EXPLORING THE EFFECT OF USING GRAPHING CALCULATOR STRATEGY IN MATHEMATICS LEARNING ON STUDENTS' METACOGNITIVE AWARENESS

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Abstract

Two phases of quasi-experimental study with non-equivalent control group posttest only design were conducted to investigate the effects of using graphing calculators in mathematics teaching and learning on Form Four Malaysian secondary school students' level of metacognitive awareness. Experiment in Phase I was conducted for six weeks to provide an initial indicator of the effectiveness of graphing calculator strategy on students' metacognitive awareness. Graphing calculator strategy refers to the use of TI-83 Plus graphing calculator in teaching and learning of Straight Lines topic. The experimental group underwent learning using graphing calculator while the control group underwent learning using conventional instruction. Further, experiment in Phase II was carried out for six weeks incorporating comparison on two levels of mathematics ability (low and average) and two types of instructional strategy (graphing calculator strategy and conventional instruction strategy). The Metacognitive Awareness Survey instrument was used in this study. The data for Phase I were analysed using independent t-test and planned comparison test while data for Phase II were analysed using multiple analysis of variance and planned comparison test. The results of experiment in Phase I on analysis of metacognitive awareness of mathematics learners indicated that integrating the use of graphing calculators in teaching and learning of mathematics can improve level of students' metacognitive awareness. The results of experiment in Phase II supported findings from experiment in Phase I pertaining to metacognitive awareness. The results showed a significant main effect of type of instructional strategy on mean overall level of metacognitive awareness, with large effect size of .73 based on Cohen (1988), implying that the GC strategy was effective in improving students' metacognitive awareness in solving Straight Lines problems. However, the interaction effect between mathematic ability levels and instructional strategy type were not significant. Thus overall, this study shows that the graphing calculator instruction induced higher levels of students' metacognitive awareness in learning of Straight Lines topic for both groups of low and average mathematics ability, thus helping students to achieve in-depth understanding of mathematical concepts and facilitating students in solving mathematical problems.

Introduction

The growing influence of graphing technology advancement has also affected Malaysian mathematics education. It is essential for Malaysian mathematics teachers to be prepared in dealing with educational changes, challenges and demands. Besides being experts in mathematics content and pedagogical skills, they should also be equipped with the needs of an ever-changing technological society and always be updated with the innovations and inventions of the latest technology. Consistently, it is also stated in the Malaysian Mathematics Curriculum Specifications that the use of technology such as calculators, computers, educational software, websites and relevant learning packages can help to upgrade the pedagogical approach and hence promote students' understanding of mathematical concepts in depth, meaningfully and precisely (Curriculum Development Centre, 2005).

Recently, there has been a steady increase in interest in using hand-held technologies, in particular the graphing calculator. Generally, this tool has gained widespread acceptance as a powerful tool for learning mathematics. However, the maximum potential for this technology has not been explored (Kastberg & Leatheam, 2005). Thus, this study directly responds to the need for

empirical evidence regarding the effects of integrating the use of graphing calculators in mathematics instruction at the Malaysian secondary schools.

Distributed Cognition Theory

The positive effects of the integration and the use of graphing calculators in the teaching and learning process of mathematics can be understood by explaining and illustrating the theory of distributed cognition in relation to this tool. The distributed cognition theory claims that cognition is better understood as a distributed phenomenon: one that goes beyond the boundaries of a person but to include environment, artifacts, social interaction, and culture (Hutchin & Hollan, 1999; Roger, 1997). This perspective is adopted to explain cognitive effects when using technology (Jones, 2000; Salomon, Perkins & Globerson, 1992). It is the effect obtained during intellectual partnership with the technology, and the transferable cognitive residue that this partnership leaves behind. These are in the form of better mastery of skills and strategies. Some researchers view that the effect of technology is that "intelligent" technology "offloads" part of the cognitive process as a result of distributions of cognition. Further, this will allow users to focus on cognitive resources elsewhere (Pea, 1985; Salomon et al., 1992). They also believe that over time the users will develop cognitive skills to accomplish many of the cognitive processes demonstrated when using technology and would be capable of demonstrating these skills without requiring the aid of technology any longer.

Distributed Cognition and Graphing Calculator

Distributed cognition is related to any cognitive tool that is employed in the process of learning mathematics such as computer, calculator, graphing calculator, paper and pencil and transparency. In this review, the researcher will discuss only on the explanation of the distributed cognition in relation to the graphing calculator. Let us focus mainly on one area of learning mathematics in Malaysian Integrated Curriculum for Secondary School for Form Four, namely the Straight Lines topic.

Suppose that the learning outcome is to determine the relationship between the value of the gradient and the steepness (Curriculum Development Centre, 2005). Here, it is crucial to draw graphs on the same Cartesian coordinate plane to represent the learning outcome. Thus, the purpose of learning the skill to draw graphs is important whether we employ the paper and pencil or the graphing calculator. Here, graphs are not drawn to produce straight lines, however they were drawn to represent that the bigger the gradients of the straight lines, the steeper the lines. The question arises is how do we produce the graphs? If we use the paper and pencil medium, we have to have knowledge of scales, plotting points on a Cartesian coordinate plane and joining the points. We also have to do the same skills to draw a few straight lines to display the relationship between the value of the gradient and the steepness. On the other hand, if we use a graphing calculator, we have to have a different kind of knowledge such as how to manipulate the scale of the axes, how to use the zoom, graph, Y=, functions and which button to press.

Either we use the paper and pencil medium or the graphing calculator both cases provide the essential knowledge of how to organise the cognitive tool to produce the graphs. However, the process of producing the graphs using the paper and pencil is more tedious while using graphing calculator is less tedious, less time consuming and also more efficient and accurate. Why? This is because when using the graphing calculator, a larger part of the cognitive process is taken over by the tool such as scaling and plotting point. Only a small part of the cognitive process is carried out by the individual such as determining the range. On the other hand, when using the paper and pencil medium, a larger part of the cognitive process is carried out by the individual such as

knowledge of scales, determining the range, deciding what goes on what axis and plotting the points. Only a small part of the cognitive process is taken over by the tools. For example, the graph paper which has the square grid provides for the equal spacing of points and ruler can aid in joining points to form graphs.

Therefore, what is employed to produce graphs is not of significance in the process of learning, but it is important that the graphs are drawn to represent the relationship between the value of the gradient and the steepness. Thus graphing calculator is a powerful tool to employ in teaching and learning straight lines because the greater part of cognitive process in constructing the graphs is taken over by the tool.

Metacognitive Awareness
Based on the work of Flavell (1987; 1979) and Brown (1987), several researchers have operationally defined students' metacognition as a construct consisting of several subscales. According to Pintrich and DeGroot (1990), metacognition consists of strategies for planning, monitoring and modifying one's cognitions. O'Neil and Abedi (1996) and O'Neil and Schacter (1997) also view metacognition as composed of planning, monitoring or self-checking, and cognitive strategies. O'Neil and Abedi (1996) assert that one is self-aware of the process in the following ways. For planning, one must have a goal either assigned or self-directed and a plan to achieve the goal. For self-checking, one needs the mechanism of self-monitoring to monitor the goal achievement. Finally, for cognitive strategy, one must have a cognitive or affective strategy to monitor either domain-independent or domain-dependent intellectual activity. A few other researchers suggest that metacognition involves major operations such as planning, sequencing, self-checking or monitoring, self-questioning, evaluating, and revising (Schraw & Dennison, 1994; Zimmermann, 1990; Bayer, 1988; Garafalo & Lester, 1985).

As a strategy, Bayer (1988) suggests that metacognition consists of three major operations: planning, monitoring/directing, and assessing a thinking task, where each of these operations consists of a number of subordinate procedures by which that operation is carried out. The first step in Bayer's model is planning. It involves thinking about the overall process of solving tasks or problems. The second step is monitoring. At this stage, an individual executes the thinking plan and also consciously checks what is going on mentally to ensure execution of the task as planned. He/she also avoids skipping or using incorrectly any steps or rules. Further, he/she sees if the operations being used are producing the desired results. The third major step is assessing, which involves thinking about the processes employed in achieving the goal and the efficiency of the overall plan.

For the purpose of this study, the term metacognitive awareness was used and it refers to levels of students' awareness on planning, cognitive strategy and self-checking while solving Straight Lines problems.

Methodology
Two phases of experiments were conducted to investigate the causal effects of integrating the use of graphing calculators in mathematics teaching and learning. All the experiments were of the quasi-experimental of non-equivalent control group with posttest only design. For Phases I, the independent variable was the instructional strategy (graphing calculator (GC) strategy and conventional instruction (CI) strategy), while the dependent variable was the measure of metacognitive awareness. The second phase of the study was further incorporated, comparing the different levels of mathematics ability (low and average) and instructional strategy (GC strategy and CI strategy). In this phase, the researcher would like to consider the effectiveness of using

graphic calculator in the teaching and learning of mathematics on different levels of mathematics ability. Therefore, in addition the 2 x 2 factorial design was implemented in this phase. The dependent variable was similar as in Phase I.

Phase I involved four classes with a total of 65 students and they were also assigned to experimental and control groups. Phase II involved two average mathematics ability and two low mathematics ability classes with total of 77 students. For both levels of mathematics ability classes, one class was randomly assigned as the experimental group and the other class was assigned as the control group. In this study, the low mathematical ability groups were randomly selected from classes that consist of students who had obtained grade 'D' in the Mathematics Paper of Lower Secondary Examination (PMR). The average mathematical ability groups were randomly selected from classes that consist of students who had obtained grade 'B' or 'C' in the PMR Mathematics Paper.

The Metacognitive Awareness Survey (MCAS) instrument was to measure students' metacognitive awareness. The MCAS comprised of three subscales vis-à-vis cognitive strategy, planning and self-checking. Each subscale consisted of 11 items with four point Likert scale and these amounted to 33 items. Based on the general rule provided by Nugent, Sieppert and Hudson (2001), mean scores ranging from 1.00 to 2.00 indicated a low score, 2.00 to 3.00 indicated a moderate score, whilst means scores ranging from 3.00 to 4.00 indicated a high score.

In addition, the Straight Lines Lesson Plan (SLLP) was prepared by researcher to provide the general guideline for teaching Straight Lines topic for graphing calculator strategy and conventional instruction strategy groups. The instrument was validated by a panel of judges, and the reliability of the instrument was considered sufficiently acceptable.

For all phases, the procedures for the experiment were the same. The pre-experiment procedures were carried out before each experiment which includes a general briefing about the study and three periods of introducing the graphing calculator usage for the experimental group and collecting students' profiles information. For all phases, the total duration of the experiment was six weeks. The MCAS is then administered at the end of the experiments.

Results – Phase I

The means and standard deviations of students' metacognitive awareness levels, students' metacognitive awareness levels for cognitive strategy, planning and self-checking subscales for both the GC and the CI strategy groups and results of the independent samples t-test followed by planned comparison analysis are shown in Table 1.

The overall mean level of students' metacognitive awareness of the GC strategy group was 2.63 (SD=.40) while the CI strategy group was 2.44 (SD=.37). An independent t-test revealed that the difference in means was significant, t(63)=2.05, p<.05. Results showed that there was a significant difference in the mean level of students' metacognitive awareness between the GC strategy group and the CI strategy group. The effect size for the treatment was .06 using eta squared value which was considered moderate based on Cohen (1988).

Further, planned comparison test showed that the mean level of students' metacognitive awareness of the GC strategy group was significantly higher than those of the CI strategy group, F(1,63)=4.22, p<.05. This finding indicated that the GC strategy group had better level of metacognitive awareness while solving problem related to the Straight Lines topic as compared to that of CI strategy group. Specifically, the GC group indicated high level of awareness pertaining to using appropriate formula to determine the gradient (item 3) and asking themselves what is *m* and *c* of a straight line with equation $y = mx + c$ (item 16). In addition, the group also indicated

moderate level of awareness towards items such as 5, 20, 22, 14, 29, 26 and 33 with mean score above 2.70.

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Table 1: Means, standard deviations, and independent sample t-test and for students' metacognitive awareness levels in Phase I

	Group	n	M	SD	SEM	t	df	p
Overall metacognitive awareness	GC strategy	33	2.63	.40	.07	2.05	63	.044
	CI strategy	32	2.44	.37	.07			
Cognitive strategy subscale	GC strategy	33	2.66	.44	.08	2.10	63	.040
	CI strategy	32	2.43	.45	.08			
Planning subscale	GC strategy	33	2.65	.44	.08	1.12	63	.269
	CI strategy	32	2.54	.37	.07			
Self-checking subscale	GC strategy	33	2.59	.41	.07	2.47	63	.016
	CI strategy	32	2.34	.40	.07			

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The mean level of students' metacognitive awareness for cognitive strategy subscale of the GC strategy group was 2.66 (SD=.44) while that of the CI strategy group was 2.43 (SD=.45). An independent t-test further showed the difference in the means was significant, $t_{(63)}=2.10$, $p<.05$. The results showed that there was a significant difference in the mean level of students' metacognitive awareness for cognitive strategy subscale between the GC strategy group and the CI strategy group. The effect size for the treatment was .07 using eta squared value which was moderate based on Cohen (1988). Further, planned comparison test showed that the mean level of students' metacognitive awareness for cognitive strategy subscale for GC strategy group was significantly higher than those of the CI strategy group ($F_{(1,63)}=4.40$, $p<.05$). This finding indicated that the use of graphing calculator induced higher level of metacognitive awareness for cognitive strategy subscale while solving problems related to the Straight Lines topic than that of

the conventional instruction. For example, majority of the students in the GC strategy group indicated that they often used an appropriate formula to determine the gradient of a straight line (87.89%). In addition, they also responded quite high frequencies (78.79%) on item 16 which is "I asked themselves what is m and c of a straight line with equation $y = mx + c$ to write the equation of the straight line given the gradient and the y-intercept".

The mean level of students' metacognitive awareness for planning subscale of the GC strategy group was 2.65 (SD=.44) while the CI strategy group was 2.54 (SD=.37). From the analysis of an independent t-test, it was found that the difference in the means was not significant, $t(63)=1.12$, $p>.05$. Results showed that there was no significant difference in the mean level of students' metacognitive awareness for planning subscale between the GC strategy group and the CI strategy group. The effect size for the treatment was .02 using eta squared value which was small based on Cohen (1988). This indicated that only 2% of the variance of planning subscale was accounted for by the strategy imposed on the group. Further, planned comparison test showed that the mean level of students' metacognitive awareness for planning subscale for GC strategy group was not significantly higher than those of the CI strategy group, $F(1,63)=1.25$, $p>.05$. Hence, this finding indicated that both the GC strategy and the CI strategy groups do not differ in their level of metacognitive awareness for planning subscale while solving problem related to the Straight Lines topic. However, the graphing calculator group responded high frequencies, 81.82%, 78.79% and 75.76% on items 15 "I determined the steps I needed to take when I have to find the x-intercept and y-intercept values of a straight line", 10 "I determined the steps when I have to draw a graph of the form $y = mx = c$" and 5 "I made sure I knew that m is the gradient and c is the y-intercept of a straight line with equation $y = mx = c$ when I have to write the equation of the straight line given the gradient and y-intercept", respectively.

The mean level of students' metacognitive awareness for self-checking subscale of the GC strategy group was 2.85 (SD=.80) while the CI strategy group was 2.16 (SD=.63). Further, analysis of the independent t-test revealed that the difference in the means was significant, $t(63)=2.47$, $p<.05$. Findings suggest that the mean level of students' metacognitive awareness for self-checking subscale differ significantly between the students of the GC group and the CI group. However, an eta squared obtained was .09 which was considered moderate based on Cohen (1988). Further, planned comparison test showed that the mean level of students' metacognitive awareness for self-checking subscale for GC strategy group was significantly higher than those of the CI strategy group, $F(1,63)=1.25$, $p<.05$. Thus, using graphing calculator in teaching and learning the Straight Lines topic induced better level of metacognitive awareness for self-checking subscale while solving problems related to the Straight Lines topic than that of conventional teaching. About 69.70% of the students in the GC strategy group indicated that they often corrected their errors when writing the equation of the straight line. Responses to the item "I monitored the planning steps when determined the straight line equation" were also found to be above average (66.67%).

In summary, it was found that the GC strategy group had better level of metacognitve awareness than the CI strategy group. This suggested that the instruction using the graphing calculator induced better metacognitive awareness as compared to conventional instruction

Results – Phase II

Students' metacognitive awareness level was obtained using the MCAS which was similar to that of Phase I. As in Phase I, there were 11 items associated with students' metacognitive awareness based on each subscale with the overall total of 33 items posed to the respondents.

The means, standard deviations and ANOVA statistics have been determined for the overall metacognitive awareness variable. In addition, planned comparison was conducted. Table 2

illustrates the means and standard deviations for the level of students' metacognitive awareness as a function of the level of mathematical ability and type of instructional strategy. As can be seen from the table, the mean level of students' metacognitive awareness of the GC strategy group was 2.98 (SD=.36) and the mean level of students' metacognitive awareness of CI strategy group was 2.21 (SD=.39). Hence these indicated that the GC strategy group had better level of metacognitive awareness as compared to CI strategy group. The mean level of metacognitive awareness of the average ability group was 2.63 whilst the low ability group was 2.59.

Table 2. Means and standard deviations for level of students' metacognitive awareness as a function of mathematical ability level and instructional strategy type in Phase II

Mathematical ability	Instructional strategy	N	M	SD
Average	CI	15	2.25	.46
	GC	16	2.98	.23
	Total	31	2.63	.51
Low	CI	19	2.18	.34
	GC	20	2.97	.45
	Total	39	2.59	.56
Total	CI	34	2.21	.39
	GC	36	2.98	.36
	Total	70	2.60	.54

Table 3 presents the test of between-subjects effects using the two-way ANOVA on the mean level of metacognitive awareness. For this variable, it was found that Levene's test was significant, F=4.13, p<.05. Hence the homogeneity of variance assumption was violated. However, according to Leech et al. (2005) this problem was less important because SPSS uses the regression approach to calculate ANOVA.

Table 3: Test of between-subjects effect using two-way ANOVA for metacognitive awareness

Source	Type III Sum of Squares	df	MS	F	p	Partial Eta Squared
Corrected Model	10.28[a]	3	3.43	23.35	.000	.52
Intercept	465.24	1	465.24	3170.21	.000	.98
Ability	.03	1	.03	.18	.671	.00
Strategy	10.01	1	10.01	68.19	.000	.51
Ability * Strategy	.02	1	68.19	.11	.738	.00
Error	9.69	66	.11			
Total	494.90	70				
Corrected Total	19.97	69				

a. R Squared = .515 (Adjusted R Squared = .493)

As can be seen in Table 3, the ANOVA performed on the mean level of the metacognitive awareness showed that there was a significant main effect based on instructional strategy, $F(1,66)=68.19$, p<.05, with large effect size (partial eta squared=.51) based on Cohen (1988). Thus, H_o3 was rejected. However, the interaction effects between mathematic ability levels and instructional strategy type was not significant, $F(1,66)=.11$, p>.05, and partial eta squared =.00. Therefore, H_o4 was not rejected. About 52% of the variance in the test performance can be accounted for, by the different levels of instructional strategy and mathematical ability and the interaction. The results showed that there was a significant main effect of instructional strategy on

the mean level of students' metacognitive awareness. However, the results showed that there was no significant interaction effect of instructional strategy and levels of mathematics ability on the mean level of students' metacognitive awareness. Hence integrating the use of the graphing calculator in learning mathematics induced better level of metacognitive awareness for both low and average mathematics ability groups. Specifically, all average ability group in the GC strategy group responded high frequencies on item 14 "I thought of the planning steps to draw a graph of the form $y = mx + c$". Majority of the average students also indicated that they often used an appropriate formula to determine the gradient, thought through the planning steps to determine the straight lines equations, and thought of comparing the gradients of two lines to verify that two lines are parallel (93.75%). Whereas, the low ability group in the GC strategy group responded high frequencies on item 13 "I used several ways to determine the gradient of a straight line" and 33 "I judged the correctness of my work in solving problems involving equations of straight lines (85.00%).

Results for planned comparison showed that the mean level of metacognitive awareness of the GC strategy group was significantly higher than those of the CI strategy group, $F(1,68)=71.57$, $p<.05$. This finding suggested that the use of graphing calculator have induced greater level of metacognitive awareness while solving problems related to the Straight Lines topic, thus is superior compared to conventional instruction.

In summary, results for ANOVA showed that there were significant main effects of instructional strategy on all means variables. However, the interaction effect of mathematical ability level and instructional strategy type did not reach statistical significance for these variables. Further analyses on planned comparison test on the mean metacognitive awareness of the GC strategy group were significantly higher than those of the CI strategy group. These results indicated that integrating the use of the graphing calculator in teaching and learning of the Straight Lines topic improved the levels of students' metacognitive awareness for both low and average ability groups.

Discussion

The results indicated that the GC strategy group had higher means for the overall level of metacognitive awareness, cognitive strategy subscale and self-checking subscale as compared to that of the CI group. The etas squared ranged from .06 to .09, which were moderate effect according to Cohen (1988). Even though statistically, there was no significant difference in the mean level of students' metacognitive awareness for planning subscale, the GC strategy group had higher mean level as opposed to that of the CI strategy group. Overall, the results suggested that there was sufficient evidence to conclude that the use of the graphing calculator in teaching and learning mathematics can boost students' metacognitive awareness level during Straight Lines problem solving.

One reason why the differences were significant could be the long-term use of the graphing calculator was sufficient in establishing the metacognitive awareness. Further, students in both GC and CI strategy groups were asked to do tasks and solve problems in pairs and also were encouraged to discuss among them during learning, thus these may benefit students in GC strategy group in demonstrating higher level of metacognitive awareness

Another reason for the marginally better level of students' metacognitive awareness could be due to possible formation of an intelligent partnership (Salomon et al., 1991). According to Salomon, these partnerships are characterised by a complementary division of working capacity between the user and the technology. For this study, the students plan and implement the solutions, but they pass the responsibility over to the graphing calculator at the appropriate time, for example,

when the points of intersection are to be determined. Jones (2000) emphasised that this aspect of partnership is the constant monitoring and checking of the information generated by the calculator to make sure the solution produced is consistent with the students' knowledge and understanding of the problem at hand. Thus this would help improve the level of students' metacognitive awareness while solving problems related to Straight Lines topic. Besides that, the advantage of the use of graphing calculator is it served as a prompt checker to correct answer.

Conclusion

Overall, the results of Phase I on analysis of metacognitive awareness of mathematics learners indicated that integrating the use of graphing calculators in teaching and learning of mathematics can improve level of students' metacognitive awareness. The findings here concur with other studies such as Gage (2002), Hylton-Lindsay (1998) and Keller and Russell (1997). For example, Keller and Russell noted that calculus students using the TI-92 CAS technology for problem solving were more successful, exhibited more metacognitive behaviours, hence had greater confidence in their problem solving ability than did students without access to CAS technology.

The results of experiment in Phase II supported findings from experiment in Phase I pertaining to metacognitive awareness. The results showed a significant main effect of type of instructional strategy on mean overall level of metacognitive awareness, with large effect size of .73 based on Cohen (1988), implying that the GC strategy was effective in improving students' metacognitive awareness in solving Straight Lines problems. However, the interaction effect between mathematic ability levels and instructional strategy type were not significant. The results suggested that the use of graphing calculator induced better level of metacognitive awareness in solving Straight Lines problems for both low and average mathematics ability groups.

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