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Mathematical Thinking Styles among Engineering Students: Perceptions versus Actual Thinking Style Application in Problem Solving

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Abstract: Algebra is regarded as one of the primary learning domains as it represents the fundamental entry knowledge to higher forms of learning in mathematics, science, technology and engineering. The acquisition of Algebraic knowledge depends greatly on learners' Mathematical Thinking Style (MTS). Therefore, this study aimed to investigate the university students' MTS through the algebraic problem-solving topic. In general, the MTS was composed of analytical, visual, and integrated thinking styles. In this research, mixed method research design was adopted in which questionnaire and assessment test were used for data collection. A total of 248 engineering students in Universiti Tun Hussein Onn Malaysia were involved in the data collection process. Descriptive statistics was used to analyse the quantitative data obtained from the questionnaire, whereas the written answers from the assessment test were analysed using document analysis technique. The findings indicated that majority of the participating students perceived that they commonly practiced the Analytical Thinking Style in learning Algebra. However, analysis on the students' problem solving steps in the assessment test revealed that the students were actually applying Visual Thinking Style in Algebraic problem solving tasks instead of Analytical Thinking Style. This study revealed that there was a difference between students' perception and the analysis outcomes from the assessment test which reflected the actual MTS of the students. This difference reflects the fact that how an individual perceives his behaviour might not be consistent with his actual behaviour. In conclusion, instructors should know the actual MTS of the students instead of finding out students' perception on their thinking style. This will help instructors design more relevant learning activities that beneficial to students.

Keywords: Mathematical Thinking Styles, Integrated Thinking, Visual Thinking, Analytical Thinking

1. Introduction

Mathematics is a unique domain which can be regarded as a basic knowledge for the development of other sciences. In engineering education, mathematics is one of the main components that must be mastered by the engineering students. The core objective for engineering students to learn mathematics is to enable them to enhance their ability to use a wide range of mathematical techniques and skills in their engineering courses and later in their professional work (Croft & Ward, 2001). For instance, the knowledge of Calculus allows engineering students to work with several mathematical philosophies and apply this knowledge in their engineering fields (Roselainy, Sabariah & Yudariah, 2007). Nevertheless, mathematics is regarded as one of the most challenging subjects by most of the students due to complicated formulas, tedious problem solving procedures and methods, memorization of equation, and aversive teaching style used by teachers (Gafoor & Kurukkan, 2015). Findings from Kashefi *et. al* (2012) revealed that many students cannot understand Engineering Mathematics owing to a few reasons: too many concepts/ facts/ theorems/ formulas, fail to remember methods and formulas, complex calculations, and poor recall of prior knowledge. On top of that, the lack of basic skills (e.g., numeracy skill) also contribute to the weakness of students in Engineering Mathematics.

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When it comes to mathematical problem solving, it is closely related to logical thinking and non-prioritized thinking that integrate with low degrees of structure and complex information processes (Rentzos & Simpson, 2010). Mathematics deals with various theories, concepts and ideas that students need to combine them together to solve mathematical problems using various mathematical thinking styles (Liljedahl, Santos, Malaspina, & Bruder, 2016). There are a number of mathematics education researchers debate on the issue of mathematical thinking. For example, Sevimli & Delice, (2012) assert that mathematical thinking is a type of thinking that affects the representation to explain mathematical problems,yet there is always difficulty for students to reach proble solving goal due to the lack of mathematical thinking. Their previous study discovered that the difference between the successful and less successful students was on the interpretation in mathematical problems solving task which is closely related to thinking style. . Research indicated that teaching and learning styles contribute a big impact onthinking style (Borromeo Ferri, 2004; Cilliers & Sternberg, 2001; Grigorenko & Sternberg, 1997). Sternberg and Grigorenko (1993) found that certain thinking styles correlated positively to student's achievement in a several learning domains, whereas other thinking styles tended to correlated negatively to achievement in the same domain. Likewise, Van der Walt (2008) also found out that the effective learning and teaching of mathematics will influence students' thinking style which drives the achievement in mathematics.

In terms of thinking style, Burton (2001) recognized three styles of thinking about mathematics from a representational perspective, namely, Style A: Visual (or thinking in pictures, often dynamic) and Style B: Analytic (or thinking symbolically, formalistically); and Style C: Conceptual (thinking in ideas, classifying). Nevertheless, Borromeo Ferri and Kaiser (2003) have partially reconstructed these styles in the MTS for the students aged 15-16 years old. In specific, Borromeo Ferri (2004) conducted an empirical study on MTS of the 15–16-year-old learners in Germany. In her research, she found out that the learners' MTS could be generally classified into Visual Thinking Style, Analytical Thinking Style as well as Integrated Thinking Style. These thinking styles are important for solving mathematical problems. As claimed by Van der Walt (2008), learners' thinking styles may cause inability to solve mathematical problems. Even though leaners have the required knowledge, the lack of relevant thinking style might influence the ability to solve mathematical problems.

Study from Spangenberg (2012) revealed that there is a relationship between learners' thinking style dimensions and the subject they are studying. This is to say that students tend to apply certain thinking style in certain subject, and use other thinking style in other subject. To be more effective in mathematical thinking, students need to be aware of how the knowledge structures operate and how to develop over time (Tall,2009).

Within Malaysia context, Ngasiman (2014) found out that many students at diploma level are weak in mathematics even though they have been exposed to 11 years of formal learning in mathematics. Results from her study revealed that the lack of comprehensive understanding in mathematics was the major factor that contribute to the weakness in mathematics especially for computational subjects. Similarly, in a more resent research conducted in Universiti Tun Hussein Onn Malaysia by Mohd Razali (2015), the outcome indicated that the engineering students' achievement in mathematics were not satisfactory. This outcome might be attributed to the lack of MTS among the non-engineering students. In the present study, we aimed to determine the MTS ,which consisted of Visual, Analytical and Integrated Thinking styles, among engineering students of UTHM in the topic of "simultaneous equation" in algebra. In addition, this study also aimed to compare the dominant thinking styles applied by engineering students between their perceived thinking style and the actual thinking style.

1.1 Thinking Styles

A style is a specific procedure or method to do something or a particular way unique to a person (Soanes, 2002). Whereas thinking is considered an intellectual process in which the learner develops knowledge through mental interaction processes between the experiences that he/she acquires to develop structures of knowledge and come out with new assumptions (Qatami, 2001). Thinking includes making many mental and knowledge processes, such as attention, cognition, memory, classification, reasoning, analysis, comparing and generalizing, and synthesis, (Abou El-Maati, 2005) In the aspect of thinking style, it is regarded as a basis of individual differences in academic performance that are associated on how people use their abilities (Zhang & Sternberg). In addition, Zhang (2002) also stated that "students who reasoned at a higher cognitive developmental level tended to use a wider range of thinking styles than students who reasoned at a lower cognitive developmental level". This statement indicates that people who possesses various thinking styles will be able to provide quality argumentation with higher cognitive level.

The thinking style is equally important as the level of ability and it is not constant, but changeable (Sharma, 2011). Apart from that, Sternberg (2002) defines the 'Thinking Styles' as way of thinking as the individual's preferred thinking style when doing business, and defines how the individual uses or exploits the capabilities that he owns knowledge which is located between the character and capabilities not only ability. He further stated that thinking style is an approach of using the ability to identify the connections between studying mathematics and the students' general thinking.

Research on thinking styles has produced several significant outcomes. Firstly, students' thinking styles vary as a function of their personal characteristics and their learning environment. Secondly, the thinking styles of teachers, as presented in teaching, are difference depending on their personal characteristics and teaching experiences, also the school environment. Thirdly, students will get better academic results when their styles of thinking are equal with their teachers' thinking styles. Finally, students' thinking styles contribute to their academic achievement (Grigorenko & Sternberg, 1997; Sternberg & Grigorenko, 1993). Zhang (2002) puts forwards that cognitive developmental levels can be predicted by thinking styles. He expected that relativism would be connected to the use of a large range of thinking styles and that dualism would be connected to the use of a relatively narrower range of thinking styles.

1.2 Mathematical Thinking Styles

The cognitive growth of an individual in mathematics occurs in a biological brain. It involves the structure of mental objects that can be manipulated in the mind through analogy with actions on the objects experienced in reality. According to Tall (1994), conceptual knowledge were compressed in many ways to compensate for the limitations of the focus of attention of the brain. The way in which the development occurs seems to depend on the nature of the different forms of information presented to our senses. He added that advanced mathematical thinking not only involves a greater complexity of ideas, it also organizes them in a controlled manner.

Research from Borromeo Ferri (2006) revealed that there are many ways to explain mathematical facts and that there are as many ways to understand and to think them through. Some people prefer to understand mathematical facts by drawing sketches or using other graphical methods, while others tend to search for structures, patterns, formulas or application related to the to-be-learnt mathematical facts. This means that people may have preferences in the way of learning, such as visual or analytical technique. Some even prefer to combine both of them (visual plus analytical ways) in order to learn and understand a mathematical concept. In fact, such ways of learning will actually expose learner's MTS.

Karadag (2009) stated that MTS is a style of thinking that supported by thinking skills. Generally, MTS is composed of three styles, namely Visual Thinking Style, Analytical Thinking Style, and Integrated Thinking Style. Empirical grounded findings from Borromeo Ferri (2012) explain the development of characteristics of the visual, analytical and integrated thinking styles as in Table 1.

Table 1: Description of Thinking Styles

Visual thinking style	Analytical thinking style	Integrated thinking style
Preferred for internal graphic imaginations and externalized graphic representations which is unique as well as preferences for understand of mathematical facts and connections through holistic representations. Experience is the most important factor that influences the internal imaginations.	Preferred for internal formal imaginations and for externalized formal representations. They are able to understand mathematical facts through existing symbolic or verbal demonstrations and be able to continue by sequence of steps.	Preferred for the combination of thinking between visual and analytical ways of thinking and are able to shift flexibly between different representations.

Based on the Table 1, it can be comprehended that MTS is not only about mathematical abilities, but it also emphasizes how the students use the abilities to generate approach and solve the mathematical problems.

1.3 Theoretical Framework

A theoretical framework is a structure to guide research by relying on a formal theory. It is constructed by using an established, coherent explanation of certain phenomena and relationships (Underhill, 1991). The framework provides theories and parameters to the study. The core theories underpinning this study are Mental Self-Government (Sternberg, 1997) and cognitive ability (Cattell- Horn, 1987). The theory of Mental Self-Government (MSG) holds that styles of thinking can be understood in terms of constructs from our nations of governments. On this view, the kind of governments we have in the world are not just coincidental but rather are external reflections of ways that we can organize by ourselves(Sternberg, 1997). Based on this theory, thinking styles can be roughly understood as the government of individual that contains the functions, forms, levels, scope and learning process.

Sternberg clearly defined the notion of 'thinking styles' in terms of their derivation from an underlying theory of cognitive organization: the *(*MSG*)*. MSG is based on a metaphor between the way that an individuals organize their thinking and the way that society is governed (Sternberg, 1999). There are possibilities that the thinking styles is changeable but the change depend greatly on time, surroundings and life demands.

On the other hand, Cognitive Ability (Gf-Gc) is a key conceptualization of human cognitive ability by Raymond Cattell in the early 1940s. Cattell based his theory on the factor-analytic work of Thurstone conducted in the 1930s. Cattell revealed that "Fluid Intelligence (Gf) included inductive and deductive reasoning abilities that were influenced

by biological and neurological factors as well as incidental learning through interaction with the environment. He suggested further that Crystallized Intelligence (Gc) consisted of primarily of acquired knowledge abilities that reflected, to a large scope, the influences of acculturation" (Cattell, 1957, 1971).

The key proposition of the theoretical framework is that thinking style is a cognitive process that related to experience of life. Action taken to solve problems in mathematics are depends on brain and intellectual abilities (using inductive or deductive reasoning) that reflected to the interaction with the environment.

2. Methodology

This research was conducted by involving 248 engineering students who have registered for the Algebra class in Universiti Tun Hussein Onn Malaysia. The participating engineering students were selected using simple random sampling method. There were two instruments used in this research, namely questionnaire and assessment test. The survey questionnaire consisted of four parts. Part A measures demographic data, Part B, C and D were designed to measure Analytical, Visual, and Integrated Thinking styles respectively. The questionnaire obtained adequate level of reliability, α = XXXX. Additionally, the questionnaire was also checked by three experts who have vast knowledge pertaining to thinking styles. The questionnaire was refined based on the comments provided by the experts.

The assessment test was designed and developed to capture the data related to students' thinking style through problem solving. Two questions were created and checked by two mathematics lecturers to ensure the questions were on a par with students' knowledge level. The participating students were then required to solve the questions within a given time. The answers from the assessment test were analysed using document analysis technique to find out their actual MTS. In addition, the assessment test was also incorporated with a set of questionnaire which was used to measure students' perception on MTS during the test.

3. Findings

The data collected through questionnaire were analysis using descriptive statistical procedure, whereas document analysis procedure was applied to get the information from the assessment test.

3.1 Respondent's demographic characteristic

A total of 248 students were selected to participate in this research. Out of the total, 57.25% were female students, and 42.75% were male students. Majority of them were Malay (77%), followed by Chinese (11.3%), Indian (8.47%) and Others (3.23%). Most of the students were pursuing Civil Engineering (39.2%) whereas Electrical Engineering accounted for lowest percentage of students (29.8%). Table 2 shows the students' demographic information.

Table 2:Students' demographic data

Socio Demographic		Number	Percentage (%)
Gender			
	Male	106	42.75
	Female	142	57.25
Total		248	100.00
Race			
	Malay	191	77.00
	Chinese	28	11.30
	Indian	21	8.47
	Others	8	3.23
Total		248	100
Course			
	Mechanical	77	31.00
	Civil	97	39.20
	Electric	74	29.80
Total		248	100.00

3.2 Perception on Mathematical Thinking Styles

Table 3 presents the mean score of mathematical thinking styles based on the respondents' perceptions. The highest score is Analytical Thinking with the mean of 3.20. This result revealed that the participating students have perceived that they applied Analytical Thinking Style in mathematical problem solving On the contrary, the Integrated Thinking style yielded the lowest mean score (M=2.99; SD=??) which indicated that the students have perceived that they did not apply Integrated Thinking broadly in mathematical problem solving.

Table 3: Mean scores of mathematical thinking styles based on perceptions

Thinking Style	Mean Score	Level of Mean
Analytical	3.20	High
Visual	3.09	High
Integrated	2.99	Moderate

In order to identify the students' MTS during the problem solving process, they have been tested using problems solving questions through the assessment test. Table 4 indicates that means score of mathematical thinking styles.

Table 4: Mean scores of mathematical thinking styles

Thinking Style	Mean Score	Level of Mean
Analytical	2.70	Moderate
Visual	2.94	Moderate
Integrated	2.64	Moderate

Table 4 shows that those two type of thinking styles are moderate with the means score 2.70 (SD=?) (Analytical Thinking), 2.94 (SD=?) (Visual Thinking) and 2.64 (SD=?) (Integrated Thinking). In general, Visual Thinking can be considered the most common thinking style applied by students during the problem solving process. Nonetheless, given that those means scores are all at a moderate level, it is, therefore, plausible to interpret that the students have perceived that they applied all thinking styles equally throughout the problem solving process.

3.3 Document Analysis on Assessment Test

There were two to-be-solved questions in the assessment test. The test was given to the participating students to determine their actual thinking style in problem solving. Figure 1 shows the example of a question asked in the assessment test. The answers provided by the students were analysed by the lecturer using document analysis technique in which the students' thinking style would be categorised either as analytical, visual or integrated thinking style.

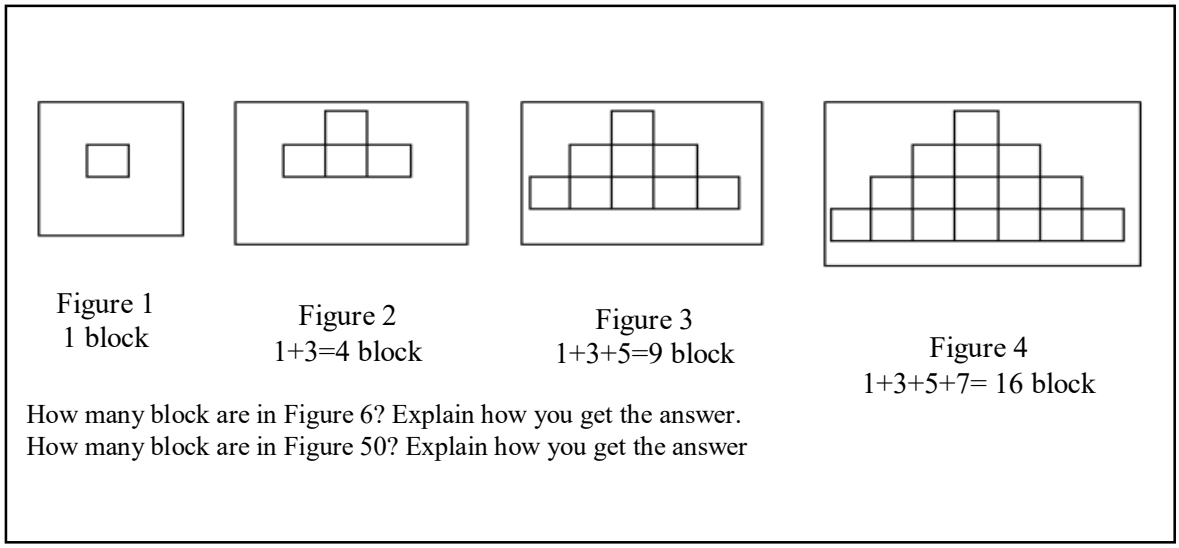
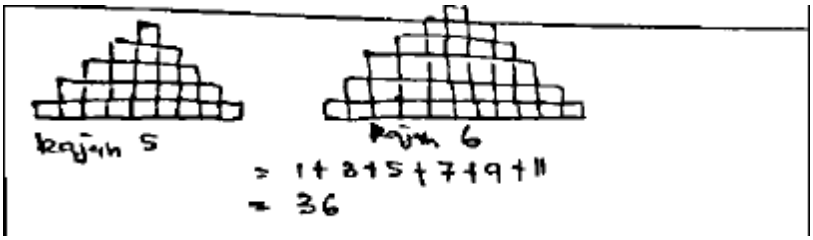
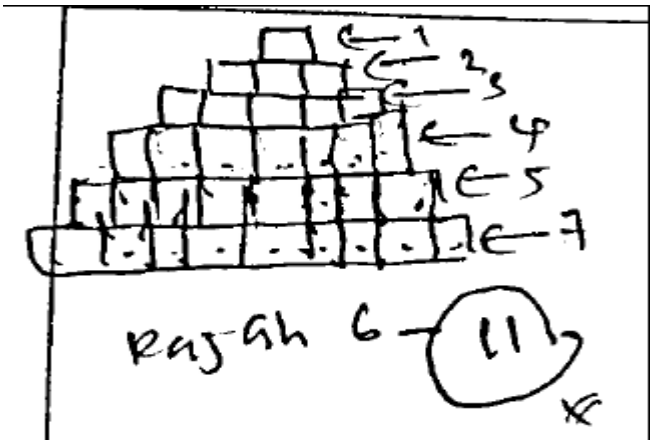
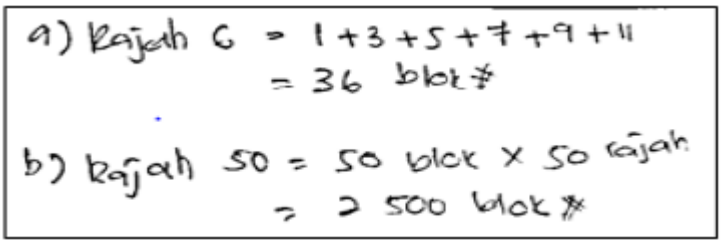
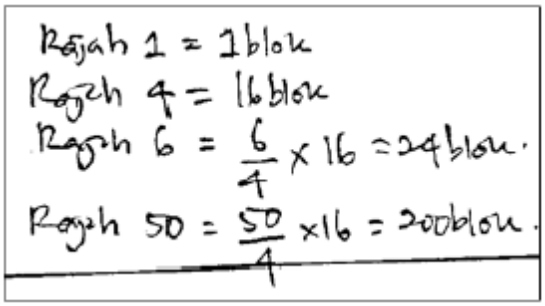
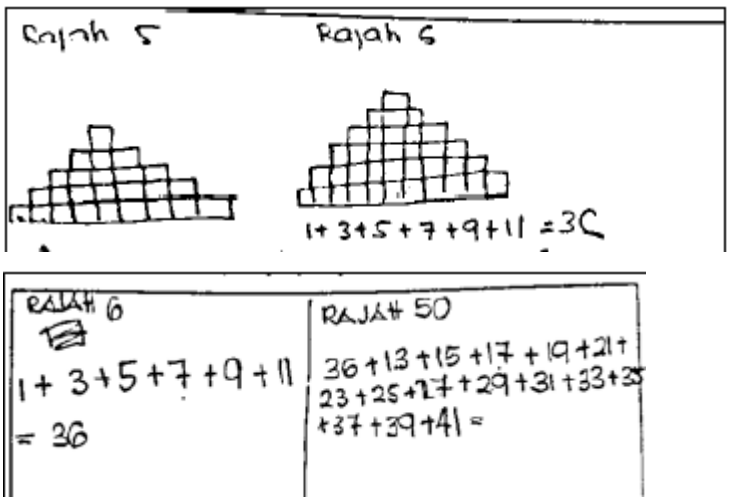


Figure 1: A question taken from the assessment test

Out of 248 students, 111 students answered the question by using graphical approach which belongs to Visual Thinking. Whereas the solution steps provided by another 84 students reflected that they applied Analytical Thinking and the rest (54 students) applied Integrated Thinking in answering the question. Table 5 shows the examples of answer provided by some students in the assessment test. .

Table 5: Example of Students' Solution for Problem Solving Question

Nu	Case	Description
1		A student solved the problem by drawing the blocks. The solution was based on a graphical method (Visual Thinking) in which the student attempted to obtain the answer from the drawing. With the assistance from the drawing, the student performed the calculation to get the final answer.
2		From the drawing, the student listed down the number of blocks in every layer of block. Although the given answer was wrong, the solution method can be categorised as visualisation (Visual Thinking) because the student attempted to visualise the problem state through drawing.
3.		A student attempted to solve the given problem by writing the number sequences. This student tried to solve the problem by writing the sequence of number based on the given sets of numbers that were arranged in certain patterns (Analytical Thinking).
4.		A student expressed the problem solving steps by examining and synthesising the given information. The problem solving procedure reflected that the students applied Analytical Thinking style.

5.		A student attempted to solve the problem using both diagram and calculation. Although the answer was wrong, the solution procedures indicated that the student applied Integrated Thinking during the problem solving process.

In short, the findings from the assessment test show that majority of the students utilised Visual Thinking when they attempted to solve the given problems. Surprisingly, the thinking style that actually applied by the students during the problem solving process was not consistent with the perceived thinking style (Analytical thinking).

4. Discussions

All in all, there is a different finding between students' perception before and during the test. Specifically, the result from the questionnaire indicates that the participating students have perceived that they tend to apply Analytical Thinking style in problem solving. However, when they were given the questions, their perception changed. This finding seems to suggest that student's thinking style might change in accordance to the problem that they are faced with. According to Borromeo Ferri (2012), Analytical Thinking will initially trigger the internal cognitive process to allow an individual to understand the problem-solving task and simplify or restructure the task in order to solve the given task. Then, the mathematical procedure will be symbolised externally or in a real context. In other words, individual with Analytical Thinking tends to understand mathematical facts through the existence of symbolic or verbal symbolism and prefer to make their way in sequences of solutions.

The present finding is consistent with the findings of Haryati, Masduki & Kholid (2016) who found out that Visual Thinking Style is the most common style applied by learners. In their study, the results of the test found that 17 people had a visual thinking style that was described first before answering the mathematical questions. This is because the teacher starts learning by first describing using story telling approach. Teachers' approaches of teaching affects the way students solve the problems influenced by teachers approach in teaching and learning process. A person who is able to imagine a shape, pattern and object by adapting it to the environment and time different from the original place and time also has a partial visualization ability (Nordin & Saud, 2006). Examples of visualizations that apply to mathematical learning are when students translate circles as months or balls, multi-hexagonal combinations as 'honey-comb', and cube-shaped objects as a box. Therefore, when respondents draw the blocks to answer questions, the respondents actually have imagined the image in his mind and then translated by drawing. Zazkis et al. (1996) defined visual thinking are rather narrow, and there is a reason for this. It is appropriate that visual thinking is reasoning that consists of mental transformations of objects that are either constructed in the mind or in some perceived external" reality."

The findings between perceptions and assessment test are difference. This is because when solving mathematical problems, students are more realise on how they answer the questions. How to solve a problem that a student thinks to use before is different when they really need to solve the mathematical problem (Sevimli, Delice, 2012).

5. Conclusion

In conclusion, the present findings indicates that the perception of an individual on MTS and the actual application of MTS of that individual in problem solving is different. Within the context of this research, "perception" is regarded as cognitive or internal representation of an individual which shows how he/she apprehends the application of thinking style in problem solving. In addition, perception is based on the relationship between humans and the environment, and about how an individual describes or communicates with his/her surroundings through his/her knowledge and understanding. Nevertheless, what a person perceives Thinking Style in problem solving might not be consistent with his/her actual thinking that takes place when he/she is authentically engaging in problem solving task. Application of appropriate thinking style in learning will enhance learning outcome in mathematics because different thinking style utilizes different way to understand mathematical facts and establishes connection between facts using linking internal imagination with externalized representation.

Mathematical thinking is a crucial cognitive skill that needs to be applied in learning in order to improve performance in mathematics. On the other hand, however, learning mathematics might also help students improve and develop thinking style based on individual's preference. In order to further enhance learning performance and fruitful learning experience, instructor should play an important role by acquiring knowledge related to different MTS, and then design and develop effective learning activities/materials to assist students to capture the learning contents optimally.

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