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# The Effects of Using Graphing Calculators in Teaching and Learning of Mathematics on Students' Performance

*(Kesan Penggunaan Kalkulator Grafik Terhadap Prestasi Pelajar dalam Pengajaran dan Pembelajaran Matematik)*

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## Abstract

Three phases of quasi-experimental study with non-equivalent control group post-test only design were conducted to investigate the effects of using graphing calculators in mathematics teaching and learning on Form Four Malaysian secondary school students' performance. Experiment in Phase I was conducted for two weeks to provide an initial indicator of the effectiveness of graphing calculator strategy on students' performance. Graphing calculator strategy refers to the use of TI-83 Plus graphing calculator in teaching and learning of Straight Lines topic. The first phase involved one experimental group (n=21) and one control group (n=19) from two Form Four classes in a randomly selected school in Selangor. The experimental group underwent learning using graphing calculator while the control group underwent learning using conventional instruction. Experiment for Phase II was further carried out for six weeks incorporating measures of mathematical performance, mental effort and instructional efficiency. This phase involved two experimental groups (n=33) and two control groups (n=32) from four Form Four classes in one randomly selected school in Malacca. As in Phase I, the same learning conditions were given for both experimental and control groups. Finally, experiment in Phase III 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). Form Four students from one of the schools in Malacca were the sample for Phase III. Altogether there were four groups of students given four learning conditions vis-à-vis: the average mathematical ability given the use of graphing calculators (n=15), the low mathematical ability were also given graphing calculators (n=19), the average mathematical ability were given the conventional instruction (n=16) and the low mathematical ability were also given the conventional instruction (n=20). There were two instruments used in this study namely, Straight Lines Achievement Test and Paas Mental Effort

Rating Scale. The data for Phases I and II were analysed using independent t-test and planned comparison test while data for Phase III were analysed using multiple analysis of variance and planned comparison test. The study shows that the graphing calculator instruction enhanced students' performance with less mental effort invested during the 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. These findings indicated that the graphing calculator instruction is superior in comparison to the conventional instruction, hence implying that it was more efficient instructionally than the conventional instruction strategy. The average mathematics ability group greatly benefited from the graphing calculator instruction as it decreased the amount of mental effort by double than the low mathematics ability group.

**Keywords:** Graphing calculator, quasi-experimental design, instructional efficiency.

## Abstrak

Tiga fasa kajian kuasi-eksperimen dengan reka bentuk ujian pos bagi kumpulan kawalan tidak serupa telah dilaksanakan untuk mengkaji kesan penggunaan kalkulator grafik dalam pengajaran dan pembelajaran matematik ke atas prestasi pelajar sekolah menengah Malaysia Tingkatan Empat. Eksperimen Fasa I dikendalikan selama dua minggu untuk memberi indikasi awal keberkesanan strategi kakulator grafik terhadap prestasi pelajar. Strategi kalkulator grafik adalah merujuk kepada penggunaan kalkulator grafik TI-83 Plus dalam pengajaran dan pembelajaran topik Garis Lurus. Fasa ini melibatkan satu kumpulan eksperimen (n=20) dan satu kumpulan kawalan (n=19) daripada dua kelas Tingkatan Empat dalam sebuah sekolah yang dipilih secara rawak di Selangor. Kumpulan eksperimen melaksanakan pembelajaran menggunakan strategi kalkulator grafik, manakala kumpulan kawalan menggunakan strategi pengajaran konvensional. Eksperimen bagi Fasa II pula dikendalikan selanjutnya selama enam minggu dengan menggabungkan ukuran prestasi matematik, daya mental dan kecekapan pengajaran (*instructional efficiency)*. Fasa ini melibatkan dua kumpulan eksperimen (n=33) dan dua kumpulan kawalan (n=32) yang terdiri daripada empat kelas Tingkatan Empat dalam sebuah sekolah yang dipilih secara rawak di Melaka. Kedua-dua kumpulan eksperimen dan kawalan menggunakan strategi pembelajaran yang sama seperti pada Fasa I. Akhirnya, eksperimen Fasa III juga dikendalikan selama enam minggu menggabungkan pula perbandingan ke atas tahap keupayaan matematik (rendah dan sederhana) dan jenis strategi pengajaran (strategi kalkulator grafik dan strategi pengajaran konvensional). Keseluruhannya, terdapat empat kumpulan pelajar dengan kaedah pembelajaran masing-masingnya iaitu: keupayaan matematik tahap sederhaha dengan penggunaan kalkulator grafik (n=15), keupayaan matematik tahap rendah juga dengan penggunaan kalkulator (n=19), keupayaan matematik tahap sederhana dengan pengajaran konvensional (n=16) dan keupayaan matematik tahap rendah juga dengan pengajaran konventional (n=20). Dua instrumen telah digunakan dalam kajian ini iaitu Ujian Pencapaian Garis Lurus dan *Paas Mental Effort Rating Scale*. Data bagi Fasa I dan Fasa II dianalisis menggunakan *independent samples t-test* dan *planned comparison test* manakala data bagi Fasa III dianalisis menggunakan analisis varian univariat dan *planned comparison test*. Kajian menunjukkan bahawa pengajaran menggunakan kalkulator grafik dapat mengukuhkan prestasi pelajar dengan pengurangan beban kognitif semasa fasa-fasa pembelajaran dan ujian dan seterusnya meningkatkan indeks kecekapan pengajaran *(instructional efficiency)* 3-dimensi dalam pembelajaran topik Garis Lurus bagi kedua-dua kumpulan keupayaan matematik tahap rendah dan sederhana. Oleh itu dapatan ini memberi indikasi bahawa pengajaran menggunakan kalkulator grafik didapati lebih baik daripada pengajaran secara konvensional kerana pengajaran tersebut adalah lebih cekap berbanding pengajaran secara konvensional. Pelajar dalam kumpulan keupayaan matematik tahap sederhana memperolehi lebih faedah daripada pengajaran menggunakan kalkulator grafik kerana jumlah penggunaan daya mental berkurangan dua kali ganda jika dibandingkan dengan kumpulan keupayaan matematik tahap rendah.

**Kata kunci:** Kalkulator grafik, reka bentuk kuasi-experimen, kecekapan pengajaran.

## Introduction

The increased use of technology and the changing demands of the workplace have changed the nature of mathematics instructions since the last few years. There is a need to develop students who can survive in today's society of technology. This requires highly skilled workers and ability to apply their mathematical knowledge which includes and goes beyond the simple skills of solving complex problems. Indeed, the National Council of Teachers of Mathematics (NCTM) (1989) reflects a shift in the changing importance of thinking and problem solving in school. The vision of the recommendation by the NCTM (2000) is learning mathematics with understanding. In fact, this learning environment is the ultimate goal of many research and implementation efforts in mathematics education (Hiebert & Carpenter, 1992). According to Hiebert and Carpenter (1992), students who learn mathematics with understanding will retain what they learn and transfer it to novel situations. Thus, parallel with the growing influence of technological advancement, there is a need for a curriculum that can develop the mathematical power of students. This involves a shift from a curriculum dominated by memorization of isolated facts and procedures to one that emphasises on conceptual understanding and mathematical problem solving.

For several years, mathematics educators have been intrigued at powerful computer software such as graphing plotter, computer assisted instruction, hypermedia assisted instruction, and computer algebra systems that may alter the way mathematics is taught and learned. Indeed, the NCTM has consistently emphasized that technology has the potential to make mathematics and its applications accessible in ways that were heretofore impossible (NCTM, 1998). However, the problem of accessibility has hindered the use of technology in the mathematics classroom. For example, in the developing world, access to computer labs is more limited than in America (Berger, 1998). Furthermore, in some countries, computers are hardly used in the classroom largely due to economic factors (Silva, 1996).

In reality, the hand-held technology, specifically the graphing calculator represents the direction of the pedagogical future (Berger, 1998). The availability and accessibility to students at all time (Kissane, 2000) and the portability of graphing calculator with the capabilities to graph functions and relations, manipulate symbolic expressions, and perform high precision numerical integration and root findings of functions. This facility enables a more realistic mathematics lesson to take place. Further, because of many advantages, the graphing calculator has gained widespread acceptance as a powerful tool for mathematics classroom (Dick, 1992; Wilson & Kraptl, 1994). Therefore, mathematics educators today has the responsibility to help students better understand more complex mathematics topics through the use of modern technological tools namely, the graphing calculator.

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).

In Malaysia, the calculator was strictly prohibited at both the primary and lower secondary levels before the year 2002. In 2002, its usage was introduced for Form Two and Three students in lower secondary mathematics curriculum. Currently, the scientific calculators are already allowed to be used in the SPM Examination level. However, Malaysia has not started on compulsory implementation of using graphing calculator in teaching and learning of mathematics. In comparison, countries such as England, Australia, Singapore, Japan and the United States of America has for a long time implemented the usage of graphing calculators 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 graphing calculators in Malaysian public examinations. This would bring the 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.

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) is still not well understood, universally accepted, nor well-documented. The usage of graphing calculators in Malaysian schools is still in the early stage and there are not many schools which have explored the use of the technology (Noraini Idris & Norjoharuddeen Mohd Nor, 2008, Noraini Idris, 2006; 2004; Lim & Kor, 2004). Further, studies on using graphing calculators in teaching and learning of mathematics in Malaysian school were carried out, these however, were limited and not in depth. The premise that graphing calculators can help to create an environment that assist students in acquisition of knowledge need to be further investigated in Malaysia. In addition, this study will provide empirical evidence on the use of graphing calculators in teaching and learning of mathematics at Malaysian secondary school level, hence expanding the knowledge base for this technology.

## Cognitive Load Theory

The positive effects of the integration and the use of graphing calculators in the teaching and learning of mathematics can be understood by explaining and illustrating the theory of cognitive load which provides a basis for the theoretical and conceptual framework of the study.

Cognitive load theory (CLT) (Sweller, 2004; 1988, Paas, Renkl & Sweller, 2003) is an internationally well known and widespread theory which 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, van Merrienboer & Paas, 1998). Recently, more applications of CLT have begun to appear in the field of technology learning environment (van Merrienboer & Ayres, 2005; Mayer & Moreno, 2003, Pass et al.,2003a).

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 emphasises 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 limitation in both capacity and duration. Under some conditions, these limitations will somehow impede learning.

Cognitive load is a construct that represents the load impose on cognitive capacity while performing a particular task (Sweller et al., 1998). CLT researchers have identified three sources of cognitive load during instruction: intrinsic, extraneous and germane cognitive load (Pass et al., 2003; Cooper, 1998; Sweller et al., 1998). Intrinsic cognitive load is connected with the nature of the material to be learned. The 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 the working memory. With a given intrinsic cognitive load, a well-designed instruction minimises extraneous cognitive load and optimises germane cognitive load. This type of instructional design will promote learning efficiency, provided that the total cognitive load does not exceed the total mental resources during the learning process.

Since little consideration is given to the concept of CLT, that is without any considerations 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 can be detrimental to the learning process. 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 the working memory.

Earlier research on CLT had primarily found instructional formats that reduce extraneous cognitive load. Sweller et al., (1998) summarised examples of some major effects that may be attributed to a decrease in extraneous cognitive load such as goal free, worked example, completion problem, split attention, modality and redundancy effects. A more recent development is the search for instructional strategies that reduce extraneous and increase germane cognitive load (van Merrienboer & Sweller, 2005; Paas et al., 2003; Sweller et al., 1998). The basic assumption is that an instructional strategy may results in unused working memory capacity due to low intrinsic cognitive load and/or, low extraneous cognitive load may be further improved by encouraging learners to invest cognitive resources in activities relevant to schema construction and automation, evoking germane cognitive load.

As mentioned previously, more applications of CLT have begun to appear recently in the field of technology learning environment. Some researchers have also 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 hypothesised that integrating the use of graphing calculators in teaching and learning of mathematics can reduce cognitive load and lead to better performance in learning. Specifically, this method uses an instructional strategy that minimises extraneous cognitive load and hence optimises germane cognitive load.

## Conceptual Framework of the Study

The conceptual framework for this study is depicted in Figure 1. The framework is based on the cognitive load construct. This study will investigate the effects of instructional strategy (independent variable) such as using graphing calculator (GC) strategy and conventional instruction (CI) strategy in the teaching and learning of mathematics on students' performance (dependent variables). For this study, there are two causal factors that represent task environment characteristics namely, GC strategy and CI strategy. These factors affect the cognitive load. The assessment factors are mental effort, performance, and instructional efficiency. These factors are affected by the cognitive load. The density of the mental effort expanded by learners is considered the essence of the cognitive load. The learners' performance is a reflection of the mental effort, and the aforementioned causal factors. Performance is measured by variables such as the test performance, the number of problems solved during the test phase, the numbers of errors committed per test phase problems, the conceptual knowledge performance, the procedural knowledge performance, the number of similar problems solved during the test score, performance on similar problems, the number of transfer problems solved during the test phase, and performance on transfer problems.

Based on the concepts from the cognitive load theory that provided the background bases for the positive effects of the use and integration of graphing calculators in mathematics teaching and learning reviewed in the context of this study, it was hypothesised that the use of graphing calculator strategy in the teaching and learning of Straight Lines topic will reduce students' cognitive load. This will lead to a reduction of students' mental effort and hence an increase in level of students' performance and a higher level of instructional efficiency. It was also hypothesised that the use of conventional instruction strategy will increase the cognitive load, which in turn will lead to an increase in mental effort invested and a reduction in performance and a lower level of instructional efficiency.

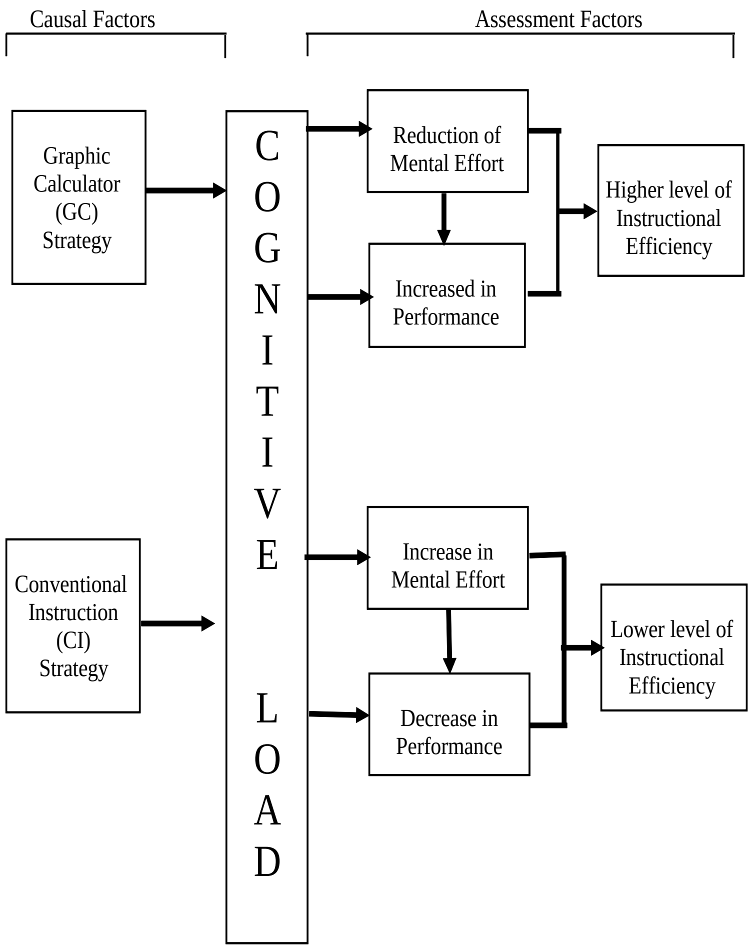


**Figure 1** Conceptual Framework of the Study

**About the Study**

The purpose of this study is to investigate the effects of integrating the use of graphing calculator in mathematics teaching and learning on students' performance for Form Four secondary school students when learning 'Straight Lines' topic. Thus, two types of instructional strategy that is the graphing calculator strategy and the conventional instruction strategy were compared on performance, mental load and instructional efficiency. Three phases of experiments were conducted in this study. Experiment in Phase I was a preliminary study. It was carried out for two weeks. Phase II was partly a replication of the experiment in Phase I. In addition, the possibility that the use of graphing calculators can reduce cognitive load was tested in this phase. Finally, Phase III was conducted to investigate whether the effectiveness of using graphing calculator depended on different levels of mathematics ability. Both experiments in Phases II and III were carried out for six weeks.

## Methodology

### *Design*

The quasi-experimental non-equivalent control-group posttest only design (Cook & Campbell, 1979; Creswell, 2002) was employed. In addition, for Phase III, a 2 x 2 factorial design was integrated in order to investigate two main factors mainly the instructional strategy (graphing calculator (GS) strategy and conventional instruction (CI) strategy) and mathematics ability (low and average). For all phases, the groups that were selected were ensured for their initial equivalence (similar mathematics ability) and classes involved were randomly assigned to GC strategy and CI strategy groups.

### *Population and Sample*

The target population for this study was Form Four ($10^{th}$ grade level) students in National secondary schools in Malaysia whilst the accessible population was Form Four students from one selected school in Selangor and in Malacca. Each phase was carried out within one particular school only. A total of 40 students took part in Phase I such that there were 20 students in the GC strategy group and there were 19 students in the CI strategy group. A total of 65 students took part in the second phase of the study. The GC strategy group consisted of 33 students while the CI strategy group consisted of 32 students. A total of 77 students took part in the third phase of 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 Phase I consisted of six sets of lesson plan, whilst for Phases II and III consisted of fifteen sets of lesson plan of teaching and learning of Straight Lines topic. The Straight Lines topic includes subtopics such as understanding the concept of gradient of a straight line, understanding the concept of gradient of a straight line in the Cartesian coordinates, understanding the concepts of intercepts, understanding and using equation of a straight line, and understanding and using the concept of parallel lines. The main feature of the acquisition phase for the GC strategy group was that students used a "balanced approach" in learning of 'Straight Lines' topic. Waits and Demana (2000a, pg.6) illustrated that the "balanced approach" is an appropriate use of paper-and-pencil and calculator techniques on regular basis. Specifically, the TI 83 Plus Graphing

Calculator was used in this study. The following strategies were implemented in teaching and learning of the topic:

i. Solves analytically using traditional paper and pencil algebraic methods, and then supports the results using a graphing calculator.
ii. Solves using a graphing calculator, and then confirms analytically the result using traditional paper and pencil algebraic methods.
iii. Solves using graphing calculator when appropriate since traditional analytic paper and pencil methods are tedious and/or time consuming or there is simply no other way.
iv. Use manipulative and paper-and pencil techniques during initial concept development and use graphing calculator in the "extension" and "generalizing" phase.
v. Approach and solve problems numerically using tables on graphing calculator.
vi. Model, simulate and solve problem situations using graphing calculator and then confirm, when possible using analytic algebraic paper and pencil methods.

The CI strategy group was also guided by the same instructional format with conventional whole-class instruction without incorporating the use of graphing calculator. The following are the activities which were used by the researcher in the classroom:

i. Teacher explains the mathematical concepts using only the blackboard.
ii. Teacher explains on how to solve mathematical problems related to the concepts explained.
iii. Students are given mathematical problems to be solved individually.
iv. Teacher handles discussion of problem solving.
v. Teacher gives the conclusion of the lesson.

There were two instruments used in this study namely the Straight Lines Achievement Test (SLAT) and the Paas (1992) Mental Effort Rating Scale (PMER). The SLAT had three variations because these instruments were modified based on the results of preceding phases. For Phase I, the SLAT comprised seven questions based on the 'Straight Lines' topic covered in the experiment. The time allocated to do the test was 40 minutes. For each problem solution, one mark was allotted for each correct step in the solution. The problem solution for questions one to seven had 3, 4, 5, 5, 5, 11 and 7 steps respectively as indicated in the marking scheme. Thus, the overall performance test for the SLAT ranged between 0 and 40. There were four similar problems (Nos. 1, 2, 3 and 4) and three transfer problems (Nos. 5, 6 and 7) with total score of 17 and 23 respectively. The reliability index using Cronbach's alpha coefficient was .57. This index was not an acceptable level based on Nunnally (1978) cut-off point of .70. However, according to Ary, Jacobs and Razavieh (1996), a lower reliability coefficient (in the range of .50 to .60) might be acceptable if the measurement results are to be used in making decisions about a group. Thus, the reliability of SLAT for this phase was reasonably acceptable.

For Phase II, the SLAT comprised 12 questions and the total test score was 60. The time allocated to do the test was one hour and 30 minutes. Similarly, for each problem solution one mark was allotted for each correct step in the solution. Problem solution for questions one to twelve had 4, 5, 4, 1, 5, 4, 2, 5, 9, 7, 8, and 6 steps respectively as indicated in the marking scheme. Thus, the overall performance test for the SLAT ranged between 0 and 60. There were five similar problems (Nos. 1, 2, 3, 6 and 8) and seven transfer problems (Nos. 4, 5, 7, 9, 10,11 and 12) with total score of 22 and 38 respectively. The computed index of reliability, α, for the SLAT was determined to be .68.

Finally, for Phase III, the SLAT comprised of 14 questions. The time allocated to do the test was one hour and 45 minutes. As experiments in Phases I and II, for each problem solution one mark was allotted for each correct step in the solution. Problem solution for questions one to thirteen had five steps while problem solution number fourteen had 10 steps. Thus, the overall performance test for the SLAT ranged between 0 and 75. There were seven similar problems (Nos.1, 5, 6, 9, 10, 11, and 12) and seven transfer problems (Nos. 2, 3, 4, 7, 8, 13 and 14) with total score of 35 and 40, respectively. The computed index of reliability for the SLAT was determined to be 0.82. This index was at an acceptable level based on Nunnally's (1978) cut-off point of 0.70. Thus, the reliability of SLAT for Phase III was considered sufficiently acceptable.

The PMER was used to measure cognitive load by recording the perceived mental effort expended in solving a problem in experiments of Phases II and III. 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). For each question in SLAT of Phases II and III, the PMER was printed at the end of the test paper. After each problem, students were required to indicate the amount of mental effort invested for that particular question by responding to the nine-point symmetrical scale. The computed indices of reliability for PMER in both phases were .87 and .91 respectively.

**Data Gathering and Data Analysis**

An exploratory data analysis was conducted for all the data collected in each phase. The total number of students taking part in Phase I was as follows: GC strategy group consisted of 21 students, whilst CI strategy group consists of 19 students. For Phase II, the GC strategy group consisted of 33 students, whilst the CI strategy group consisted of 32 students. For Phase III, the outliers were taken out. Thus the total number of students taking part in this phase was as follows: group 1 designated of students with average mathematics ability undergoing CI strategy consisted of 15 students; group 2 designated of students with average mathematics ability undergoing GC strategy consisted of 16 students, group 3 designated of students with low mathematics ability undergoing CI strategy consisted of 19 students, and group 4 designated of students with low mathematics ability undergoing GC strategy consisted of 20 students.

Students' performance was measured by the overall test performance, the number of problems solved for the test phase, the number of errors obtained during the test phase, the conceptual knowledge performance, the procedural knowledge performance, the number of similar problems solved during the test phase, the performance of similar problems, the number of transfer problems solved during the test phase, and the performance of transfer problems. The overall test performance in this study refers to students' overall achievement based on the Straight Lines Achievement Test (SLAT) score. Specifically, it shows the ability of students to demonstrate their understanding of mathematical concepts in Straight Lines topic learnt during the experimental period of time. The number of problems solved in this study refers to the total number of correct problems solved by students with maximum marks for each problem. In this study, a problem is considered to be a transfer problem if the solution of the problem uses the application of previous knowledge to solve a problem in a new situation, the validators classified them as transfer problems and the items are not similar to the acquisition and evaluation phase problems. Thus, the number of transfer problems solved in this study refers to the total correct transfer problems solved by students with maximum marks for each problem,

Further, there were two kinds of subjective ratings of mental effort taken during the experiments in Phases II and III. 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.

The 3-dimensional (3-D) instructional condition efficiency indices were also calculated using Tuovinen and Paas (2004) procedure and were taken into the analyses as dependent variables. The three dimensions namely the learning effort, test effort and test performance was taken into account when calculating these indices. In the computational approach, the three sets of data (learning effort, test effort and test performance) were converted to standardized *z* scores. Then, the 3-D efficiency index was computed using the formula, $E = (P - E_L - E_T)/\sqrt{3}$, 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. The greatest instructional condition efficiency would occur 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.

For Phases I and II, comparative analyses using independent samples t-tests were used to explain differences that existed between the means of dependent variables in the GC and CI strategy groups. Further, the planned comparisons were conducted in order to ascertain that the means of dependent variables for GC strategy group are significantly higher than those of CI instruction strategy groups.

Planned comparison was used as it is more sensitive in detecting differences based on Pallant (2001). In addition, all data for Phase III were analyzed using a two-way analysis of variance (2-way ANOVA) and followed by planned comparison tests.

## Results

This section presents the results of the analysis of quantitative data for all the phases. Phase I discusses the results of the effects of GC strategy and CI strategy on performance, while Phase II and III illustrate the results of the effects of GC strategy and CI strategy on performance, mental effort and 3-D instructional efficiency.

### Phase I

#### Effects of GC Strategy and CI Strategy on Performance

The means, and standard deviations of the variables analyzed and the results of the independent samples t-test and planned comparison analysis are provided in Table 1.

For Phase I, nine performance variables namely the overall test performance, the number of problems solved for the test phase, the numbers of errors obtained during the test phase, the conceptual knowledge performance, the procedural knowledge performance, the number of similar problems solved during the test phase, the similar problems performance, the number of transfer problems solved during the test phase, and the transfer problems performance were discussed. The overall performance test ranged between 0 and 40. Mean overall test performance of the GC strategy group was 16.81 (SD=4.76) while mean overall test performance of the CI strategy group was 12.53 (SD=4.99). An independent t-test analysis showed that the difference in the means were significant, $t(38)=2.78$, $p<.05$. The results indicated that there was a significant difference in the mean overall test performance in the learning of the Straight Lines topic between the GC strategy group and the CI strategy group. The magnitude of the differences in the means was considered large based on Cohen (1988) with eta squared=.17. The guidelines proposed by Cohen (1988) for interpreting this value are: .01 = small effect, .06 = moderate effect, .14 = large effect. Planned comparison test showed that the mean overall test performance of the GC strategy group is significantly higher than those of the CI strategy group, $F(1, 38)= 7.71$, $p<.05$. This finding indicated that the GC strategy group had performed significantly better for test phase than the CI strategy group.

The results also showed that there were significant differences in the mean for almost all other important performance variables such as the number of problems solved, the conceptual knowledge performance and similar problems performance with the exception for transfer problems performance. In addition, planned comparison showed that the mean for each variable for the GC strategy group was significantly higher than that of the CI strategy group. This indicated the superiority of the use of the graphing calculator in the learning of mathematics as compared to the conventional instruction.

**Table 1** Independent samples t-test and planned comparison test for performance in Phase I

| Performance | Group | N | M | SD | SEM | t | df | p | Planned Comparison |
|---|---|---|---|---|---|---|---|---|---|
| Overall test performance | GC Strategy | 21 | 16.81 | 4.76 | 1.04 | 2.78 | 38 | .008 | F(1, 38)= 7.71, p<.05 |
| | CI strategy | 19 | 12.53 | 4.99 | 1.15 | | | | |
| No. of problems solved | GC strategy | 21 | 2.19 | 1.12 | .25 | 2.10 | 38 | .043 | F(1,38)= 4.40, p<.05 |
| | CI strategy | 19 | 1.53 | .84 | .19 | | | | |
| No. of errors obtained | GC strategy | 21 | 4.31 | 1.82 | .40 | −1.20 | 38 | .239 | F(1,38)=1.44, p>.05 |
| | CI strategy | 19 | 4.99 | 1.76 | .40 | | | | |
| Conceptual knowledge performance | GC strategy | 21 | 7.71 | 2.43 | .53 | 3.11 | 38 | .004 | F(1,38) = 9.65, p<.05 |
| | CI strategy | 19 | 5.26 | 2.56 | .59 | | | | |
| Procedural knowledge performance | GC strategy | 21 | 9.10 | 3.40 | .74 | 1.69 | 38 | .100 | F(1,38)=2.86, p>.05 |
| | CI strategy | 19 | 7.26 | 3.46 | .79 | | | | |
| No. of similar problems solved | GC strategy | 21 | 1.48 | .75 | .16 | .95 | 38 | .346 | F(1,38)=1.44, p>.05. |
| | CI strategy | 19 | 1.26 | .65 | .15 | | | | |
| Similar problems performance | GC strategy | 21 | 9.67 | 2.01 | .44 | 2.32 | 38 | .026 | F(1,38)= 5.36, p<.05 |
| | CI strategy | 19 | 8.21 | 1.96 | .45 | | | | |
| No. of transfer problems solved | GC strategy | 21 | .71 | .85 | .18 | 2.01 | 35.03 | .053 | F(1,35.03) =3.88, p>.05 |
| | CI strategy | 19 | .26 | .56 | .13 | | | | |
| Transfer problems performance | GC strategy | 21 | 7.14 | 5.00 | 1.09 | 1.92 | 38 | .062 | F(1,38)=1.44, p>.05 |
| | CI strategy | 19 | 4.32 | 4.22 | .97 | | | | |

## Phase II

### Effects of GC Strategy and CI Strategy on Performance

Table 2 illustrates the means and standard deviations of the variables analyzed, the results of the independent samples t-test and the planned comparison analysis for Phase II. As can be seen from Table 2, mean overall test performance of the GC strategy group was 24.21 (SD=9.69) and mean overall test performance of CI strategy group was 17.75 (SD=10.54). Independent samples t-test results showed that there was a significant difference in mean overall test performance between GC strategy group and the CI strategy group, t(63)=2.57, p<.05. The magnitude of the differences in the means was moderate based on Cohen (1988) using eta squared =.64. Planned comparison test showed that the mean test performance of GC strategy group was significantly higher than those of CI strategy group, F(1, 63)= 6.60, p<.05. This suggested that the GC strategy group had performed significantly better for the test phase than the CI strategy group.

**Table 2** Independent samples t-test and planned comparison test for performance

| Performance | Group | N | M | SD | SEM | t | df | p | Planned Comparison |
|---|---|---|---|---|---|---|---|---|---|
| Overall test performance | GC strategy | 33 | 24.21 | 9.69 | 1.69 | 2.57 | 63 | .012 | F(1,63)=6.60, p<.05 |
| | CI strategy | 32 | 17.75 | 10.54 | 1.86 | | | | |
| No. of problems solved | GC strategy | 33 | 2.73 | 1.96 | .34 | 1.08 | 63 | .285 | F(1,63)= 1.17, p>.05 |
| | CI strategy | 32 | 2.22 | 1.85 | .33 | | | | |
| No. of errors obtained | GC strategy | 33 | 3.83 | 1.78 | .31 | −2.68 | 45.50 | .009 | F(1,45.50)=7.18, p<.05 |
| | CI strategy | 32 | 5.70 | 3.53 | .63 | | | | |
| Conceptual knowledge performance | GC strategy | 33 | 15.70 | 4.81 | .84 | 4.30 | 57.18 | .000 | F(1,57.18)=18.49, p<.05 |
| | CI strategy | 32 | 9.59 | 6.48 | 1.15 | | | | |
| Procedural knowledge performance | GC strategy | 33 | 8.18 | 5.58 | .97 | .02 | 63 | .984 | F(1,63)=.04, p>.05 |
| | CI strategy | 32 | 8.16 | 4.59 | .81 | | | | |
| Number of similar problems solved | GC strategy | 33 | .76 | 1.20 | .21 | −1.40 | 63 | .167 | F(1,63)=1.96, p>.05 |
| | CI strategy | 32 | 1.19 | 1.28 | .23 | | | | |
| Similar problems performance | GC strategy | 33 | 8.82 | 5.46 | .95 | −.62 | 63 | .536 | F(1,63)= .38, p>.05 |
| | CI strategy | 32 | 9.66 | 5.40 | .96 | | | | |
| Number of transfer problems solved | GC strategy | 33 | 2.12 | 1.22 | .21 | 3.95 | 63 | .000 | F(1,63)=15.60, p<.05 |
| | CI strategy | 32 | 1.06 | .91 | .16 | | | | |
| Transfer problems performance | GC strategy | 33 | 15.09 | 5.33 | .93 | .30 | 63 | .000 | F(1,63)=23.14, p<.05 |
| | CI strategy | 32 | 8.41 | 5.87 | 1.04 | | | | |

In addition, the results showed that there were significant differences in the mean for almost all other important performance variables such as the conceptual knowledge performance, the number of transfer problems solved and performance on transfer problems. Further, it was found that the means for the GC strategy group was significantly higher that of the CI strategy group. This confirmed that the integration of the use of the graphing calculator leads to better performance in the learning of the Straight Lines topic as compared to the conventional instruction.

**Effects of GC Strategy and CI Strategy on Mental Effort**

Table 3 provides the means, standard deviations and analyses of independent samples t-test on mean mental effort per problem during learning and test phase. As can be seen in Table 4, the GC strategy group (M = 2.93, SD=.78) had lower mean mental effort per problem during learning phase than the CI strategy group (M = 4.13, SD=.91). The result of an independent t-test showed there was a significant difference in the mean mental effort per problem, (t(63)=−5.72, p<.05) between the GC strategy and CI strategy group. The effect size was .34 using eta squared value which was large based on Cohen (1988). Planned comparison showed that the mean mental effort for CI strategy group was significantly higher than those of CI strategy group, F(1, 63)=32.72, p<.05. Thus finding indicated that the GC strategy group had expanded less mental effort per problem than that of the CI strategy group during learning phase.

In addition, it was also found that the GC strategy group (M=5.41, SD=1.45) had lower mean mental effort per problem for test phase than the CI strategy group (M=6.44, SD=1.27). The results of an independent t-test showed that there was a significant difference in the mean mental effort per problem, ($t(63)=-3.03$, $p<.05$) between the GC strategy and CI strategy groups. The effect size was .14 using eta squared value which was large based on Cohen (1988). Planned comparison tests showed that the mean mental effort per problem invested during test phase for CI strategy group was significantly higher from that of GC strategy group, $F(1, 63)=9.18$ , $p<.05$. This finding indicated that the use of GC strategy group had expanded less mental effort per problem than that of CI strategy group during test phase.

**Table 3** Independent samples t-test for mental effort

| Variables | Group | N | M | SD | SEM | t | df | p |
|---|---|---|---|---|---|---|---|---|
| Mental effort (Learning phase) | GC Strategy | 33 | 2.93 | .78 | .14 | -5.72 | 63 | .000 |
| | CI Strategy | 32 | 4.13 | .91 | .16 | | | |
| Mental effort (Test phase) | GC Strategy | 33 | 5.41 | 1.45 | .25 | -3.03 | 63 | .004 |
| | CI Strategy | 32 | 6.44 | 1.27 | .22 | | | |

**Effect of GC Strategy and CI Strategy on Instructional Efficiency**

Table 4 shows the independent samples t-test results for evaluating the hypotheses that the experimental and control groups differ significantly on measures of 3-D instructional condition efficiency index for phase II. The 3-D instructional efficiency indices as calculated for the experimental and control groups of experiment in this phase were 0.70 and −0.73 respectively. The results of an independent samples t-test showed that there was a significant difference in mean 3-D instructional condition efficiency index ($t(63)=4.46$, $p<.05$) between the GC strategy group and that of CI strategy group. The effect size was .34 using eta squared value which was large based on Cohen (1988). The planned comparison test on mean 3-D instructional condition efficiency index showed that the mean 3-D instructional condition efficiency index for GC strategy group was significantly higher than that of CI strategy group, $F(1, 63)=19.89$, $p<.05$. This finding indicated that learning by integrating the use of graphing calculators was more efficient than using CI strategy.

**Table 4** Independent samples t-test for 3-D instructional condition efficiency index

| Variables | Group | N | M | SD | SEM | t | df | p |
|---|---|---|---|---|---|---|---|---|
| 3-D instructional efficiency | GC Strategy | 33 | .70 | 1.31 | .23 | 4.46 | 63 | .000 |
| | CI Strategy | 32 | .73 | 1.28 | .23 | | | |

**Phase III**

**Effect of GC Strategy and CI Strategy on Performance**

For this phase, students' performance was measured by overall test performance only. The means and standard deviations for overall test performance as a function of the level of mathematics ability and type of instructional strategy are provided in Table 5. The multiple ANOVA performed on the mean overall test performance showed a significant main effect of level of mathematics ability ($F(1, 66)=65.23$, $p<.05$) with large effect size (partial eta squared=.50) based on Cohen (1988). Similarly, the main effect of type of instructional strategy also yielded a significant difference ($F(1, 66)=23.82$, $p<.05$) with large effect size (partial eta squared=.27). However, the interaction effect between mathematics ability and instructional strategy did not reach statistical significance ($F(1,66)=.87$, $p>.05$, partial eta squared=.01). About 58% of variance in test performance was predictable from both the independent variables and the interaction.

**Table 5** Means and standard deviations for overall test performance as a function of mathematics ability level and instructional strategy type

| Mathematic 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 |

Planned comparisons were further conducted to ascertain that the mean of GC strategy group were significantly higher than that of CI strategy group. As can be seen from Table 5, the GC strategy group (M=24.1 7, SD=8.51) had higher mean test performance than that of the CI strategy group (M=16.32, SD=9.58). The planned comparison showed that the mean test performance for GC strategy was significantly higher than that of CI strategy group, $F(1,68)=13.18$, $p<.05$. These results indicated that the GC strategy is significantly better than the CI strategy.

**Effects of GC Strategy and CI Strategy on Mental Effort**

As in Phase II, the subjective ratings of mental effort were also taken during learning in evaluation phase for each lesson and during test phase for this phase. The means, standard deviations for mental effort invested during the learning phase as a function of the level of mathematics ability and type of instructional strategy are provided in Table 6. The multiple ANOVA performed on mean amount of mental effort invested during the learning phase showed that the main effect of level of mathematics ability ($F(1,66)=2.52$, $p>.05$, partial eta squared=.04), and the interaction of mathematics ability level and instructional strategy type ($F(1,66)<1$, $P>.05$, partial eta squared< .01) were not significant. However, the main effect of instructional strategy type ($F(1,66)=4.46$, $p<.05$) was significant with small effect size (partial eta squared=.05). About 10.1% of variance in mean amount of mental effort invested was predictable from both the independent variables and the interaction. The results of planned comparison showed that the mental effort invested during learning phase for CI strategy was not significantly higher than that of GC strategy ($F(1,55.67)=4.08$, $p>.05$). This suggested that the GC strategy and the CI strategy group had more or less the same amount of mental effort invested during the learning phase.

**Table 6** Means and standard deviations for mean amount of mental effort during learning as a function of mathematics ability level and instructional strategy type

| Mathematic 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 |

The means and standard deviations for mental effort invested during the test phase as a function of the level of mathematics ability and type of instructional strategy, respectively, are provided in Table 7. The ANOVA performed on mean amount of mental effort invested during the test phase showed a significant main effect of level of mathematics ability ($F(1,66)=15.25$, $p<.05$, partial eta squared=.19). The main effect of instructional strategy type was also significant ($F(1,66)=41.66$, $p<.05$, partial eta squared=.39). In addition, there was also a significant interaction between mathematic ability levels and instructional strategy type ($F(1,66)=5.68$, $p<.05$, partial eta squared=.08). About 47.8% of variance in mean amount of mental effort invested was predictable for both the independent variables and the interaction.

Figure 1 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 the 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 a decrease of about 2.16 points (6.69 – 4.53) which is doubled the mean amount of mental effort than the low mathematics ability group which reported a decrease in mean amount of mental effort of about 7.06 – 6.06= 1.00 points.

Further planned comparison results showed that the mental effort invested during the test phase for CI strategy group was significantly higher than that of

GC strategy group (F(1,68)=30.25, p<.05) such that students in GC strategy had invested less mental effort during the test phase as compared to that students in CI strategy group. This finding suggested that the GC strategy had invested less mental effort during the test phase as compared to the CI strategy.

**Table 7** Means and standard deviations for mental load during test as a function of mathematics ability level and instructional strategy type

| 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 |

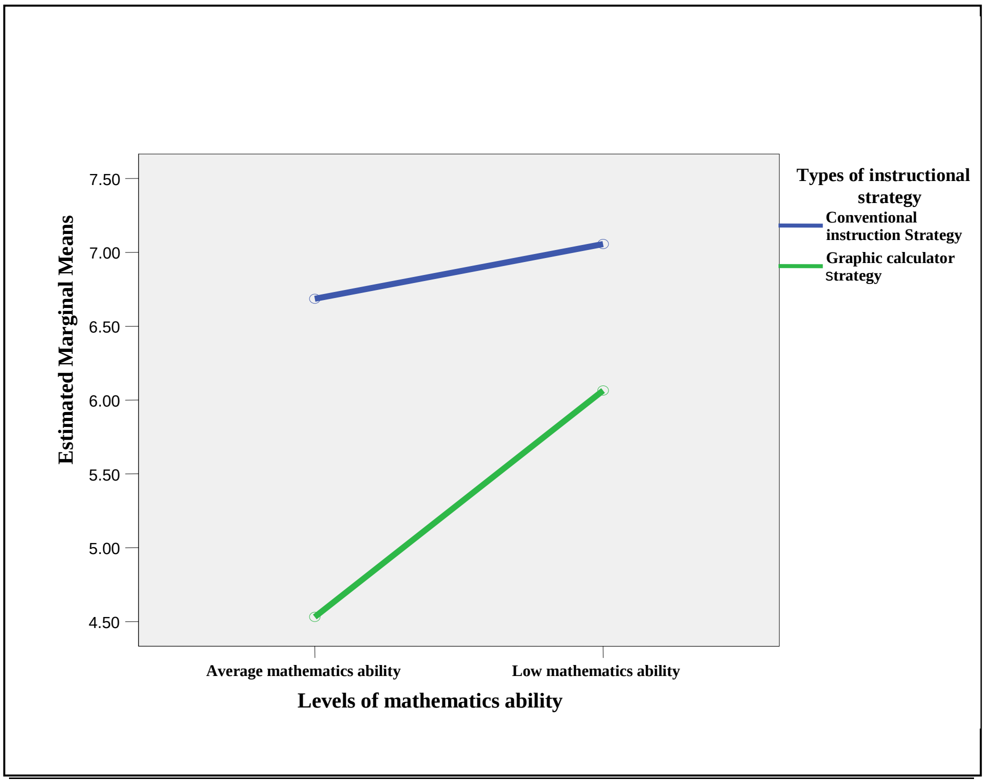


**Figure 1** Interaction between levels of mathematics ability and types of instructional strategy on mental effort during test phase

**Effects of GC Strategy and CI Strategy on 3-D Instructional Efficiency Index**

The means and standard deviations for 3-D instructional condition efficiency indices as a function of the level of mathematics ability and type of instructional strategy, respectively, are provided in Table 8. The multiple ANOVA performed on the 3-D instructional condition efficiency indices revealed a significant effect of mathematics ability level ($F(1,66)=31.59$, $p<.05$, partial eta squared=.32). The main effect of instructional strategy type was also significant ($F(1, 66)=33.40$, $p<.05$, partial eta squared=.34). However, the interaction between mathematics ability level and instructional strategy type was not significant ($F(1,66)=1.24$, $p>.05$, partial eta squared=.02). About 49.9% of variance in mean 3-D instructional condition efficiency index was predictable for both the independent variables and the interaction.

The planned comparison test on mean 3-D instructional condition efficiency index showed that the mean 3-D instructional condition efficiency index for GC strategy group was significantly higher than that of CI strategy group, $F(1,66)=22.37$, $p<.05$. This finding suggested that GC strategy was more efficient than CI strategy.

**Table 8** Mean and standard deviation for 3-D instructional condition 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 |

## Discussions

Past studies on effects of the use of graphing calculators produced different results. Generally the results have favoured the use of this technology in mathematics classroom (for example, Acelajado, 2004; Horton et al., 2004; Noraini Idris, 2004; Noraini Idris et al., 2002, 2003; Connors & Snook, 2001; Graham & Thomas, 2000; Hong et al., 2000; Adams, 1997; Smith & Shotberger, 1997; Quesada & Maxwell, 1994; Ruthven, 1990;). Those studies reported that the use of graphing calculators improved students' mathematics performance.

The findings from this study suggest that integrating the use of graphing calculators can reduce cognitive load and lead to better performance in learning in

'Straight Lines' topic at Form Four level. These findings also suggest an increase in instructional efficiency for both low and average mathematics ability groups. Overall findings from the second and third phases 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 on the effects GC strategy being more efficient as compared to 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 graphing 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 in Phases II and III. The qualitative data also provide evidence for the positive results. This interpretation is bolstered by students' in GC strategy group views that the graphing calculator usage helps them to understand the straight lines concept better with various graphing capabilities that help them draw accurate graphs, visualise graphs, save times and check the answers quickly. Hence the availability of graphing calculator, helps to facilitate them in solving the Straight Lines problems.

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 Phase I showed that the difference were not significant in several instances that involved important performance variables particularly the transfer problems performance. 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 graphing calculator may have interfered with learning of content (for example, Wilson & Naiman, 2004; Upshaw, 1994; Giamati, 1991). However, in this study for Phases II and III, the treatments were conducted for about six weeks and the findings were in favour of the GC strategy. More importantly, the GC strategy group solved higher number of transfer problems and performed better on transfer problems performance as compared to the control group that executed the CI strategy. Such findings suggest that the GC strategy group have acquired effective schemas that enabled transfer to be enhanced (Gick & Holyoak, 1983).

The findings of Phases II and III also suggest that the GC strategy group possibly may not have split attention effect with the use of worksheet (for graphing calculator instructions) and the graphing calculator screen. The results showed that if the split attention effect exists, its negative consequence far outweighs the reduction in cognitive load. In both phases, students in GC strategy group were found to be sufficiently proficient enough in using the graphing calculator because apart from having the pre-experiment training of introducing the graphing calculator and learning how to use the graphing calculator, they had longer duration of intervention. Thus, this explanation confirms the results for Phase I such that the difference were not significant in the transfer problems performance that could be due to any advantage of using graphing calculator which was negated by the split attention effect. This was further noted from findings of qualitative data Phase I such that this interpretation is bolstered by students' comments, as they don't have enough time to learn the different function keys of the graphing calculator, claimed that the keys on graphing calculator are difficult to remember, and many steps to follow in the instructions of using graphing calculator.

Hence, it is significant to note that if students who had hardly knew how to use the graphing 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 were proficient with the use of graphing calculator had been selected in this phase.

Another important finding in this study (specifically, Phase III) was that both factors, mathematics ability and instructional strategy, separately influence the test performance, the mental effort invested during learning and the 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 the 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.

The findings of this study further support the contention of the distributed cognition perspective in realising the potential of graphing calculator as an intelligent technology. From this perspective, the graphing calculator as an intelligent technology offloads part of the cognitive process as a result of distribution of cognition (Pea, 1985). For example, graphing calculators were used by students such as to plot quickly and accurately several straight line graphs of the form $y = mx + c$ to identify the properties of changing the values of $m$ and $c$, a task that without graphing technology was non-trivial and requires a considerable amount of mental effort for most students as compared to students in the CI strategy group. Hence, this benefited the GS strategy group to focus more attention on conceptual knowledge and work on application problems. These were evident from the significantly lower levels of cognitive load reported and significantly higher conceptual knowledge performance and transfer problems performance by the GC strategy group for Phases II and III.

The findings from this study also indicate that there is sufficient empirical evidence of the pedagogic potential of the graphing calculator from the perspective of how a student might interact with the graphing calculator when involves in mathematics activities. The GC strategy group showed better test performance as compared to the CI strategy group in all phases, specifically for conceptual knowledge performance and transfer problems performance as presented in the results for Phases II and III. This may probably be due to the effect on mathematical ability when students are working in partnership with the graphing calculators and effect on mathematical ability when students are working without the aid of graphing calculators but where the technology has been used in the instruction. In addition, the qualitative data provide a possible explanation for the results. Students in the GC strategy group explained that the graphing calculator usage help them to understand the straight lines concept better. They claimed that they could draw graphs accurately in many ways, visualise the graphs drawn, and hence facilitate them in solving straight line problems. A few students noted that integrating the use of graphing calculator in learning of Straight Lines topic also help students to increase thinking memory, developed mathematical ability, produced ambitious students in future, and they needed less mental effort in learning.

It is also pertinent to note that the findings of this study also showed that the GC strategy group had better conceptual knowledge performance as compared to CI strategy group and most important they did not lose procedural knowledge skills. These findings were in accordance with Barton's (2000) meta-analysis study which suggests that when graphing technologies were used appropriately they did assist in increasing conceptual knowledge without adversely affecting procedural knowledge. However, she also noted that simply having access to technology did not ensure that it would be used to enhance learning.

## Practical Implications

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

Using graphing calculators in learning mathematics make less cognitive demand (reduction of cognitive load) because a larger part of the cognitive process is taken over by the graphing 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 graphing 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 basis" as suggested by Waits and Demana (2000a, 2000b) with teacher guidance was used for the graphing calculator strategy group. The results of this study showed that the graphing 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" (National Council of Teachers of Mathematics, 1999). Students will not lose their ability to think if they were to use the graphing 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 implies that the balanced approach that make the best use of graphing technology in teaching and learning Straight Lines topic enables the development of students' understanding of mathematical concepts without loosing the procedural knowledge.

From the findings of the study, the graphing calculator strategy group was generally found to be sufficiently proficient in graphing calculator use. The results also showed that if the split attention effect exists, its negative consequences far outweigh 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 graphing calculator had been selected. The results on performance might have been further magnified if students very proficient with the use of graphing calculator had been selected. Based on these findings, another important implication for integrating the use of graphing calculator is that the graphing calculator technology should be learnt 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

The findings from this study reaffirm Sweller's (1994, 1999) contention that the limited capacity of working memory is a very important factor to consider when planning instructions. 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 graphing 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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