' physics achievements. Afterwards, test scores in physics problems are categorized into five levels. The relationship between each of the mathematical thinking skills and physics achievements was being identified and the most influential mathematical thinking skill to physics achievements would be determined by using multiple regressions. Furthermore, the study also took consideration of gender differences as one of the factors that would affect both mathematical thinking and physics achievements.

■5.0 LITERATURE REVIEW

The definition of mathematical thinking was not well defined even there were lots of the previous studies about this topic before. This was because each and every researcher has their own way of thinking resulting in a different kind of conclusion. Hence, this study pointed out to the various perspectives of mathematical thinking and summarized it with the support of Gagne's Model of Learning (Gagne, 1972). In the study of Karadag (2009), he defined mathematical thinking as a thinking style supported by thinking skills. Among all the thinking skills, it had been categorized into seven major areas, which are modelling, reasoning, symbolization, representation, proving, abstraction, and mathematization. However, these major cognitive activities are hard to be categorized due to their similarity and interrelation.

Lim and Hwa (2006) defined that mathematical thinking was the mental operation supported by the mathematical knowledge and disposition towards the solution of the problem. Lim and Hwa (2006) had listed out the characteristics of mathematical thinking by describing it as involving the manipulating of the cognitive process and strategies. The one equipped with mathematical thinking skills will be the only one able to know their own cognitive thinking and control it to the solution of a problem. Lastly, mathematical thinking is strongly sustained by mathematical knowledge.

Mubark (2005) pointed out that mathematical thinking is a fundamental of mathematics which there is many aspects of mathematical thinking. In his research, he divided mathematical thinking into six aspects, which are generalization, induction, deduction, use of symbols, logical thinking and mathematical proof. Students with high mathematical thinking level are usually high achievers in mathematics. Good thinkers routinely use strategies and effective planning to solve problems (Santrock, 2009). It will help a student to excel in scientific areas and also in their general life. As a result, mathematics curriculum should be designed to facilitate the development of mathematical thinking in order to bring mathematics into practical situations.

In the previous study of mathematical thinking, there were some incomplete parts when defining it. In the study of Karadag (2009), he stated that mathematical thinking is a thinking style supported by thinking skills. The definition of this mathematical thinking is not emphasized on the attitudes of the students. However, if the students do not show good attitude in mathematics, they will not confident in solving problems. This situation is the same as in the work of Mubark (2005), when he defined that mathematical thinking consists of six aspects, which is generalization, induction, deduction, use of symbols, logical thinking, and mathematical proof.

Lim and Hwa (2006) defined mathematical thinking as a mental operation supported by the mathematical knowledge and disposition towards problem solving. This definition of mathematical thinking was good since it concluded attitudes in its definition. However, there was still a lacking of intellectual skills, which is the procedure during problem solving. Not every student is good in cognitive process and it is hardly taught during the class. As a result, intellectual skills can be used as a guidance or clue for the students to think step by step towards the solution of a problem. Based on the overall views towards mathematical thinking, this study concluded that mathematical thinking is a cognitive strategy supported by verbal information, intellectual skills and good attitudes towards the attainment of mathematical problem solving. This definition was based on Gagne's Model of Learning (Gagne, 1972), by considering the learning domains as the components in mathematical thinking.

Both mathematics and sciences were dispensable in the development of science and technology (Aghadiuno, 1992). Due to the complexity of mathematics, mathematics is hard to be defined in a simple way. However, mathematics could be categorized into "pure" and "applied" mathematics, where "pure" mathematics did not have any practical purpose while "applied" mathematics was used to understand and solve any nature occurred problem. Mathematics is the language of sciences, an abstract language to explain nature

phenomena (Chorin & Wright, 1999). Mathematics also serves as a symbolic expression in physics to show the structure of the relationship between different factors (Torigoe, 2008). Symbolic expression allows learners to have a better understanding of physics contents and improve their procedural knowledge to interrelate various symbols during solving physics problem.

Mathematics is a system of postulations and axioms, which involved the use of logical reasoning to prove validity of certain theories and system. Besides that, mathematics also acts as a tool for physics to handle any calculation and proofing of realistic phenomena (Tuminaro, 2004). The lack of understanding of development in mathematics and physics among the students had narrowed down their views in these two fields and further affected their preference in mathematics and physics (Liu & Liu, 2011). Besides that, physics involves a lot of representation like experiments, formulas and calculations, graphs, and conception explanations (Ornek, Robinson, & Haugan, 2008). In conclusion, mathematics is used to evaluate nature phenomena in more precise way while physics is applied to discover and develop a new theory to explain nature phenomena.

6.0 METHODOLOGY

A total of 127 Form 4 science stream students around Johor Bahru had been participated in this study. After thorough consideration of the respondents, three out of four cluster schools were chosen as representative. The number of respondents consisted of 35 males (27.6%) and 92 females (72.4%) with the sum of 127 people. The research instruments used in this study were tests and questionnaires. Test paper was used to investigate the level of students' mathematical thinking (intellectual skills and verbal information) and also their physics achievement. Mathematical thinking items were taken from standardized test like TIMSS while physics achievement items were adapted from Physics Problem Solving Ability Test (PPSAT) (Seth, Fatin & Marlina, 2007). Questionnaires were used to assess students' attitudes towards mathematics and also their cognitive strategies. Fennema-Sherman Mathematics Attitude Scales (MAS) was adopted and used to assess the students' attitudes towards mathematics (Fennema & Sherman, 1976). On the other hand, cognitive strategies of the students were being assessed by using Metacognitive Skills Questionnaire (MSQ), adapted from the study of Seth, Fatin and Marlina (2007). Pilot study results showed a high coefficient of Alpha Cronbach reliability with 0.854 and 0.851 for Items of Students' Attitudes towards Mathematics and Items of Students' Cognitive Strategies in Mathematics respectively. Furthermore, the overall reliability coefficient for both mathematical thinking and physics test was 0.865 and 0.867 respectively. Data collected had been analyzed via descriptive and inferential methods.

7.0 RESULTS

Data was analyzed via Statistical Package for Social Sciences (SPSS) version 16.0 to explore and identify the relationship between mathematical thinking and physics achievement. The relationship between each of the mathematical thinking skills and physics achievement had been explored independently and the most influential mathematical thinking skill to physics achievement was determined.

Table 1 shows the overall mean distribution of respondents' mathematical thinking skill level. Among all of the mathematical thinking skills, the findings found that respondents had achieved an excellent level in their verbal information, with the highest mean of 4.38. Besides that, respondents' attitudes towards mathematics also situated at an excellent level with a mean of 4.08. On the other hands, both of the respondents' intellectual skills and cognitive strategy were in good level, with mean 3.92 and 3.81 respectively.

Table 1 Level of respondents' Mathematical thinking skills

No	Mathematical Thinking Skills	Mean	Level
1	Intellectual Skills	3.91	Good
2	Verbal Information	4.38	Excellent
3	Cognitive Strategy	3.81	Good
4	Attitudes Towards Mathematics	4.08	Excellent

Table 2 shows the frequency distribution of respondents' physics achievement. A total of 40 marks in physics achievement test had divided equally into five levels. Findings showed that only 9 respondents (7.1%) out of 127 respondents had obtained excellent results in their physics achievement test. On the other hand, there were 42 respondents (33.1%) achieved good result and 15 respondents (11.8%) achieved average results in their physics achievement test. The findings also showed that there were 27 respondents (21.2%) and 34 respondents (26.8%) who achieved weak and very weak results for their physics achievement test.

Table 2 Distribution of respondents' Physics achievement

Score	Level	Frequency	Percentage (%)
0 – 8	Very Weak	34	26.8
9 – 16	Weak	27	21.2
17 – 24	Average	15	11.8
25 – 32	Good	42	33.1
33 – 40	Excellent	9	7.1

Table 3 shows that male respondents' mathematical thinking mean (M = 4.16, SD = 0.73) was slightly higher than female respondents' mathematical thinking mean (M = 4.13, SD = 0.94). The t value (t = 0.175) was not statistically significant because p = 0.861 > 0.05, implied there was no evidence of significant difference between male and female students on mathematical thinking level. Meanwhile, findings also show that male respondents' physics achievement mean (M = 2.57, SD = 1.42) was slightly higher than female respondents' physics achievement mean (M = 2.42, SD = 1.80). The t value (t = 0.444) was not statistically significant because p = 0.658 > 0.05, implied there was no evidence of significant difference between male and female students on their physics achievement.

Table 3 t-test results for Mathematical thinking and Physics achievement with gender

Variable	Gender	No of Sample, N	Mean, M	Standard Deviation, SD	t	df	p (2-tailed)
Mathematical Thinking	Male	35	4.16	0.73	0.175	125	0.861
	Female	92	4.13	0.94			
Physics Achievement	Male	35	2.57	1.42	0.444	125	0.658
	Female	92	2.42	1.80			

Simultaneous multiple regression was conducted to investigate the best predictor of students' physics achievement. Table 4 shows the means, standard deviations, and intercorrelations for physics achievement with mathematical thinking as a predictor. The findings showed each of the mathematical thinking skills had significant relationship with physics achievement independently. Intellectual skills showed the strongest significant relationship to physics achievement with a correlation coefficient of 0.473 at significant level of 0.01. Meanwhile, there existed weak significant relationship between mathematical attitudes and physics achievement with correlation coefficient of 0.383 with p = 0.01. Cognitive strategy and verbal information also showed weak significant relationship with physics achievement with correlation coefficient of 0.352 and 0.349 at p = 0.01 respectively. Table 5 shows simultaneous Multiple Regression results for mathematical thinking predicting physics achievement. The combination of mathematical thinking skills to predict students' physics achievement was statistically significant with F (4,122) = 18.678, p < 0.001. Intellectual skills were the best predictor with β value of 0.370 while cognitive strategy was the least predictor with β value of 0.179 to physics achievement. In addition, all of the mathematical skills significantly predict physic achievement. Furthermore, Table 4.20b reveals the combination of mathematical thinking skills will predict 35.9% of the variances in physics achievement among the students.

Table 4 Means, standard deviations, and intercorrelations for Physics achievement and Mathematical thinking as predictor

	M	SD	Intellectual Skills	Verbal Information	Mathematical Attitudes	Cognitive Strategy
Physics Achievement Predictor	2.46	1.70	0.473**	0.349**	0.383**	0.352**
Intellectual skills	3.91	1.39	- -	0.221**	0.174*	0.147
Verbal Information	4.38	0.85		- -	0.224**	0.145
Mathematical Attitudes	4.08	0.58			- -	0.480**
Cognitive Strategy	3.81	0.55				- -

Table 5 Simultaneous multiple regression results for Mathematical thinking predicting Physics achievement

	Unstandardized Coefficients		Standardized Coefficients
	B	Standard Error	β
Intellectual skills	0.453	1.086	0.370**
Verbal Information	0.400	0.090	0.199**
Mathematical Attitudes	0.556	0.150	0.189*
Cognitive Strategy	0.554	0.244	0.179*
Constant	-5.441	0.253	- -

R2 = 0.380, Adjusted R2 = 0.359, F (4,122) = 18.678, p = 0.000 < 0.001
***p < 0.05, **p < 0.01**

■8.0 DISCUSSIONS

This study revealed that although the students' verbal information and mathematical attitudes were in excellent level, but unfortunately the other two mathematical thinking skills, intellectual skills and cognitive strategy were situated in good level. This result implied that the students' mental process ability still needs to be improved in order to perform well not only in their mathematics, but also other subjects relating to mathematics like physics. Karadag (2009) had found out that analyzing, conjecturing, and reasoning were the mathematical thinking skills triggered most in problem solving, indicated that mental process was the most important elements compared with verbal information and mathematical attitudes. Students who were not familiar in physics problem solving will tend to insert any information given into physics equation without understanding (Karadag, 2009).

Mubark (2005) proposed that mathematical proof was the most important factor for mathematical achievement and time allocation to teach mathematical proof also longer compared to other mathematical aspects. This situation pointed out the difficulty faced by students in mathematics usually involved of students' intellectual skills and cognitive strategy instead of verbal information and mathematical attitudes due to massive activation of mental operation in problem solving (Ornek, Robinson, & Haugan, 2008). In the meantime, this result indicated that mental process was difficult to deliver compared with verbal information and mathematical attitudes. This research results had explained the reason of students' intellectual skills and cognitive strategy were lower if compared with verbal information and mathematical attitudes. In conclusion, teachers should emphasize on delivering mathematical thinking skills especially intellectual skills and cognitive strategy in order to enhance students' performance.

There were several researches related to gender difference in mathematical thinking. The study of Lutfiyya (1998) showed there was no statistically significant difference ($p=0.01$) between the mean score of male and female high school students on all aspects of mathematical thinking. However, study conducted by Mubark (2005) was opposite with the findings in this study. His study had revealed that gender factor had both direct and indirect effects on students' mathematical thinking and achievement. Gender difference was significant at the students' logical thinking and mathematical proof, where females were better than males in these two aspects. Meanwhile, this study findings correlated with study of Seth, Fatin and Marlina (2007), where t-test results showed no gender difference in physics problem solving skills where $p = 0.304 > 0.05$. The findings of Yildirim & Eryilmaz (1999) opposed to this study and proved there existed a significant gender difference in physics achievement at significant level of 0.05, denoted that male students scored higher than female students in physics achievement. In conclusion, gender bias is not an issue and both male and female students had the equal opportunity their learning.

This study showed that each of the mathematical thinking skills had significant relationship with physics achievement of the students. Furthermore, Simultaneous multiple regression had been conducted and showed the combination of mathematical thinking skills to predict students' physics achievement was statistically significant with $F(4,122) = 18.678$, $p< 0.001$. Mathematical thinking acted as the bridge that connected mathematics and physics. In the research done by Torigoe (2008) to investigate the relationship between mathematical ability and success in physics, he found out that symbolic questions tend to be more difficult if compared with numeric question. Hence, intellectual skills were required to relate the use of mathematics in physics contexts since physics consisted a lot of equations or symbols that representing the physical phenomena. Therefore, intellectual skills undoubtedly were the most influential factor in students' physics achievement.

Although students have enough mathematical knowledge, but they are unable to solve mathematical problem in the context of physics due to failure to apply their mathematical knowledge in physics situations (Tuminaro, 2004). Students should fully understand the role of mathematics in physics because mathematics was a language for sciences (Aghadiuno, 1992), not merely a tool for physics. Furthermore, Liu and Liu (2011) found out the prospective teachers did not realize the organic interaction between physics and mathematics. This incomplete understanding had driven them to not promote the relationship between mathematics and physics to their future students and hindered the students' interest in learning physics. As a result, learners should understand the interrelationship between these two subjects in order to have a fruitful learning.

■9.0 CONCLUSION:

This study had defined mathematical thinking as a cognitive strategy supported by verbal information, intellectual skills and good attitudes towards the attainment of mathematical problem solving. The findings revealed that students' mathematical thinking was able to predict their physics achievement, implied there were interconnections between mathematics and physics. The findings showed there existed significant relationship between each of the mathematical thinking skills to physics achievement of the students. However, there was no gender difference among the students for both mathematical thinking and physics achievement. Each mathematical thinking skill had significant influence on students' physics achievement. Further study should involve a large amount of heterogeneous respondents in order to obtain a general picture whether gender difference existed or not in Malaysia. Investigation of mathematical thinking should be done in more detail way to analyze the influence of mathematical thinking to not only academic achievement, but also its application to daily life problem solving. Teachers have to understand mathematical thinking as a bridge to connect mathematics and physics. Besides that, the educational institution shall consider the importance of mathematical thinking and instill mathematical thinking to prospective teachers so that they can promote mathematical thinking to their students in the future. In conclusion, the Malaysian curriculum serves for integrated curriculum, not an isolated curriculum.

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