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Mathematical thinking among KS4 (grade 9 and 10) students in Maldives

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ABSTRACT

The role of developing Mathematical thinking through Mathematics education is an imperative goal of Mathematics teaching and learning in schools. Various findings across the globe has depicted the notion of poor standard of learning taking place in classroom teaching that to a large extend inhibit students' development of mathematical thinking and various measures has been taken for the countries involved. What about the development of mathematical thinking in Maldives? Thus, this cross sectional study utilizing a quantitative approach was embarked upon with the aim to investigate the mathematical thinking of key Stage 4 (Grade 9 and Grade 10) students in Maldives. A descriptive research design by using a paper and pencil test was administered among 298 samples comprising from both Government Schools and International Schools. The findings of the study showed that the overall KS4 students' mathematical thinking achievement was low with a percentage score of 26.97%. Furthermore, Grade 10 students did not attain a significant high scores than their Grade 9 counterparts as one will expect so based on cognitive growth. The findings suggest that radical efforts are needed to be taken by higher authorities to further curb the erosion of mathematics learning in schools.

Keywords
Achievement, Mathematical Thinking, Non-Routine, Problem Solving.

Introduction

The central focus of mathematics education is developing mathematical thinking (Goos & Kaya, 2020; National Council of Teachers of Mathematics, 2019; Onal, Inan & Bozkurt, 2017; Stacey, 2006,) where is it generally defined as a thinking process that occurs in the application of strategies, procedures and concepts while solving problems (Uyangör, 2019). These problems that can be categorized into routine and non-routine problems plays a key role in mathematics education as it develops mathematical thinking (National Council of Teachers of Mathematics, 2019). In most routine problem solving, the right procedure or information to work on the problem comes to one's mind easily with the application of learnt formulas (Schoenfield, 1985). On the other hand, non-routine problems require higher order thinking (Daguplo, 2013) and Polya recommended the utilization of non-routine mathematical problems to improve students' critical and creative thinking which is a requirement to develop problem-solving skills (Saygili, 2017). An example was provided by Parmjit and Teoh (2016) to illustrate the distinct difference between this two types of problems (Refer Fig, 1 and Fig 2.). Figure 1 represents a routine problem where it requires the formula application of ½ x base x height in deriving the solution. However, on the other hand Figure 2 is classified as non-routine as the application of the formula without the usage of Pythagoras or trigonometry functions will not be suffice. The findings showed 100% of High school leavers were successful in findings the area in Figure 1. On the other hand, the success rate for area in Fig. 2 was a low 15%.

a) Find the area

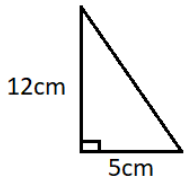

Figure 1

b) Fine the area without using pythagoras theorem or any trigonometry functions

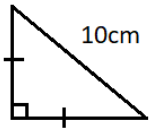

Figure 2

In Polya's scholarly work, he said "A great discovery solves a great problem, but there is a grain of discovery in the solution to any problem." This grain of discovery is perceived as mathematical thinking from the cognitive process. This discovery is usually attained through his general outline of solving problems namely i) Understand the problem, 2) Devise a plan, 3) Carry out the plan and 4) Look back. These guidelines first and foremost elucidated by Polya in his book, "it should teach those young people to THINK" and it ends with the statement "mathematics is the cheapest science, requiring no expensive equipment and only a pencil and paper".

Problem solving improves students' mathematical thinking (Ersoy, & Guner, 2015) as it involves an in-depth learning and application of concepts. The biggest problem in mathematics education is that students follow the steps that their teachers tell them in solving problems in mathematics classes without understanding the concepts (Sonawat & Kothari, 2013). Students use memorization and rote learning to remember the steps they are being told to use in solving the problems. The outcome is the lack of ability in tapping into their thinking processes to make sense of the concepts learnt. Students memorize these steps, mainly, to score high marks in the examinations. As reiterated, using routine steps

in problem solving does not improve mathematical thinking. This could be the reason for students' low mathematical thinking scores.

An examination orientation culture is another issue of concerns that suggests to inhibit the development of mathematical thinking among students. Henry, Nyaga, & Oundo (2014) found that exam oriented cultures hinder the achievement of students' academic goals, because the teaching and learning in these cultures are focused only on getting good grades rather than providing holistic education. In such classroom teachings, students' thinking does not go beyond knowledge and theory due to teacher centred approaches, depriving students from meaningful learning. In another study by Parmjit and White (2006) conducted in Malaysia, they also found that the grades obtained in the national examination does not correlated with their mathematical thinking development prowess due to an over reliance on exam orientation culture. They warranted on the action needed to curb this issue of concern especially in the context of student's development of mathematical thinking. To be noted, since 2015, Malaysian Education developed a blueprint (2015-2025) in curbing these issues of concerns.

In short, the culture sets the tone of learning philosophy where exams drive the learning instead of learning drives the exams. An over emphasis to answer exams questions deprives learners the opportunity to contextualize the learning process in terms of context, structure and situation that Cooper (1988 cited in Singh, et. al.,2018) elucidated as "richly inter-connected spaces" as a vital part of constructing mathematical knowledge (p.291). The question to ponder, is this situation prevalent in Maldives education system that it inhibits learner's development of mathematical thinking?

Providing quality education is an essential commodity for nation development especially in the perspective of poverty and economics. Thus, providing free education is a priority especially for developing country like Maldives. Despite free education provided, there is a demand for international schools in the Maldives. Nonetheless, regardless of the type of school, both work to achieve high grades in the O' Level examinations in KS4. Is there a difference in the quality of education from the perspective of mathematics learning provided by both governments schools and international schools? These factors made the researcher interested in finding the difference between the government and international school students' mathematical thinking as the results would determine if international schools give quality mathematics education compared to government schools.

A baseline study done by NIE and UNICEF (2014) in the Maldives revealed that grade 4 and grade 9 students' problem solving skills and reasoning skills were low. However, the findings of this study did not explain students' issues and concerns in solving non-routine mathematical problems. Therefore, examining students' mathematical thinking through non-routine problem-solving would help the mathematics community to identify the areas to improve and issues to address in order to improve mathematics education. However, in the Maldives, the present assessment procedure does not depict a picture of the level of students' mathematical thinking as compared to other countries that participate in International Math studies such as PISA and TIMSS. There is a dire need for more studies on examining students' problem solving skills and comparative studies among grades and type of schools. Thus, the aim of this study is to examine the mathematical thinking development of key Stage 4 (Grade 9 and Grade 10) students in Maldives together with the comparison with grade level and type of schools. These new findings will provide a description of the quality of learners mathematical thinking attainment after undergoing 8-9 years of formal education in schools, ascertain cognitive growth between grade levels and the quality of mathematics education provided in international schools as compared to publics schools in Maldives.

Methodology

This study used a quantitative approach utilizing a descriptive research design to examine KS4 students' attainment in mathematical thinking. The population for this grade 9 and 10 students ages 14 to 16 years in 2019. Samples were selected using a stratified sampling technique based on the strata of Grade level (Grade 9 and Grade 10) and types of schools (Government and International). Thus, for the first phase, a total of 350 samples were approximated for the selection of study based on Krejcie & Morgan (1970) table requirement. However, due to some unforeseen circumstances only 298 participated using stratified random sampling. Due to this constraint, the researcher acknowledges that the total sample of 298 is considered a limitation of study, especially in the context for generalization purposes. The samples were Grade 9 (n=172) and Grade 10 (126) from four schools (2 Government Schools and 2 International Schools). The distribution of samples by grade and type of schools are shown in table 1. The selection of these samples comprised the top classes within each grade based on the schools selected. Therefore, the top International school and the top 2 government schools were selected based on their performance of 2018 Cambridge O' Level examinations. Samples were selected on the basis of their first semester examination results in mathematics.

Table 1: Samples participation according to Grade and type of school

Grade	Government	International	Total
9	129	43	172
10	94	32	126
Total	223	75	298

A Paper and pencil test comprising 10 questions were used to assess the level of KS4 students' mathematical thinking. This test was adapted from Singh, et. al., (2018) where they used it to examine the effects of problem-solving heuristic application among students whom have formally learnt the fundamental topics of mathematics such as arithmetic, algebra, ratio and proportion, time, sequences and patterns, geometry, types of numbers, in their school curriculum. Sample of the non-routine questions are as follows:

Question 1: *Eva and Alex want to paint the door of their garage. They first mix 2 cans of white paint and 3 cans of black paint to get a particular shade of gray. They add one*

more can of each. Will the new shade of gray be lighter, darker or are they the same? Please explain.
Question 2: *Three water hoses are used to fill a children swimming pool. The first hose alone takes 3 hours to fill the pool, the second hose alone takes 4 hours to fill the pool, and the third hose pipe alone takes 12 hours to fill the pool. If all three hoses are opened at the same time, how long will it take to fill the pool? Please explain.*

The total score for this Mathematical Thinking test was 30 marks with 3 marks for each question. The scoring criterion is shown in table 2.

Table 2: ***Scoring Criterion***

Marks	Details
0	If no work is done or if the working does not make any sense
1	If there is a possible direction to its solution
2	If and only if a silly error causes the candidate not to get the correct answer. However, student have to get an answer
3	If correct answer

The time limitation for the test was one hour (60 minutes). The content validity of the Mathematical Thinking Test was firstly established by checking the questions of the test against the syllabus of KS4 (Cambridge IGCSE Mathematics 0580). Secondly, in order to investigate the extent to which the Mathematical Thinking Test adequately represents the content of the assessment domain being sampled (in terms of its relevance, simplicity and clarity), content validity was established by giving the test to three experts comprising two senior instructors and one senior teacher within the area of the said specialization. The feedback obtained from these experts were taken to further enhance the validity of the Mathematical Thinking Test.
The reliability of the Mathematical Thinking Test was established via test-retest reliability analysis. To test the reliability, the result from the test should be similar after pre-test and post-test from the same person. These tests (Pre-Post) which were spaced a week apart, were administered to 18 students comprising eight each from Grade 9 and Grade 10 respectively. The findings from table 3 indicate a high and significant correlation ($r = .986$, $p < .05$) from the test-retest reliability indicating a high level of reliability. Hence, based on both the validity and reliability analysis, the instrument was a valid tool in measuring students' ability in Mathematical Thinking.

Table 2: Paired Sample Statistic

		Mean	N	S. D	t	df	Sig
Pair 1	Test	8.04	18	2.14	-1.832	17	.751
	Re-Test	8.15	18	2.39			

Max score: 30

Table 3: Test-retest Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Test & Re-Test	18	.936	.000

The findings from the validity and reliability test above indicate that the Mathematical Thinking Test is a valid measuring tool to assess students Mathematical Thinking ability.
The data collected from the Mathematical Thinking Test was analysed using the SPSS version 22. Both descriptive and inferential statistics were used in the analysis. The former involved frequency counts, percentages, and mean scores with standard deviation whilst the latter involved t-tests.

Results, Discussion and Conclusion

The first section details the demographic data of samples academic achievement based on their math grades obtained in their year-end school examination. This is followed by findings from the Mathematical Thinking Test (MTT) and discussion of the results.

Table 4: Math grades obtained in year-end school examination

Grade	Frequency	Percentage
A	187	62.8
B	93	31.2
C	18	6.0
Total	298	100.0

Table 4 shows 62.8% (187) of the samples achieved an A grade, followed by 31.2% (93) and 6% (18) with B grade and C grade respectively. This data surmises that 93.8% of the samples involved are above average students based on the grades obtained in this examination.

Students' achievement in Mathematical Thinking Test

Table 5 shows the descriptive_statistics and T-test analysis of MTT Scores obtained by the students involved in the study by grade level

Table 5*:* Descriptive statistics an T-test for MTT Scores between Grade levels

Grade	N	Mean	SD	t	df	p
Grade 9	172	7.90	4.47	-0.797	296	0.44
Grade 10	126	8.35		5.20		
KS4 (Overall)	298	8.09		4.79		

Total maximum score: 30

The mean score obtained in the MTT among KS4 students is 8.09 with a standard deviation of 4.79. In other words, this depicts a very low percentage score of 26.97% (8.09/30 x 100). This finding shows the KS4 students in Maldives has a very low level attainment in the MTT.

In terms of grade level achievement, the mean scores obtained by grade 9 and grade 10 students are 7.90 (SD=4.47) and 8.35 (SD=5.20) respectively. In other words, the percentage score obtained by grade 9 and grade 10 students were 26.33% and 27.8%. To investigate if there exist significant differences between these scores (refer Table 6), an independent sample t-test was used with the following hypotheses:

H_0: There is no significant difference in the Mathematical Thinking Test scores between grade 9 and 10 students.
H_1: Grade 10 students has a significant higher Mathematical Thinking Test scores than grade 9 students (One tail test)
Table 5 shows no significant difference [t (296) = -0.797, p=0.44/2 = 0.22] of these scores at the 0.05 level. Therefore, we fail to reject the null hypothesis. That is, the average score of grade 10 students (M=8.35, *SD*=5.20) is not significantly higher than grade 9 students (*M* = 7.90, *SD* =4.47).
Table 6 shows the descriptive statistics and t-test analysis of MTT Scores between government schools and International schools. The mean scores obtained by samples in government schools and international schools are 8.15 (SD=4.85) and 7.92 (SD=4.65) respectively.

Table 6*:* Descriptive statistics and t-test analysis for MTT Scores between schools

Type of schools	N	Mean	SD	t p	df
Government	223	8.15	4.85	0.356 0.717	296
International	75	7.92		4.65	

Total maximum score: 30

The conversion to percentage scores were 27.17% and 26.4% respectively. The findings indicate government schools' attained a slightly higher scores in the MTT as compared to their International school's counterpart. To investigate if there exist statistical difference between government schools and international schools test scores, an independent sample t-test was used (refer Table 7).
H_0: There is no significant difference in the Mathematical Thinking Test scores between Government schools and International schools'.
H_1: There is a significant difference in the Mathematical Thinking Test scores between Government schools and International schools'.
The analysis in Table 7 reveals no significant difference in the test scores between Government schools and International schools' [t (296) = 0.717, p=0.717] at the 0.05 level. Therefore, we fail to reject the null hypothesis. This indicates that the MTT scores does not differ between International schools and Government schools in Maldives.

Discussion

Mathematical thinking of KS4 students was investigated using non-routine questions. The findings of the study revealed that overall, KS4 students' mathematical thinking was significantly low. KS4 students (N=298) obtained scores of 26.97% (mean=8.09, maximum score=30) and these students are among the above average KS4 students (grade 9 and grade 10) participated in the study. In the year-end examinations, the majority of these 298 participants obtained
A grade (62.8%) and B (31.2%) grades. These findings show that there is a wide disparity between the scores of the mathematical thinking test and students' year end examination results. These results provide evidence that year end examination outcomes do not reflect students' mathematical thinking development. These findings are consistent with some previous studies. In a study by Singh et al. (2018), they found that high school students' mathematical thinking attainment was low and the year-end examination results obtained by them were not reflected in their mathematical thinking test scores. Similar findings were also reported by previous researchers (Wulandari & Wutsqa, 2019; Ersoy & Guner, 2015; Atteh, et, al., 2014). Their findings denote that the learning of mathematics in classroom over the years for these students to a large extent does not develop their mathematical thinking growth. In a recent finding by Cresswell and Speelman (2020), they found that the mathematics training learners undergo in schools based on the traditional curriculum does not lead to better logical thinking and reasoning in mathematics.
This study also examined the difference between grade 9 and grade 10 students' mathematical thinking attainment in the MTT. Contrary to expectations, the study found that there was no significant difference [t (296) = 0.44, p > 0.05] between these two groups of students' mathematical thinking scores. One would expect as grade level increased, cognitive growth will follow pursuit, however it was not the case in this study. In the education structure of Maldives, grade 9 and grade 10 are in the same key stage (KS4). The reason there is no significant difference among the grades could be due to repetitive working on past paper questions as well as teacher centered learning resulting in no progression in terms of mathematical thinking. As mentioned above, students dive into preparations for the O' Level examinations at the end of this key stage and in these grades, student's learning is mainly limited to past paper questions.
Additionally, it was interesting to see that there was no significant difference [t (296) = 0.717, p >. 05] among government and international school students' mathematical thinking. In the Maldives, there is demand for international schools in public. In fact, some of these schools are ranked the best schools among Maldives schools by the public due to their achievement in the O' Level examination. Students who participated in this study from government and international schools were among the highest ranked schools in public based on their achievements in the O' Level examinations. These results revealed that regardless of the type of school, mathematical thinking tests cores remained similar. As mentioned above, this could be due to the deep rooted practices and beliefs in the system of teaching and learning in terms of achievement, success and learning.
Another probable cause of students low scores could be due to the pedagogical practices in math classrooms. We strongly believe that this could be the case for KS4 students in the Maldives. Due to a lack of opportunity for their

thinking development, students face difficulties in solving non-routine mathematical questions that need higher order thinking. One can observe that, there is no difference between grade 9 and 10 students' mathematical thinking scores. However, in all probability, there may be a difference between the two grades, if students are given routine questions. Because, unlike non-routine questions, solving routine questions requires only memorized steps and grade 10 students rehearse mathematics more than grade 9 students due to their upcoming O'Level examinations at the end of the year.

Problem solving skills develop when students are given the opportunity to think on their own. Students need to be given opportunities to think about different ideas to solve problems, to make conjectures and to take risks. In contrary to teacher centred approaches, student centred approaches provide students with an avenue for self-exploration thus improving their analytical skills resulting in deep and meaningful learning. In these approaches, teachers are merely facilitators and encourage students to take responsibility for their own learning and hence construct their own knowledge. In short, students' problem solving skills are developed when students are given the opportunity to learn rather than being spoon fed.

Performance in non-routine problem solving portrays students' abilities in problem solving. This is attributed to the fact that unlike routine problems, there is no definite rule, formula nor steps that one can use in solving non-routine problems. Students need to employ mathematical thinking in non-routine problems. Mathematical thinking helps students combine, classify, dissect, gather, transform, use heuristics, analyze, interpret, synthesize, evaluate, take reasonable judgements, use metacognition and communicate processes. Mathematical thinking plays one of the most vital roles in developing students' minds. It helps students use higher order thinking and is a necessity in daily life situations. It is one of the most important components in the workplace (Singh et al., 2018). It cannot be denied that mathematical thinking is at the heart of technology and economic world (Stacy, 2006). Mathematical thinking is needed for problem solving and problem solving skills are included in contemporary education to shape students who are able to tackle unexpected problems, that they encounter (Yavuz, Arslan & Gulten, 2010). One often construes the quality of education provided in a school based on students mathematical thinking. Consequently, these findings support the notion for the requirement of quality mathematics education in the Maldives.

Conclusion

Mathematical thinking is one of the most important skills required in learning as well as everyday life. It is needed in the development of all sectors and hence it plays an imperative role in the development of a country. One of the most important skills required amongst students are problem solving skills and for successful problem solving mathematical thinking is needed. Mathematical skills are a must in various problem solving scenarios ranging from the home, school, college, university or the workplace. The goal of schooling is to prepare students to confront global challenges as they are the leaders of tomorrow. Consequently, it is our responsibility to make sure that we build a future generation that is prepared to encounter problems and solve them successfully. In real life, we are not aware of the problems that we may face tomorrow and students have to be empowered to face uncertain situations. For this reason, solving non-routine problems are an important inclusion in mathematics learning facilitating students to think about unfamiliar situations. As highlighted in this research, solving non-routine mathematical problems develop students' problem solving skills by improving their mathematical thinking.

As a result, investigating the mathematical thinking of students is vital to understanding the situation of mathematics education in the Maldives. KS4 is one of the most important stages in the Maldives as the quality of education is mainly determined by the KS4 students' achievement in the O' Level examinations. At the same time, finding the difference between the groups within KS4 students would make it more helpful to understand and address the issues related to these groups. Bearing this in mind, KS4 students' mathematical thinking, the difference between grade 9 and 10 as well as government and international school students' mathematical thinking was studied. In the light of these findings, educators can work together to improve students' mathematical thinking. At the same time, the reasons for KS4 students' low mathematical thinking attainment could be studied to get more insight into the situation.

The exam oriented culture in the Maldives is such that students undergo intensive past year papers practice or past year questions drill and attend countless tuition classes with the sole aim of attaining good grades in the O' level examinations. The mind-set of parents and the whole society defines and determines the success of the students based on the grades they obtain in such examinations. The higher authorities recognize the examination success of these students by giving them awards and prizes. The set of culture definitely needs a paradigm shift for meaningful learning to take place. More studies are needed to probe into students thinking and the difficulties faced both via quantitative and qualitative approaches to enhance the quality of students learning of mathematics.

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