EFFECT OF GRAPHIC CALCULATOR-BASED PERFORMANCE ASSESSMENT ON MATHEMATICS ACHIEVEMENT

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ABSTRACT

The purpose of this study was to examine the effect of performance assessment that incorporated the use of graphic calculator on secondary students' mathematics achievement. This study adopted a quasi-experimental non-equivalent control group design and random sampling to select eleven public secondary schools from six states in Malaysia that represent different geographical locations and diverse economic, social and cultural backgrounds of the student population in the country. Quantitative data were collected through pretest and posttest to assess secondary students' mathematics achievement before and after the intervention. The results show that the experimental groups in all the eleven schools performed significantly better than the control groups in the mathematics achievement test after the intervention, indicating that graphic calculator-based performance assessment was effective in improving secondary students' mathematics achievement.

Keywords: graphic calculator; instruction; assessment; mathematics achievement; secondary schools

INTRODUCTION

Since the invention of electronic calculators more than 40 years ago, calculator technology has evolved tremendously from simple calculator to scientific calculator and to the present advanced graphing or graphic calculator technology. Graphic calculators are handheld mathematical computers with standard computer processors, display screen, built-in graphing software, and are fully programmable (Waits & Demana, 2000). The major advantages of using graphic calculator over desktop computer are its portability and easy accessibility (especially when completing homework or assignments and during formal examinations), as well as its diminishing price which is still relatively cheaper than the cost of buying a desktop or laptop computer (Kemp, Kissane & Bradley, 1995).

Graphic calculator is a powerful tool for exploring mathematics. It empowers students to solve mathematical problems by actively engaging them in doing mathematics. In fact, a growing body of research shows that the incorporation of graphic calculator in the teaching and learning of mathematics improves students' learning of mathematics. More specifically, several research findings have shown that the use of graphic calculator in the teaching and learning of mathematics can improve students' achievement in mathematics (Ellington, 2003; Heller, Curtis, Jaffe, & Verboncoeur, 2005; Khoju, Miller, & Jaciw, 2005; Noraini Idris, 2002, 2003; Noraini Idris, Tay, Ding, Goh, Anis Sabarina, & Nilawati Mahfud, 2003). In addition, research also shows that students using graphic calculator develop flexible strategies for problem solving and a deeper appreciation of mathematical meaning than students who do not use graphic calculator (Ellington, 2003; Khoju et al., 2005).

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In light of the positive research findings, the current mathematics reform has recommended the use of graphic calculator in the teaching and learning of mathematics in secondary schools (Kissane, 2000). The use of graphic calculators in the mathematics classroom began in the United States of America in the early 1990s and then spread to continental Europe and Australia where it is now commonly used in the upper secondary schools (Jones, 2003). In South East Asia, neighboring Singapore was the first country to permit the use of graphic calculators, without CAS, in the Further Mathematics paper of the national examination beginning 2001 (Rosihan, Daniel, Zarita Zainuddin, Suraiya Kassim, Hajar Sulaiman, Hailiza Kamarul Haili & Mokhtar Ismail , 2003).

In contrast, the use of graphic calculator in Malaysia is still in the early stage as compared to the developed countries (Noraini Idris, 2004). In fact, the integration of graphic calculator in the teaching and learning of mathematics was introduced to secondary schools beginning 2004. The Curriculum Development Centre in collaboration with Texas Instruments provided graphic calculators to 250 secondary schools throughout the country. Further, the Malaysian Ministry of Education has included some examples of using graphic calculator in the Form Four (the fourth year of secondary school education) Mathematics and Additional Mathematics textbooks starting from 2006. However, the use of graphic calculator in primary and secondary public examinations is not allowed, even though the use of simple calculator and scientific calculator is permitted in the *PMR* (public examination for the third year of secondary school education) Mathematics paper and in the *SPM* (public examination for the fifth year of secondary school education) and *STPM* (public examination for the second year of high school education) Mathematics papers, respectively.

Even though graphic calculator can help to build students' conceptual understanding by allowing them to explore through numeric, graphic and symbolic representations concurrently (Harvey, Waits, & Demana, 1995), some papers had also been written that questioned the policy of prohibiting the use of graphic calculator in the assessment of mathematical learning. For instance, Rosihan et al. (2003) argued that, "if a student learns differently from a changed pedagogy, then assessment must be done differently" (p. 78). Further, if students are taught how to use the graphing calculator, this use must also be assessed or else they will not be interested in learning and using it. They will prefer to work with scientific calculators once they realized that they cannot use graphic calculators in formal tests or examinations (Kor & Lim, 2003). In other words, if students use the graphic calculator to learn mathematics, then they must be allowed to use it in the assessment process. This is because the purpose of mathematics assessment is to find out how well students know, understand and are able to do mathematics (Kemp et al., 1995).

However, research findings are inconclusive regarding the effectiveness of using graphic calculator during instruction and assessment. For example, Heller et al. (2006) found that increased use of graphic calculators during instruction resulted in higher test scores even when students did not use graphic calculators during testing. Further, Ellington (2003) showed that students using graphic calculator during instruction, but not during assessment, performed as well or better in all five mathematics skill areas, namely conceptual, computational, operational, problem solving, and selectivity. Moreover, it is always recognized officially that the links between teaching, learning and assessment of mathematics are important because the nature of and the conditions for assessment have significant effects on the teaching and learning of mathematics in the classrooms (Kissane, 2000). Likewise, mathematics assessment in the form of public examinations is widely seen to have significant influence on the teaching and learning of mathematics in the Malaysian classroom. But, research on the incorporation of graphic calculator in mathematics assessment at the upper secondary school level is still limited in Malaysia as compared to other developed countries such as Australia and Singapore. Therefore, there is an urgent need to investigate the integration of graphic calculator in performance assessment on secondary students' mathematics achievement in Malaysia.

OBJECTIVE OF THE STUDY

The objective of this study was to examine the effect of performance assessment that incorporated the use of graphic calculator on secondary students' mathematics achievement. Specifically, this study aimed to address the following research question:

Was there any significant difference in mathematics achievement between students who learned mathematics with graphic calculator-based performance assessment and students who learned mathematics without graphic calculator-based performance assessment?

To answer the above research question, the following null and alternative hypotheses were evaluated:

H_0: There was no significant difference in mathematics achievement between students who learned mathematics with graphic calculator-based performance assessment and students who learned mathematics without graphic calculator-based performance assessment.

H_1: There was a significant difference in mathematics achievement between students who learned mathematics with graphic calculator-based performance assessment and students who learned mathematics without graphic calculator-based performance assessment.

METHODOLOGY

Research Design and Sample

The research design of this study was a quasi-experimental non-equivalent control group design. Random sampling was employed to select eleven public secondary schools from six states in Malaysia, namely Malacca, Selangor, Pahang, Terengganu, Johor and the Federal Territory of Kuala Lumpur. These states represent different geographical locations and diverse economic, social and cultural backgrounds of the student population in the country. Of the eleven schools selected for the study, eight of them are located in the various state capitals and thus the students were from a more urban background, especially the three city schools in Kuala Lumpur. However, the students in the school in Pahang were from a more rural background whose parents were mainly involved in agricultural and fishing activities. The schools chosen had to have at least two Form Four classes with a trained Mathematics teacher teaching them. For each school, one of the classes served as the experimental group whilst the other class served as the control group.

The sample consisted of Form Four students. The average age of the students was 16 years old. They represented all the major races in the country, namely Malays, Chinese and Indians. At Form Four, these students had successfully completed three years of lower secondary education which culminated in a major public examination called the Lower Secondary School Assessment (*Penilaian Menengah Rendah or PMR*) at the end of Form Three. To be promoted to Form Four, these students had to pass seven subjects in the *PMR,* namely Malay Language, English Language, Mathematics, Science, History, Geography and Living Skills. Some students might also opt to take Islamic Studies, Chinese Language or Tamil Language as an additional subject. The total number of students in the sample was 844 students with 423 students in the experimental group and 421 students in the control group as shown in Table 1.

Table 1 Location and number of students in the sample (N=844)

No.	State	School	Experimental Group (n)	Control Group (n)
1	FT of Kuala Lumpur	School A, Kuala Lumpur	31	26
2	FT of Kuala Lumpur	School B, Kuala Lumpur	33	30
3	FT of Kuala Lumpur	School C, Kuala Lumpur	36	37
4	Malacca	School D, Malacca	39	42
5	Malacca	School E, Malacca	39	41
6	Johor	School F, Johor Bharu	39	38
7	Pahang	School G, Kuantan	43	45
8	Terengganu	School H, Kuala Terengganu	41	42
9	Selangor	School I, Selangor	40	41
10	Selangor	School J, Selangor	43	41
11	Selangor	School K, Selangor	39	38
		TOTAL	423	421

Note: FT = Federal Territory

Instrument

The Mathematics Achievement Test (MAT) was used to assess students' mathematics achievement before and after the intervention. The MAT was designed to measure students' content knowledge of and ability to solve problems related to Straight Line and Statistics in the Form Four Mathematics syllabus. The research team constructed the test based on the Form Four Mathematics Curriculum Specifications. To ensure its content validity and construct validity, the MAT was meticulously constructed based on the Form Four Mathematics Curriculum Specifications by the research team who has expertise in this field from the Mathematics Education Department in a local public university. A class of Form Five students in a school in the Federal Territory of Kuala Lumpur piloted the MAT. The degree of internal consistency as estimated by Cronbach's alpha for the overall MAT was 0.8. The MAT was thus found to be valid and reliable for use in the actual study.

Research Procedure

Prior to the administration of the treatment, the teachers from the eleven participating schools were invited to attend a one-day training workshop. During the workshop the teachers were introduced by the researchers to the objective and procedures of the study. They were first briefed on the various steps of carrying out the study in their respective schools. They were then presented with five assessment tasks for the topic of Straight Line and six assessment tasks for the topic of Statistics. Next, they were given the opportunity to perform one of the tasks with the help of the TI-83 Plus graphic calculator. Subsequently, they were introduced to the rubrics for interpreting students' performance in the eleven assessment tasks. At the end of the workshop, the researchers distributed the eleven assessment tasks and rubrics for the two topics to the teachers. The teachers also collected the MAT to be administered to the experimental and control groups before and after the treatment.

During the treatment, students in the experimental group were given formatively eleven assessment tasks by their mathematics teacher that required them to use graphic calculator to perform the tasks. The tasks required students to investigate, explore and solve real-world problems related to the topics of Straight Line and Statistics. Each student in the treatment group was provided with a TI-83 Plus graphic calculator to complete the given tasks. Students in the treatment group were asked to perform the following five tasks on Straight Line and six tasks on Statistics as shown in Table 2.

Table 2 Contents of the tasks on Straight Line

Topic	Task	Contents
Straight Line	One	Gradient
	Two	Gradient in Cartesian Coordinate
	Three	Developing Linear Equation
	Four	Equation of Straight Line
	Five	Investigating Linear Equations
Statistics	One	Modal class, class interval and Mean
	Two	Grouped Data Modal
	Three	Cumulative Frequency
	Four	Histogram
	Five	Frequency Polygons
	Six	Measures of Dispersion

An example of the first task on Straight Line and an example of the first task on Statistics are provided below:

Assessment Task One on Straight Line

Purpose:

a) To assess students' understanding of the concept of gradient and gradient of straight line graph.

b) To assess students' reasoning when using the gradient of straight line graphs in drawing conclusions about the real-world context being modeled by the graphs.

c) To assess students' communication when presenting the conclusions they had drawn about the real-world context based on the information contained in the gradient.

In this task, students were assessed when they constructed the graph based on the real-world data and used the graph to draw conclusion about the real world involving outdoor activities. In this task, students were provided with real-world data in which they were asked to graph the data and find the gradient of the various graphs. Students used the gradient to conclude about the geographical terrain used for outdoor activities like kayaking and mountain climbing. They modeled the data and the graphs using an equation and used the equation for making decisions about the outdoor activities. Finally, students were assessed as they explored the real-world context using the gradient they had found by using graphic calculator.

Assessment Task One on Statistics

Purpose:

a) To assess students' understanding of the concept of modal class, interval class and means.

b) To assess students' reasoning when investigating the relationship between the class size and the mean of grouped data.

c) To assess students' communication when presenting their findings about the relationship between class size and mean of grouped data.

In this task, students were assessed when they investigated the relationship between the class size and the mean of grouped data. In this investigational task, students were provided with real-world data in which they were asked to find the mean and mode of the ungrouped data. Students had to explain the meaning of the mean they had found. They then grouped the data according to several different class sizes and constructed several tables of frequency for the different class sizes. For each table of frequency, they calculated the mean of the data set. Next, they determined the class size that had the nearest mean to the mean of the ungrouped data and made a generalization about the relationship between the mean and class size. Lastly, they explored the effects of changing the size of class intervals on the mean of the grouped data of other data sets.

The teachers used assessment rubrics to interpret and evaluate students' performance of the tasks and to provide feedback to the students on their performance and progress in learning the topics of Straight Line and Statistics.

The students in the control group were also taught Straight Line and Statistics by the same mathematics teacher using TI-83 Plus graphic calculator. However, they were not given any of the eleven performance assessment tasks by their teacher during the teaching and learning of the two topics.

Before the intervention which involved administering the treatment to the experimental class, the teachers collected the pre-test data on students' mathematics achievement by administering the MAT to their students in both the experimental and control groups. After the intervention, the same teachers collected the post-test data on students' mathematics achievement by administering the same instrument.

Data Analysis

To answer the research question and to evaluate the null hypothesis of this study, the data collected from the pre-test and post-test were analyzed using both descriptive and inferential statistics. The independent-samples t test was first conducted on the scores of mathematics achievement in the pretest to determine whether the difference in mathematics achievement between the experimental group and the control group of each participating school prior to the intervention was significant at $p < .05$. If the test showed that the difference between the two groups prior to the intervention was not significant, then the independent-samples t test would be conducted on the scores of mathematics achievement in the post-test to determine whether the difference in mathematics achievement between the experimental group and the control group of each participating school after the intervention was significant. On the contrary, if the test showed that the difference between the two groups prior to the treatment was significant, then the ANCOVA test would be conducted on the scores of mathematics achievement in the post-test to determine whether the difference in mathematics achievement between the experimental group and the control group of each participating school after the intervention was significant at $p < .05$. The ANCOVA test would be used to make correction to the difference that existed between the experimental and control groups prior to the intervention so that the difference observed between the experimental and control groups after the intervention was only due to the treatment and not because of the difference that existed between the two groups prior to the intervention.

RESULTS AND DISCUSSION

Pre-test results

The mean and standard deviation of the mathematics achievement scores in the pre-test, as well as the results of the independent-samples *t* tests for all the eleven schools are presented in Table 3. The results of the independent-samples *t* tests show that there was no significant difference in the mean mathematics achievement scores between the experimental and control groups for all the eleven schools at $p < .05$, indicating that there was no significant difference in mathematics achievement between the experimental and control groups for all the schools.

Table 3 Mean, standard deviation, *t*- and *p*-values for the experimental and control groups

School	Groups	Mean	Standard deviation	*t*	Sig. (2-tailed)
School A, Kuala	Control (n = 26)	11.26	3.40	- 1.17	.907
Lumpur	Experimental (n = 31)	11.23	1.17		
School B, Kuala	Control (n = 30)	9.53	1.62	2.43	.310
Lumpur	Experimental (n = 33)	9.11	1.73		
School C, Kuala	Control (n = 37)	8.30	0.74	-0.90	.370
Lumpur	Experimental (n = 36)	8.16	0.56		
School D, Malacca	Control (n = 42)	12.07	2.19	0.79	.413
	Experimental (n = 39)	11.51	2.77		
School E, Malacca	Control (n = 41)	9.07	2.19	0.72	.373
	Experimental (n = 39)	9.51	2.77		
School F, Johor	Control (n = 38)	8.07	2.19	0.69	.813
	Experimental (n = 39)	8.51	2.77		
School G, Kuantan	Control (n = 45)	11.07	2.19	0.53	.713
	Experimental (n = 43)	10.51	2.77		
School H, Kuala	Control (n = 42)	8.07	2.19	0.66	.613
Terengganu	Experimental (n = 41)	7.51	2.77		
School I, Selangor	Control (n = 41)	9.07	2.19	0.57	.412
	Experimental (n = 40)	8.51	2.77		
School J, Selangor	Control (n = 41)	9.57	2.19	0.44	.613
	Experimental (n = 43)	10.12	2.77		
School K,	Control (n = 38)	9.07	2.19	0.57	.523
Selangor	Experimental (n = 39)	8.51	2.77		

*significant at $p < .05$

Post-test results

The mean and standard deviation of the mathematics achievement scores in the post-test, as well as the results of the independent-samples *t* tests for all the eleven schools are presented in Table 4. The results of the independent-samples *t* tests show that there was a significant difference in the mean mathematics achievement scores between the experimental and control groups for all the eleven schools, indicating that there was no significant difference in mathematics achievement between the experimental and control groups for all the schools at $p < .05$. In addition, for each of the eleven schools, the mean mathematics achievement score of the experimental group was higher than that of the control group, indicating that the experimental groups performed significantly better than the control groups in the mathematics achievement test for the two topics of Straight Line and Statistics. The results suggest that graphic calculator-based performance assessment was effective in improving Form Four students' mathematics achievement in the topics of Straight Line and Statistics.

Table 4 Mean, standard deviation, *t*- and *p*-values for the experimental and control groups

School	Groups	Mean	Standard deviation	*t*	Sig. (2-tailed)
School A, Kuala Lumpur	Control (n = 26)	30.73	7.48	4.89	.010*
	Experimental (n = 31)	35.35	6.15		
School B, Kuala Lumpur	Control (n = 30)	34.73	3.33	7.18	.002*
	Experimental (n = 33)	39.81	2.27		
School C, Kuala Lumpur	Control (n = 37)	27.91	3.13	2.80	.007*
	Experimental (n = 36)	31.13	3.64		
School D, Malacca	Control (n = 42)	25.08	8.20	2.67	.008*
	Experimental (n = 39)	29.65	7.12		
School E, Malacca	Control (n = 41)	32.08	8.20	2.62	.003*
	Experimental (n = 39)	39.65	7.12		
School F, Johor	Control (n = 38)	28.08	8.20	2.22	.005*
	Experimental (n = 39)	31.65	7.12		
School G, Kuantan	Control (n = 45)	31.08	8.20	2.57	.003*
	Experimental (n = 43)	38.65	7.12		
School H, Kuala Terengganu	Control (n = 42)	27.08	8.20	2.77	.004*
	Experimental (n = 41)	36.65	7.12		
School I, Selangor	Control (n = 41)	27.08	8.20	3.12	.006*
	Experimental (n = 40)	28.65	7.12		
School J, Selangor	Control (n = 41)	31.08	8.20	2.76	.007*
	Experimental (n = 43)	39.65	7.12		
School K, Selangor	Control (n = 38)	32.08	8.20	2.17	.003*
	Experimental (n = 39)	39.65	7.12		

*significant at $p < .05$

The results of this study in general concur with the results of several recent studies on the usage of graphic calculator in the teaching and learning of mathematics that were conducted in Malaysia (Noraini Idris, 2006) and also in other parts of the world (Graham & Thomas, 2000; Horton, Storm & Leonard, 2004). Noraini Idris's study which investigated the effect of using graphic calculator in the teaching and learning of secondary mathematics on students' mathematics achievement showed that the pre-test mean mathematics achievement score for the experimental group (using graphic calculator) was 12.20 (SD=3.68) as compared to the pre-test mean mathematics achievement score for the control group (without using graphic calculator) of 12.21 (SD=3 .22). The post-test mean mathematics achievement score was higher than the pre-test mean mathematics achievement score for both the experimental group (29.27, SD=3 .15) and control group (29.27, SD=3 .15), with the experimental group showing a greater increase than the control group. The results revealed that the students in the experimental group showed significantly greater improvement in mathematics achievement than the students in the control group, suggesting that using graphic calculator in the teaching and learning of secondary mathematics was effective in improving students' mathematics achievement.

In addition, Graham and Thomas' (2000) study which examined the effect of using graphic calculator activities in the teaching and learning of algebra on students' mathematics achievement showed that the experimental groups significantly outperformed the control groups on the post-test, even though there was no significant difference in mathematics achievement between the two groups on the pre-test.

Further, Horton, Storm and Leonard's (2004) study which sought to determine if the Casio FX2.0 tutorial would help students improve their skills in solving linear equations. The results of a one-tailed independent-samples *t* test showed that the experimental group (M = 2.74) significantly outperformed the control group (M = 2.25) on the post-test. Post hoc statistics were performed to determine on which questions there was a significant difference between the two groups. The experimental group outperformed the control group on six questions; the control group did not outperform the experimental group on any questions.

CONCLUSION

The results of this study show that graphic calculator-based performance assessment was effective in improving Form Four students' mathematics achievement in the two topics of Straight Line and Statistics. One of the factors that contributed to the improvement of students' mathematics achievement in the two topics might be the students' use of graphic calculator in the performance assessment tasks had increased their use of graphic, numeric and symbolic solution strategies which, in turn, enhanced their understanding of the mathematical topics studied. At the same time, graphic calculator-based performance assessment increased the time spent by the teachers in the experimental groups on the teaching and learning activities which involved more problem solving and investigation as compared to the teachers in the control groups. In general, the results suggest that performance assessment that incorporated the use of graphic calculator has influenced the teaching and learning of mathematics which supports students' visualization, allowing them to explore problems which they may not otherwise be able to solve and thus enable them to better understand the two mathematical topics. In conclusion, graphic calculator-based performance assessment enables students to solve problems graphically, numerically and symbolically which, in turn, enable them to better understand the mathematics they are learning.

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