# The use of Graphic Calculator in Teaching and Learning of Mathematics: Effects on Performance and Metacognitive Awareness

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## Abstract

*A quasi-experimental study with non-equivalent control group posttest only design was conducted to investigate the effects of using graphic calculators in mathematics teaching and learning on Form Four (11th grade level) Malaysian secondary school students' performance and their metacognitive awareness The experiment was carried out for six weeks incorporating comparison on two levels of mathematics ability (low and average) and two types of instructional strategy (graphic calculator strategy and conventional instruction strategy). The sample for this study was selected randomly in one school in Malacca. There were four groups involved such that the average mathematics ability of experimental and control groups consisted of 17 and 18 students respectively whereas the low mathematics ability of experimental and control groups consisted of 20 and 22 students respectively. The experimental group underwent learning using graphic calculator strategy while the control group underwent learning using conventional instruction strategy. There were three instruments used in this study namely, the Straight Lines Achievement Test, the Paas Mental Effort Rating Scale and the Metacognitive Awareness Survey. The data were analyzed using analysis of variance and planned comparison test. The findings of the study indicated that graphic calculator instruction enhanced students' performance and induced better levels of their metacognitive awareness with less mental effort invested during learning and test phases and hence increased 3-dimensional instructional efficiency index in learning of Straight Lines topic for both groups of low and average mathematics ability. In addition, as mathematics ability increased, the amount of mental effort invested during learning and test phases of the graphic calculator group decreased. The average mathematics ability group greatly benefited from the graphic calculator instruction as it led to decrease doubled amount of mental effort than the low mathematics ability group. Findings from this study provide evidence of pedagogical impact of the use of graphic calculator as a tool in teaching and learning of mathematics in Malaysia.*

**Keywords:** graphic calculators, instructional strategy, metacognitive awareness

## *Introduction*

Teaching and learning of mathematics should portray an active and dynamic classroom with students thinking, exploring and applying what they have learnt. Recently, technology tools are increasingly available to enhance and promote mathematical understanding. Among those, there has been a steady increase in interest in using hand-held technologies, in particular the graphic calculator. Generally, this tool has gained widespread acceptance as a powerful tool for learning mathematics. Therefore the integrating of graphic calculator in learning mathematics may have benefit in inducing active learning with teacher instructional guidance and thus would help to improve students' performance. Current literature on the graphic calculator ultimately gave rise to questions and criticisms. For example, critical reviewed by Penglase and Arnold (1996) concerning the methodology used found that the use of experimental and control groups fails to look into issues pertaining to the relationship between the use of the graphic calculator and the important influences such as upon conceptual understanding. Recently, a brief overview of literature related to the nature of graphic calculator research by Berger (1998) found that there is a scarcity of research directed towards an explication or interpretation of how the graphic calculator functions as a tool for learning.

Penglase and Arnold (1996) urged that research should go beyond those effectiveness studies; it should address in detail the fundamental issues such as the actual process of learning and thinking with the graphic calculator as a cognitive tool which involve the knowledge acquisition. In the same vein, Jones (2000) and Kaput (1992) highlighted that there is a need to go beyond the immediate issues of curriculum and classroom practice by focusing at more fundamental issues. Thus, apart from studying the effectiveness of integrating the use of graphic calculator in teaching and learning of mathematics, this research attempts to provide explanation on the benefit of graphic calculator as a tool for learning from the cognitive load perspectives.

According to Burrill et al. (2002), although handheld graphing technology has been available for nearly two decades, research on the use of the technology is not robust; its use in secondary classrooms (for example in Great Britain, France, Sweden, New Zealand, Netherlands, and United States) still is not well understood, universally accepted, nor well-documented. The usage of graphic calculators in Malaysian school is still in the early stage and there are not many schools which have explored the use of the technology (Noraini Idris 2006; 2004; Lim and Kor 2004). Further, limited studies on using graphic calculators in teaching and learning of mathematics in Malaysian school were done and if any, they were not carried out in depth (Mohd. Khairiltitov 2003). The premise that graphic calculators can help to create environment that assist students in knowledge acquisition needs to be further investigated in the Malaysian scene. In addition, thus study will provide empirical evidence on the use of graphic calculators in teaching and learning of mathematics at Malaysian secondary school level hence expanding the knowledge base for this technology.

At this point of writing, the scientific calculators are already allowed to be used in the Malaysian Certificate of Education Examination level. Currently, Malaysia has not started on compulsory implementing in using graphic calculator in teaching and learning of mathematics. In comparison, countries such as England, Australia, Singapore, Japan and United States of America has longed implement the usage of graphic calculator as early as 1998. Since the scientific calculators are already used in the SPM examination level, it would also be timely to think about using graphic calculators in Malaysian public examination. In conjunction, this would bring Malaysian secondary mathematics education to be at par with other countries. Thus, there is a need to carry out this research as it will give some indications in considering the use of this technology in mathematics classroom and examination

### *Cognitive Load Theory*

Cognitive load theory (CLT) (Sweller 1988, Paas et al. 2003) focuses on the role of working memory in the development of instructional methods. The theory originated from the information processing theory in the 1980s and underwent substantial changes and extensions in the 1990s (Pass et al. 2003; Sweller et al. 1998). Recently, more and more applications of CLT have begun to appear in the field of technology learning environment (van Merrienboer and Ayres 2005; Mayer and Moreno 2003; Pass et al. 2003). Research within cognitive load perspective is based on the structure of information and the cognitive architecture that enables learners to process that information. Specifically, CLT emphasizes structures that involve interactions between long term memory (LTM) and short term memory (STM) or working memory which play a significant role in learning. One major assumption of the theory is that a learner’s working memory has only limited in both capacity and duration. Under some conditions, these limitations will somehow impede learning.

Cognitive load is a construct that represents the load impose while performing a particular task the cognitive system (Sweller et al. 1998). CLT researchers have identified three sources of cognitive load during instruction: intrinsic, extraneous and germane cognitive load (for example, Pass et al. 2003; Cooper 1998; Sweller et al. 1998). Intrinsic cognitive load is connected with the nature of the material to be learned, extraneous cognitive load has its roots in poorly designed instructional materials, whereas germane cognitive load occurs when free working memory capacity is used for deeper construction and automation of schemata. Intrinsic cognitive load cannot be reduced. However, both extraneous and germane cognitive load can be reduced.

According to CLT, learning will fail if the total cognitive load exceeds the total mental resources in working memory. With a given intrinsic cognitive load, a well-designed instruction minimizes extraneous cognitive load and optimizes germane cognitive load. This type of instructional design will promote learning efficiently, provided that the total cognitive load does not exceed the total mental resources during learning. Since little consideration is given to the concept of CLT, that is without any consideration or knowledge of the structure of information or cognitive architecture, many conventional instructional designs are less than effective (Pass et al. 2003). Therefore, many of these methods involve extraneous activities that are unrelated to the acquisition of schemas and rule automation.

In addition, Bannert (2002) and Sweller et al. (1998) argued that in many cases it is the instructional design which causes an overload, since humans allocate most of their cognitive resources to working memory activities when learning. These extraneous activities will only contribute to the unnecessary extraneous cognitive load in which it can be detrimental to learning. Thus, to achieve better learning and transfer performance, the main idea of the theory is to reduce such form of load in order to make more working memory capacity for the actual learning environment. In other words, the main premise of CLT is that in order to be effective, instructional design should take into account the limitations of working memory. As discussed earlier, cognitive load theory (CLT) builds upon the cognitive perspective on learning. The concepts of CLT such as long-term memory, short-term memory or working memory and schema construction are key concepts of information processing approach to learning. Valcke (2002) remarked that further development of CLT had not made an attempt to incorporate some other features of the information processing model namely, the importance of monitoring activities that influence the different processes: monitoring/controlling the selection and organization of sensory information to working memory; back and forth storage and retrieval of schemas from long-term memory (LTM) to short-term memory (STM) and organization monitoring of output.

Valcke suggested to extend CLT with the conception of monitoring, specifically the explicit monitoring of cognitive process or metacognition. He also argued that metacognition neglected can be related to the types of knowledge that researcher focus upon during their researches. The researchers often focus on declarative and procedural knowledge in a variety of knowledge domains while metacognitive knowledge has not been considered. CLT is enriched by its ability to cope with the monitoring activity and thus integrating a metacognitive perspective in its frame of reference (Valcke 2002). Valcke (2002) urged researchers to investigate the impact of instructional strategies that focus upon the incorporation of metacognitive awareness, for instance, instructional strategies that force learners to reflect explicitly upon their processing activity and/or strategies during which learners are offered metacognitive tools that help them to make explicit the steps they take, their reflection upon these steps and their doubts and feelings of surity.

To date, there are not many studies that contribute to the issue of metacognition from the cognitive load perspectives. Valcke (2002) commented that even though some researchers mentioned about metacognition, but they do not elaborate the relationship between this concept and CLT and do not integrate the concept in the overall CLT. Their contributions only offer a starting point to discuss metacognitive load in the context of CLT. As mentioned previously, more and more applications of CLT have begun to appear recently in the field of technology learning environment. Some researchers also have suggested that the use of calculators can reduce cognitive load when students learn to solve mathematics problems (Jones 1996, Kaput 1992; Wheatley 1980). Thus, in this study, it was hypothesized that integrating the use of graphic calculators in teaching and learning of mathematics can reduce cognitive load and lead to better performance in learning and improve metacognitive awareness levels while solving mathematical problems. Specifically, this method uses an instructional strategy that minimizes extraneous cognitive load and hence optimizes germane cognitive load.

## *Objectives*

A progressive phase of three experiments was conducted in this study. Phase I was a preliminary study. This phase sought to provide indicators of the effectiveness of graphic calculator strategy on students' performance. Phase II of the study was further carried out incorporating measurements of metacognitive awareness, mental load and instructional efficiency. Findings from experiments in Phases I and II indicated that integrating the use of graphic calculator lead to better performance in learning of Straight Lines topic as compared to the conventional instruction. It was also found that the GC strategy group had better level of metacognitve awareness than the CI strategy group. This suggested that the instruction using graphic calculator induced better metacognitive awareness as compared to conventional instruction. The results also revealed that the GC strategy group had invested less mental effort per problem during learning and test phases. This suggested that the instruction using graphic calculator imposed less mental effort during learning and test phases as compared to conventional instruction.

In addition, the finding also indicated that learning by integrating the use of graphic calculator was instructionally more efficient than learning using conventional strategy. For further detailed of the findings for Phases I and II, readers are encouraged to refer to Nor'ain Mohd. Tajudin, Rohani Ahmad Tarmizi, Wan Zah Wan Ali & Mohd. Majid Konting (2005a, 2005b, 2006a, 2006b, 2006c, 2006d, 2007a, 2007b, 2007c, 2007d) and Rohani Ahmad Tarmizi & Nor'ain Mohd. Tajudin (2006). Thus, the third phase of the study which will be discussed in this article was further carried out incorporating comparison on different levels of mathematics ability (low and average) and instructional strategy (GC strategy and CI strategy). Specifically, this study intends to achieve the following objectives:

- To compare the effect of instructional strategy and the interaction effect between the instructional strategy and the mathematics ability on students' performance in learning of Straight Lines topic.
- To compare the effect of instructional strategy and the interaction effect between instructional strategy and mathematics ability levels on students' metacognitive awareness while solving problems related to Straight Lines topic.
- To compare the effect of instructional strategy and the interaction effect between thee instructional strategy and mathematics ability levels on measure of mental effort per problem invested during learning and test phases.
- To compare the effect of instructional strategy and the interaction effect between instructional strategy and mathematics ability levels on measure of instructional efficiency.

## *Methodology*

### Design

The quasi-experimental nonequivalent control-group posttest only design (Cook and Campbell 1979, Creswell 2002) was employed. In addition, a 2 x 2 factorial design was integrated in order to investigate two main factors: instructional strategy (GS strategy and CI strategy) and mathematics ability (low and average). For this phase, the groups that were selected were ensured for their initial equivalence and classes involved were randomly assigned to experimental and control groups.

### Sample

The target population for this study was Form Four ($11^{th}$ grade level) students in National secondary schools in Malaysia whilst the accessible population was Form Four students from one selected school in Malacca. The experiment was carried out within one particular school only. A total of 77 students took part in the study. The average mathematics ability of GC strategy and CI strategy groups consisted of 17 students and 18 students respectively, whereas, the low mathematics ability of GC strategy and CI strategy groups consisted of 20 students and 22 students respectively.

### Materials and Instruments

The instructional materials for this phase consisted of 15 sets of lesson plans of teaching and learning of Straight Lines topic. The format of each lesson plan includes activities for the following phases: set induction phase, acquisition phase, practice phase, closure phase and evaluation phase. The main feature of the acquisition phase for the experimental group was that students used "balanced approach" in learning the Straight Lines topic. Waits and Demana (2000a, 6) illustrated that the "balanced approach" is an appropriate use of paper-and-pencil and calculator techniques on regular basis. The control group was also guided by the same instructional format with conventional whole-class instruction without incorporating the use of graphic calculator. The instruments in this study consisted of the Straight Lines Achievement Test (SLAT), the Paas (1992) Mental Effort Rating Scale (PMER) and the Metacognitve Awareness Survey (MCAS). The SLAT was designed by the researcher to assess students' performance on the Straight Lines topic. It comprised of 14 questions based on the straight lines topic covered in the experiment. The overall total score for the SLAT was 75. The reliability index using Cronbach's alpha coefficient was 0.82. Thus, the reliability of SLAT for this phase was reasonably acceptable based on Nunnally (1978) cut-off point of 0.70

The PMER was used to measure cognitive load by recording the perceived mental effort expanded in solving a problem in experiments Phases II and III only. It was a 9-point symmetrical Likert scale measurement on which subject rates their mental effort used in performing a particular learning task. It was introduced by Paas (1992) and Paas and Van Merrienboer (1994). The numerical values and labels assigned to the categories ranged from very, very low mental effort (1) to very, very high mental effort (9). There were two kinds of subjective ratings of mental effort taken during the experiment. Firstly, the subjective ratings of mental effort were taken during learning in evaluation phase for each lesson. Secondly, it was taken during test phase. The mental effort per problem was obtained by dividing the perceived mental effort by the total number of problems attempted for each evaluation phase during learning and that of the test phase. For each question in SLAT, the PMER was printed at the end of the test paper. After each problem, students were required to indicate the amount of mental effort expended for that particular question by responding to the nine-point symmetrical scale. The computed index of reliability for PMER in this phase was 0.91.

The MCAS was designed to measure students' metacognitive awareness while working on tasks or problems related to the Straight Lines topic. The MCAS was adopted and adapted from O'Neil's and Abedi's (1996) State Metacognitive Inventory, and O'Neil's and Schacter's (1997) Traits Thinking Questionnaire metacognitive components.

It was also based on the key operations of metacognition by Bayer (1988). This instrument comprised of 33 items requiring response based on four point Likert scale. Students were asked to read each statements/items in the survey and indicate how often they think or feel or do while working on tasks or problems related to the Straight Lines topic by circling the appropriate scale as described earlier. There were three subscales namely planning, cognitive strategy and self-checking. Score for each subscale may range from 11 to 44 while the overall metacognitive awareness scale may range from 33 to 132. This instrument was tested out before it was used in this phase. Fifteen Form Four students that were not involved in previous Phase II were asked to do the survey for the purpose of calculating the alpha reliability coefficient. Students were also interviewed on the clarity of the survey questions and on their understanding of the survey questions. No problem was encountered during the interview session. The computed overall alpha reliability coefficient was 0.93. In actual study for Phases II and III, the computed overall alpha reliability coefficients were 0.91 and 0.92 respectively.

**Results**

The exploratory data analysis was conducted for all the data collected in this phase. Students' performance was measured by the overall test performance and students' metacognitive awareness was measured by the total level of their metacognitve awareness while working or solving problems related to the Straight Lines topic. The mental effort per problem was obtained by dividing the perceived mental effort by the total number of problems attempted for each evaluation phase during learning and that of the test phase. Further, the 3-dimensional (3-D) instructional condition efficiency indices were calculated using Tuovinen and Paas (2004) procedure. The maximum instructional efficiency is indicated at octant when the performance scores are greatest and the effort scores are the least. On the other hand, the least instructional efficiency would occur when the performance score was the least and the effort scores were the greatest. All data were analyzed using a two-way analysis of variance (2-way ANOVA) and followed by planned comparison tests in order to ascertain the superiority of the GC strategy from that of CI strategy. Planned comparison was used as it is more sensitive in detecting differences based on Pallant (2001). For all statistical analyses, the 5% level of significant was used throughout this phase.

***Effects on Test Performance***

**Table 1. Means and standard deviations for overall test performance**

| Mathematics ability | Instructional strategy | N | M | SD |
|---|---|---|---|---|
| Average | CI | 15 | 24.20 | 8.74 |
| | GC | 16 | 30.38 | 7.74 |
| | Total | 31 | 27.39 | 8.69 |
| Low | CI | 19 | 10.11 | 4.03 |
| | GC | 20 | 19.20 | 5.26 |
| | Total | 39 | 14.77 | 6.54 |
| Total | CI | 34 | 16.32 | 9.58 |
| | GC | 36 | 24.17 | 8.51 |
| | Total | 70 | 20.36 | 9.81 |

The means and standard deviations for test performance as a function of the level of mathematics ability and type of instructional strategy are provided in Table 1. The total test score was 75. Mean test performance of GC strategy group was 24.17 (SD=8.51) and mean test performance of CI strategy group was 16.32 (SD=9.58). Hence this indicated that the GC strategy group performed better on test as compared to CI strategy group. The group of average mathematics ability scored 27.39 while the group of low mathematics ability scored 14.77, indicating that the average mathematics ability group performed better than the low mathematics ability group on test.

The ANOVA showed a significant main effect in the mean test performance of type of instructional strategy, $F(1,66)=23.82$, $p<0.05$, with large effect size (partial eta squared=.27) based on Cohen (1988). However, it was found that there was no significant interaction effect between mathematics ability and instructional strategy, $F(1,66)=.87$, $p>0.05$, partial eta squared=0.01). About 58% of variance in test performance was predictable from both the independent variables and the interaction. These results indicated that there was a significant main effect in the mean test performance between the GC strategy group and CI strategy group. However, the results indicated that there was no significant interaction effect in the mean test performance between the instructional strategy and the level of mathematics ability. Hence use of graphic calculator is efficient for both groups, low and average mathematics ability. This is another mileage for using graphic calculator in learning of mathematics. Further, planned comparison results showed that the mean test performance of GC strategy group was significantly higher from those of CI strategy group,

$F(1,68)=13.18$, $p<0.05$. This finding suggested that use of graphic calculator enhanced mathematics performance as compared to the conventional instruction.

***Effects on Metacognitive Awareness***

**Table 2. Means and standard deviations for level of metacognitive awareness**

| Mathematics ability | Instructional strategy | N | M | SD |
|---|---|---|---|---|
| Average | CI | 15 | 74.27 | 15.20 |
| | GC | 16 | 98.38 | 7.56 |
| | Total | 31 | 86.71 | 16.92 |
| Low | CI | 19 | 71.95 | 11.26 |
| | GC | 20 | 99.60 | 14.94 |
| | Total | 39 | 86.13 | 19.18 |
| Total | CI | 34 | 72.97 | 12.98 |
| | GC | 36 | 99.06 | 12.09 |
| | Total | 70 | 86.39 | 18.09 |

Table 2 illustrated the means and standard deviations for level of students' metacognitive awareness as a function of the level of mathematics ability and type of instructional strategy. As can be seen from the table, mean level of students' metacognitive awareness of GC strategy group was 99.06 (SD=12.09) and mean level of students' metacognitive awareness of CI strategy group was 72.97 (SD=12.98). Hence these indicated that the GC strategy group had better level of metacognitive awareness as compared to CI strategy group. Mean level of metacognitive awareness of the average ability group was 86.71 whilst the low ability group was 86.13. The ANOVA performed on mean level of metacognitive awareness showed that there was a significant main effect based on instructional strategy, $F(1,66)=71.86$, $p<0.05$, with large effect size (partial eta squared=0.53) based on Cohen (1988). However, the interaction effects between mathematic ability levels and instructional strategy type was not significant, $F(1,66)=0.34$, $p>0.05$, and partial eta squared =.01. About 53% of variance in test performance can be accounted for by both the different levels of instructional strategy and mathematics ability and the interaction. The results showed that there was a significant main effect of instructional strategy on 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 mean level of students' metacognitive awareness. Hence integrating the use of graphic calculator in learning mathematics induced better level of metacognitive awareness for both low and average mathematics ability groups. Results for planned comparison showed that the mean level of metacognitive awareness of GC strategy group was significantly higher from those of CI strategy group, $F(1,68)=75.86$, $p<0.05$. This finding suggested that the use of graphic calculator had induced greater level of metacognitive awareness while solving problems related to Straight Lines topic, thus is superior as compared to conventional instruction.

***Effects on Mental Effort during Learning Phase***

Table 3. Means and standard deviations for mean mental effort per problem invested during learning phase

| Mathematics ability | Instructional strategy | N | M | SD |
|---|---|---|---|---|
| Average | CI | 15 | 4.71 | .86 |
| | GC | 16 | 4.06 | .77 |
| | Total | 31 | 4.37 | .87 |
| Low | CI | 19 | 4.88 | 1.31 |
| | GC | 20 | 4.59 | .59 |
| | Total | 39 | 4.74 | 1.01 |
| Total | CI | 34 | 4.81 | 1.12 |
| | GC | 36 | 4.36 | .72 |
| | Total | 70 | 4.58 | .96 |

Table 3 presented the means and standard deviations for mental effort per problem invested during learning phase as a function of the level of mathematics ability and type of instructional strategy. Mean mental effort per problem invested during learning phase of GC strategy group was 4.36 (SD=0.72) and that of CI strategy group was 4.81 (SD=1.12). These indicated that CI strategy group had invested more amount of mental effort as compared to the GC strategy group. Mean mental effort per problem invested during learning phase of average mathematics ability group was 4.37 while that of low mathematics ability group was 4.74. Hence these indicated that the group of low mathematics ability group had invested more amount of mental effort per problem during learning phase than that of average mathematics ability group.

The ANOVA performed on mean mental effort per problem invested during learning phase revealed a significant main effect of type of instructional strategy, F(1,66)=4.46, p<0.05, partial eta squared=0.04, while the interaction effect of mathematics ability level and instructional strategy type was not significant, F(1,66)=.671, p>0.05, partial eta squared=0.05. It is to be noted that only 10.1% of variance in mean mental effort per problem invested during learning phase can be accounted for by both the different levels of instructional strategy and mathematics ability and the interaction. The results revealed that there was a significant main effect of instructional strategy on mean mental effort per problem invested during learning phase, with students in GC strategy invested less mental effort than students in CI strategy. However, the results showed that there was no significant interaction effect in the mean mental effort per learning phase problem between the instructional strategy and the level of mathematics ability. Thus, these indicated that the use of graphic calculator benefit both groups. A planned comparison test analyses showed that the mean mental effort per problem invested during learning phase for CI strategy group was not significantly higher from those of GC strategy group, F(1,55.67)=4.08, p>0.05. This finding suggested that the use of GC strategy group and the CI strategy group had invested more or less the same amount of mental effort during learning phase.

***Effects on Mental Effort during Test Phase***

**Table 4. Means and standard deviations for mental effort per problem invested during test phase**

| Mathematics ability | Instructional strategy | N | M | SD |
|---|---|---|---|---|
| Average | CI | 15 | 6.69 | .90 |
| | GC | 16 | 4.53 | .75 |
| | Total | 31 | 5.57 | 1.36 |
| Low | CI | 19 | 7.06 | 1.06 |
| | GC | 20 | 6.06 | 1.21 |
| | Total | 39 | 6.55 | 1.23 |
| Total | CI | 34 | 6.89 | 1.00 |
| | GC | 36 | 5.38 | 1.28 |
| | Total | 70 | 6.12 | 1.37 |

The means and standard deviations for mental effort per problem invested during test phase as a function of the level of mathematics ability and type of instructional strategy are provided in Table 4. As can be seen from the table, mean mental effort per problem invested during test phase of GC strategy group was 5.38 (SD=1.28) and that of CI strategy group was 6.89 (SD=1.00). Mean mental effort per problem invested during test phase for average mathematics ability group was 5.57 whilst that of low mathematics ability group was 6.55. These suggested that the use of CI incurred higher mental effort as compared to GC instruction.

The ANOVA performed on mean mental effort per problem invested during test phase showed a significant main effect of type of instructional strategy, F(1,66)=41.66, p<0.05. Further, there was also a significant interaction between mathematic ability levels and instructional strategy type, F(1,66)=5.68, p<0.05, with moderate effect size (eta squared=0.08). 47.8% of variance in mean mental effort per problem invested during test phase was accounted for by the different levels of mathematics ability and instructional strategy and the interaction. The results showed that there was a significant main effect of instructional strategy on mean mental effort per problem invested during test phase. In addition, the results also showed that there was a significant interaction effect of instructional strategy and levels of mathematics ability on mean mental effort per problem invested during test phase problem. These indicated that mental effort invested during test phase depends on both instructional strategy and mathematics ability

Figure 2 depicts the interaction between mathematic ability levels and instructional strategy type. It is observed that as mathematics ability increased, the amount of mental effort invested during test phase of the GC strategy decreased. For low mathematics ability, this strategy was less beneficial, but, for average mathematics ability group, it led to decrease about 2.16 points (6.69 – 4.53) which is doubled mean amount of mental effort than the low mathematics ability group which reported decreased in mean amount of mental effort of about 1.00 point (7.06 – 6.06).

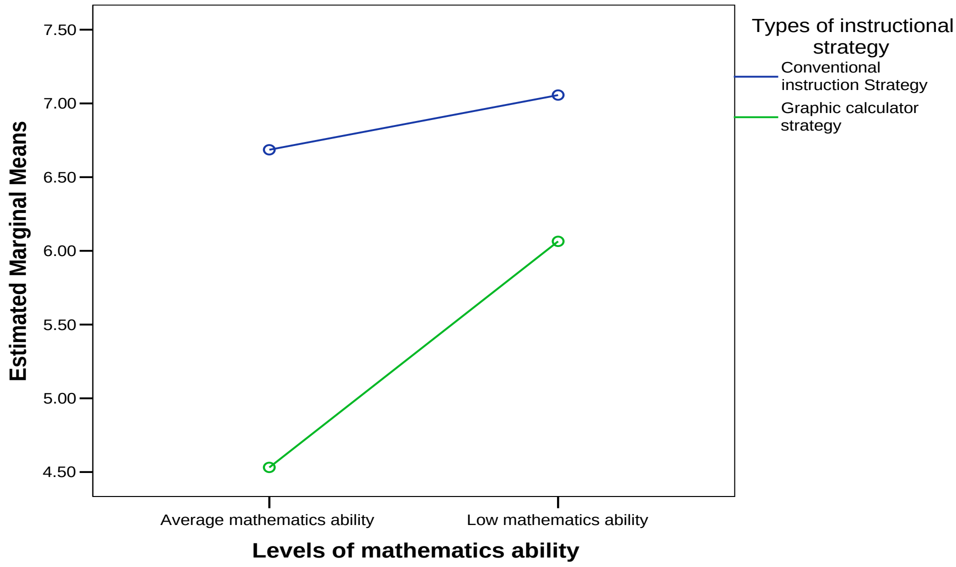


Figure 2. Interaction between Levels of Mathematics Ability and Types of Instructional Strategy on Mental Effort per Problem Invested During Test Phase

Further, a planned comparison results showed that mean mental effort per problem invested during test phase for CI strategy group was significantly higher from those of GC strategy group, $F(1,68)=30.25$, $p<0.05$. This finding suggested that the use graphic calculator imposed less amount of mental effort per problem during test phase as compared to that of conventional instruction. While previous phases showed no interaction effect between instructional strategy and levels of mathematics ability on test performance, metacognitive awareness and mental effort per problem during learning phase, on the contrary, measure of mental effort during test phase results indicated that there was a significant interaction effect. This may be explained by the small F values in ANOVA, namely the values were 0.87, 0.34 and 0.67 for test performance, metacognitive awareness and mental effort per problem during learning phase, respectively, hence these most likely produced no interaction effects. However, the F value was 5.68 for mental effort per problem during test phase, thus this produced an interaction effect.

***Effects on Instructional Efficiency***

The instructional efficiency measures for this phase were calculated using Tuovinen and Paas (2004) procedure of 3-dimensional (3-D) instructional condition efficiency index. The three dimensions namely the learning effort, test effort and test performance was taken into account when calculating these indices. . The three sets of data (learning effort, test effort and test performance) were initially converted to standardized *z* scores. Then, the 3-D efficiency index was computed using the formula, $E = \frac{P - E_L - E_T}{\sqrt{3}}$, where P is *z* score for performance, $E_L$ is *z* score for learning effort and $E_T$ is z score for the test effort (Tuovinen and Paas 2004). The greatest instructional condition efficiency would be occurred when the performance score was the greatest and the effort scores were the least. On the other hand, the worst instructional efficiency condition would occur when the performance score was the least and the effort scores were the greatest. Possible range of $E$ in this study was between −10.39 and 42.15. The minimum values of $E$ for group 1(students with average mathematics ability group undergoing CI strategy), 2 (students with average mathematics ability group undergoing GC strategy group), 3(students with low mathematics ability group undergoing CI strategy) and 4(students with low mathematics ability group undergoing GC strategy) were −1.67, −0.33, −3.36 and −1.73 respectively. The maximum values of $E$ for each group were 4.40, 3.91, 1.05 and 1.22 respectively.

Table 5. Mean and standard deviation for instructional efficiency indices as a function of mathematics ability level and instructional strategy type

| Mathematics ability | Instructional strategy | N | M | SD |
|---|---|---|---|---|
| Average | CI | 15 | −.10 | 1.11 |
| | GC | 16 | 1.57 | .94 |
| | Total | 31 | .76 | 1.32 |
| Low | CI | 19 | −1.19 | 1.15 |
| | GC | 20 | −.06 | .80 |
| | Total | 39 | −.61 | 1.13 |
| Total | CI | 34 | −.70 | 1.24 |
| | GC | 36 | .67 | 1.18 |
| | Total | 70 | .00 | 1.39 |

Table 5 provided the means and standard deviations for instructional condition efficiency indices as a function of the level of mathematics ability and type of instructional strategy. As can be seen from the table, mean instructional efficiency index of GC strategy group was .67 (SD=1.18) and mean instructional efficiency index of CI strategy group was −.70 (SD=1.24). These indicated that instruction using graphic calculator was more efficient as compared to the conventional instruction. Mean instructional efficiency index of average mathematic ability was .76 whilst that of low mathematics ability was −0.61, hence indicating that the group of average mathematics ability had better level of instructional efficiency.

The ANOVA performed on the instructional efficiency indices revealed a significant main effect of instructional strategy type, $F(1,66)=33.40$, $p<0.05$, partial eta squared=0.34. Further, the interaction effect between mathematics ability level and instructional strategy type were not significant, $F(1,66)=1.24$, $p>0.05$, partial eta squared=0.02. About 49.9% of variance in mean instructional condition efficiency index was predictable from both the independent variables and the interaction. The results showed that there was a significant main effect of instructional strategy on mean instructional efficiency index. On the other hand, the results showed that there was no significant interaction effect of instructional strategy and the level of mathematics ability on mean instructional efficiency index. Hence integrating the use of graphic calculator is instructionally efficient for both groups. The planned comparison results showed that the mean instructional condition efficiency index for GC strategy group was significantly higher from those of CI strategy group, $F(1,66)=22.37$, $p<0.05$. Thus, this finding suggested that learning by integrating the use of graphic calculator was more efficient than learning using conventional instruction strategy.

In summary, five variables namely test performance, metacognitive awareness, mental effort invested during learning and test phases, and 3-D instructional efficiency were discussed. The results of ANOVA showed that there were significant main effects of instructional strategy on all the variables' means. However, the interaction effect of mathematics ability level and instructional strategy type did not reach statistical significance for these variables except for mean mental effort during test phase. Further analyses on planned comparison tests on mean test performance, metacognitive awareness and 3-D instructional efficiency index of GC strategy group were significantly higher from those of CI strategy group. In addition, planned comparison test on mean mental effort invested during test phase of CI strategy group was significantly higher from that of GC strategy group. However, for mental effort invested during learning phase, even though planned comparison test did not reach statistical significant, mean of CI group was higher as compared to the GC group. These results indicated that integrating the use of graphic calculator in teaching and learning of Straight Lines topic enhanced students' performance, improved levels of students' metacognitive awareness, reduced mental effort during learning and test phase, hence is instructionally efficient than the conventional instruction.

## *Discussion*

### *Effects of Using of Graphic Calculator in Teaching and Learning of Straight Lines Topic on Students' Performance*

Past studies on effects of the use of graphic calculators offers different results. Generally the results have favored the use of this technology in mathematics classroom (for example, Acelajado 2004; Horton et al. 2004; Noraini Idris 2004; Noraini Idris et al. 2003; Connors and Snook 2001; Graham and Thomas 2000; Hong et al. 2000; Adams 1997; Smith and Shotberger 1997; Quesada and Maxwell 1994; Ruthven 1990). Those studies reported that use of graphic calculators improved students' mathematics performance. The findings from this study suggest that integrating the use of graphic calculator can reduce cognitive load and lead to better performance in learning, thus increase instructional efficiency when Form Four students learn Straight Lines topic for both low and average mathematics ability groups.

In addition, the findings from this study provide empirical evidence to support the contention by Jones (1996), Kaput (1992) and Wheatley (1980) that the use of calculators can reduce cognitive load and hence facilitate learning. The findings provide a possible explanation from the cognitive load theory perspectives why graphic calculator (GC) strategy is more efficient as compared to conventional instruction (CI) strategy in learning of Straight Lines topic. The GC strategy was found to have beneficial effects such that this strategy can increase germane cognitive load whereby the total amount of cognitive load stays within the limits due to low intrinsic cognitive load or due to low extraneous cognitive load. The use of the graphic calculator freed students' mental resources from the tedious computation, algebraic manipulation and graphing skills and hence enabled them to redirect their attention from irrelevant cognitive processes to relevant germane processes of schema construction. This was evident from the significantly lower levels of mental effort reported which theoretically would indicate a lower cognitive load and the significantly higher performance achieved by the students from the GC strategy group.

It is pertinent to note that the argument only holds under certain circumstances namely the sample of students participated and the particular content area learnt in this study. Changing the composition of sample to include higher achievers can lead to a decrease of intrinsic load for this Straight Lines topic. Thus, the findings are only true for that particular sample of students and also apply to the content area of Straight Lines topic for Form Four Mathematics syllabus. Therefore, the findings can only be generalized to the similar sample of secondary school students in Malaysia and might not necessary apply to other mathematics topic or other levels of Straight Lines topic.

It is also pertinent to note that the results of previous phases showed the difference were not significant in several instances important performance variables particularly the transfer problems performance (See Nor'ain Mohd. Tajudin et al. (2005a, 2005b, 2006a, 2006b, 2006c, 2006d, 2007a, 2007b, 2007c, 2007d); Rohani Ahmad Tarmizi and Nor'ain Mohd. Tajudin (2006)). The findings indicate that the interventions of very brief duration (about two weeks) was not enough to show that the GC strategy is an effective instructional strategy for obtaining schema acquisition. Dunham (2000) noted that a few studies that produced negative results due to treatment of very brief duration such that the learning of graphic calculator may have interfered with learning of content (for example, Upshaw, 1994; Giamati, 1991). However, for this phase, the treatments were conducted for about six weeks and the findings were in favor for GC strategy.

The findings also suggest that the GC strategy group possibly may not have split attention effect with the use of worksheet (for graphic calculator instructions) and the graphic calculator screen. The results showed that if the split attention effect exists, its negative consequences are far outweighed by the reduction in cognitive load. In this experiment, students in GC strategy group were found to be sufficiently proficient enough in graphic calculator use because besides having the pre-experiment training of introducing the graphic calculator and learning how to use the graphic calculator, they had longer duration of intervention. Hence, it is pertinent to note that if students who had hardly knew how to use the graphic calculator had been selected, the results might have been different. The negative consequences of the split attention effect might have outweighed the positive effects of cognitive load reduction. On the other hand, the results on performance might have been further magnified if students very proficient with the use of graphic calculator had been selected in this phase.

Another important finding in this study was that both factors, mathematics ability and instructional strategy, separately influence test performance, metacognitive awareness, mental effort invested during learning and instructional efficiency because the interaction did not reach statistical significance for these variables. However, there was a significant interaction between levels of mathematics ability and types of instructional strategy for amount of mental effort invested during test phase. It was found that as mathematics ability increased, the effectiveness of GC strategy increased. The average mathematics ability group was greatly beneficial from the GC strategy as it led to doubled decrease mean amount of mental effort than that of low mathematics ability group. However, it is pertinent to note that even though there was no significant interaction between mathematics ability and instructional strategy for test performance, practically the average ability group of GC strategy had performed better on test performance.

***Effects of Using of Graphic Calculator in Teaching and Learning of Straight Lines Topic on Students' Metacognitive Awareness***

Very little research had investigated the effects of integrating the use of graphic calculator in teaching and learning of mathematics on students' metacognitive awareness (for example, Gage 2002; Hylton-Lindsay 1998; Keller and Russel 1997).

The findings from this study suggest that there is sufficient evidence to conclude that integrating the use of graphic calculator can boost students' metacognitive awareness level during solving Straight Lines problems for both low and average mathematics ability groups. Thus, the findings of this study are consistent with earlier studies and in addition provide empirical evidence to support earlier studies in the development of metacognitive awareness behavior.

The findings from this study also suggest that integrating the use of graphic calculator can pose as an instructional mode which can force learners to reflect explicitly upon their processing activity and/or strategies during which learners are offered metacognitive tools that help to make explicit the steps they take, their reflection upon these steps, their doubts and feelings of surety, etc. Students in GC strategy might not only invest effort in the construction and storage of schemata, but they also might invest effort in the monitoring of this activity. This would imply that the first activity is linked to the latter activity, thus the latter activity is part of the overall germane cognitive load. The invested effort for the latter activity is suggested to call as a meta-cognitive load (Valcke 2002). The findings of the study suggest that the GC strategy group had invest lower amount of mental effort with higher levels of metacognitive awareness and thus lead to better performance as compared to the CI strategy group. This is in line with earlier study conducted by van Merrienboer et al. (2002) such that the "learner-controlled" experimental set-up allowed for monitoring the learning process invoking meta-cognitive load as part of germane cognitive load, and this with lower mental effort.

### *Practical Implications*

In this study, integrating the use of graphic calculator in teaching and learning of topic, namely the Straight Lines shows promising implications for the potential of the tool in teaching mathematics at Malaysian secondary school level. The findings from this study have provided valid evidence that to a certain extent, the graphic calculator strategy is superior to conventional instruction strategy. Integrating the use of graphic calculator can be beneficial for students as this instructional strategy has proven to improve students' performance and their level of metacognitive awareness while solving problems. Therefore, the findings from this study imply that graphic calculator strategy is an effective and efficient instructional strategy in facilitating the mathematics learning.

Using graphic calculators in learning of mathematics make less cognitive demand (reduction of cognitive load) because a larger part of the cognitive process is taken over by the graphic calculator. This allows students to focus attention on the problem to be solved rather than the routine computations, algebraic manipulations or graphing tedious graphs which require the switching of attention from the problem to the computation, etc and then back to the problem. According to Norman (1976), the act of switching attention may blur perception and cause confusion in one's judgment of its temporal properties. This means that reduction of cognitive load and distribution of cognition in graphic calculator medium requires students to focus only on one aspect and enhance the understanding of mathematical tasks. Therefore, more individual will be able to perform mathematical tasks and allow them to work on application problems, thus stimulate students' interest and facilitate the teaching and learning of mathematics.

In this study, the "balance approach" which means "appropriate use of paper-and-pencil and calculator techniques on regular basic" as suggested by Waits and Demana (2000a, 2000b) with teacher guidance was used for the graphic calculator strategy group. The results of this study showed that the graphic calculator strategy group had better conceptual knowledge performance as compared to conventional instruction strategy group and most important they did not lose procedural knowledge performance. These results reflect the NCTM insistence that "Calculator don't think, students do" (NCTM 1999). Students will not loose their ability to think if there were to use the graphic calculator. Instead, they need to understand the problem more than what keys to push and in what order. Furthermore, they also need to decide what information to enter, what operation to use and finally they need to interpret the results. Thus, this study also imply that the balance approach that make the best use of graphing technology in teaching and learning of Straight Lines topic enable for developing students' understanding of mathematical concepts without loosing the procedural knowledge.

From the findings of the study, the graphic calculator strategy group was generally found to be sufficiently proficient in graphic calculator use. The results also showed that if the split attention effect exists, its negative consequences are far outweighed by the reduction in cognitive load. The negative consequences of the split attention effect might have outweighed the positive effects of cognitive load reduction if students who had hardly knew how to use the graphic calculator had been selected. The results on performance might have been further magnified if students very proficient with the use of graphic calculator had been selected.

Based on these findings, another important implication for integrating the use of graphic calculator is that the graphic calculator technology should be learned prior to learning the subject area. Learning both concurrently may only be effective if students already have considerable technological knowledge because when dealing with novel material, the basic characteristics of human cognitive architecture of limited working memory can't be ignored.

## Conclusion

More efficient and effective instructional designs can be developed if the limited capacity of working memory is taken into consideration. In this study, it was found that graphic calculator strategy is instructionally more efficient and thus is superior to conventional instruction strategy. This study shows promising implications for the potential of the tool in teaching mathematics at Malaysian secondary school level.

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