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INSTRUCTIONAL EFFICIENCY OF THE INTEGRATION OF GRAPHING CALCULATORS IN TEACHING AND LEARNING MATHEMATICS

Nor'ain Mohd Tajuddin, Rohani Ahmad Tarmizi, Mohd Majid Konting & Wan Zah Wan Ali
Institute for Mathematical Research, University Putra Malaysia, Malaysia
rht@educ.upm.edu.my

This quasi-experimental study with non-equivalent control group post-test only design was conducted to investigate the effects of using graphing calculators in mathematics teaching and learning on Form Four Malaysian secondary school students' performance and their meta-cognitive awareness level. Graphing calculator strategy refers to the use of TI-83 Plus graphing calculator in teaching and learning of Straight Lines topic. The experimental group underwent learning using graphing calculator while the control group underwent learning using conventional instruction. Three instruments were used in this study namely, Straight Lines Achievement Test, Paas Mental Effort Rating Scale and Meta-cognitive Awareness Survey. The data were analysed using independent t-test and planned comparison test. The findings indicated that the graphing calculators' instruction enhanced students' performance and induced higher levels of meta-cognitive awareness among students. Less mental effort were invested during the learning and test phases and hence increased 3-dimensional instructional efficiency index in learning of Straight Lines topic. Hence it can be implied that integrating the use of graphing calculators in teaching and learning of mathematics was more efficient than the conventional instruction strategy. Even though some students experience difficulties in using graphing calculators initially during learning, they responded overwhelmingly that graphing calculators improves their understanding of the Straight Lines topic. Hence, the usage of the graphing calculator lends as an effective strategy in teaching and learning of mathematics.

Key Words: graphing calculators, instructional efficiency, mathematical learning

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 that can survive in today's society of technology. This requires highly skilled workers with the ability to apply their mathematical knowledge which includes and goes beyond the simple skills of solving mundane 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. In addition, the NCTM (2000) emphasized understanding of mathematics and technology used in mathematical teaching and learning. In fact, 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, mathematical problem solving and the integration of technology during teaching.

In reality, the hand-held technology, specifically the graphing calculator represents the direction of the pedagogical future (Kissane, 2000). The availability and accessibility to students at all time and the portability of graphing calculators with the capabilities to graph functions and relations, manipulate symbolic expressions, and perform high precision numerical integration and root findings of functions enables a more realistic mathematics lesson to take place. Further, because of many advantages, the graphing calculators 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 calculators.

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

Recently, there has been a steady increase in the use of hand-held technologies, in particular the graphing calculators. Generally, this tool has gained widespread acceptance as a powerful tool for learning mathematics. However, the maximum potential for this technology has not been explored (Kastberg & Leatheam, 2005). Technology explosion has inspired various methodologies for the purpose of effective teaching and learning in general and specifically in mathematics. In Malaysia, teachers are encouraged to use the latest technology to help students understand mathematical concepts in depth and to enable them to explore mathematical ideas (Curriculum Development Centre, 2005). This emphasis is congruent with the NCTM's Technological Principle which states that, "Technology is essential in teaching and learning mathematics, it influences the mathematics that is taught and enhances students' learning" (NCTM, 2000, p. 24).

There are many kinds of technology that are considered relevant to school mathematics which ranged from very powerful computer software such as Mathematica, Maple, and MathLab to much powerless technologies. For example, based on the Mathematics Curriculum Specification of Integrated Curriculum for Secondary School, the use of technology such as calculators, computers, educational software, websites in the Internet and relevant learning packages was highlighted as tools that can help to upgrade the pedagogical approach and thus promote the understanding of mathematical concepts in teaching and learning (Kementerian Pendidikan Malaysia, 2004). In addition, the application of these teaching resources will also help students absorb ideas, be creative, feel confident and be able to work independently or in group.

Related Learning Theories

The positive effects of the integration and the use of graphing calculators in the teaching and learning process of mathematics can be understood by explaining and illustrating the theories of cognitive load, distributed cognition and constructivism in relation to this tool. All theories provide a basis for the theoretical and conceptual framework of the study.

Cognitive Load Theory

Cognitive load theory (CLT) (Sweller, 2004; 1988, Paas, Renkl & Sweller, 2003a) focuses on the role of working memory in the development of instructional methods. Specifically, CLT emphasise 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.

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 (Tarmizi & Sweller, 1988).

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., 2003a). Therefore, many of these methods involve extraneous activities that are unrelated to the acquisition of schemas and rule automation. In addition, 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. Hence, it was hypothesised 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 meta-cognitive awareness levels while solving mathematical problems.

Distributed Cognition Theory

The distributed cognition theory claims that cognition is better understood as a distributed phenomenon: one that goes beyond the boundaries of a person but to include environment, artifacts, social interactions, and culture (Hutchin & Hollan, 1999). Briefly, cognitive process in the distributed cognition theory is viewed as a system which comprise of the individual, the whole learning context and multiple relationships between them (Dofler, 1993). It means the system consist of the subject and the cognitive tools. The system explains how the knowledge within the environment, culture and social interaction are represented; how the knowledge between different individuals and artifacts are transmitted; and how the external structures are transmitted when acted on by individuals and artifacts (Flor & Hutchin, 1991). Further, the system strives to educate one on how to use tools in an appropriate organised manner to achieve learning goals.

The distributed phenomenon perspective is adopted to explain cognitive effects when using technology (Jones, 2000; Salomon, Perkins & Globerson, 1992). It is the effect obtained during intellectual partnership with the technology, and the transferable cognitive residue that this partnership leaves behind. These are in the form of better mastery of skills and strategies. Some researchers view that the effect of technology is that "intelligent" technology "offloads" part of the cognitive process as a result of distributions of cognition. Further, this will allow users to focus on cognitive resources elsewhere (Salomon et al., 1992). They also believe that over time the users will develop cognitive skills to accomplish many of the cognitive processes demonstrated when using technology and would be capable of demonstrating these skills without requiring the aid of technology any longer.

The distributed cognition approach is a viable framework to understand the relationships and interactions between them. It can ease the cognition burden and enable performance. Therefore, distributed cognition perspectives provide the reason why the use of graphic calculator will not impede learning of mathematics.

Constructivist Learning Theory

Constructivist learning theory offers a sharp contrast to the traditional instruction which is based on the transmission or absorption view of teaching and learning. Typically, the traditional approach would firstly involve a teacher's model through the completion of several examples and then handed over to students to attempt to repeat the same procedure demonstrated. From the constructivist perspective, learners are actively involved in the construction of their own knowledge, rather than in passively receiving knowledge (Bruning, Schraw, Norby & Ronning, 2004; Shelly, Cashman, Gunter & Gunter, 2004). In the situation where learners are in control of elements in the learning environment, learning results are higher (Mayer & Moreno, 2002). For mathematic education, this constructivist perspective of learning is extremely appealing because having the learner construct his or her own understanding is very conducive to build strong problem solving skills.

For many educators, the increased availability of technology revolutionised the arts of teaching mathematics and statistics (Cobb & Moore, 1997). Traditional perspective which focused on building mechanical skills could be handled with the availability of technology. Orton (1992) suggested that the calculator can be used in an exploratory and investigatory way to help students in constructing their own understanding of arithmetic. In addition, graphic calculator usage enables students to concentrate on acquiring a deeper conceptual knowledge of mathematics. Thus, this study integrates the use of graphic calculator in mathematics teaching and learning. The graphic calculator strategy is designed in accordance with this view of constructivist learning theory. With teacher guided instructions that foster teacher-students interaction, students will use the graphic calculator to explore their own ideas and to be involved in discovering and validating the mathematical concepts. Students are no longer passive absorbers of information but constructivist participants in learning as they acquire new knowledge with the use of the graphic calculator.

Use of Graphing Calculators

In Malaysia, calculators were strictly prohibited at both the primary and lower secondary levels before the year 2002. However, in 2002, usage of calculator was introduced for Form Two and Three students in lower secondary mathematics curriculum (Kementerian Pendidikan Malaysia, 2002). Currently, the usage of calculators is still prohibited in the primary grades while the usage of scientific calculators is prohibited in Form One. The latest reform in the Malaysian Secondary School Integrated Mathematics Curriculum calls for the need to integrate information technology in teaching and learning of mathematics. In response to this call, mathematics teachers and students are now encouraged to use scientific and graphing calculators in the upper secondary mathematics classroom. Moreover, currently, scientific calculators are already allowed to be used at the Malaysian Certificate of Education examination level (Kementerian Pendidikan Malaysia, 2002).

The use of graphing calculators in teaching and learning enable various kinds of guided explorations to be undertaken. For example, students can investigate the effects of changing parameters of a function on the shape of its graph. They can also explore the relationships between gradients of pairs of lines and the lines themselves. These activities would have been too difficult to attempt without technology. Exploratory activity in mathematics may facilitate an active approach to learning as opposed to a passive approach where students just sit back passively listening to the teacher. This creates an enthusiastic learning environment. This clearly shows the application of constructivist learning environment.

Graphing calculators also offer a method of performing computations and algebraic manipulations that is more efficient and precise than paper-and-pencil method alone (Waits & Demana, 2000). Examples include finding the solutions of simultaneous equations or determine the equation of a straight line that is passing through two points. The mathematical concepts underpinning those procedures are rich and important for understanding. However, students often seem to put more effort in calculation and correspondingly less to making sense of the problems. Both attention to concepts and skill would be desirable in mathematics learning. Rather than just the development of mechanical and computational skills, graphing calculators also allow for cultivation of analytical adeptness and proficiency in complex thought process (Pomerantz, 1997). Problems representing real-world situation and data with complicated numbers can also be addressed. This would offer new opportunities for students to encounter mathematical ideas not in the curriculum at present. With appropriate use of graphing calculator, students can avoid time-consuming, tedious procedures and devote a great deal of time concentrating on understanding concepts, developing higher order thinking skills, and learning relevant applications. Jones (2000) argued that when students work with graphing calculator, they have potential to form an intelligent partnership, as graphing calculator can undertake significant cognitive processing on behalf of the user. This argument is in line with the distributed cognition and cognitive load theories. Distribution of cognition such that the larger part of cognitive process is taken over by the use of graphing calculators thus allowing learners to focus more on problem solving. From the cognitive load perspective, the focus of learning is to acquire problem solving schema rather than to acquire automation of mental arithmetic per se that distracts the real aim of problem solving. The distracting activities might exhaust learners' mental resources such that these activities will impose extraneous cognitive load and hence will be detrimental for learning. Therefore, instructional strategy that integrates the use of graphing calculator seems logical to reduce extraneous and increase germane cognitive load. This is because, as a result of distribution of cognition, graphing calculator offloads part of the cognitive process that reduces extraneous cognitive load, and this allows the learners to focus on more processing tool relevant for learning. The tool will help free the mental resources to enable them to acquire the necessary schemas and automation, or in other words the strategy simultaneously increases the germane cognitive load.

METHOD

Purpose of the Study

The purpose of this study is to investigate the effects of using graphing calculators in mathematics teaching and learning on performance and meta-cognitive awareness 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, meta-cognitive awareness, mental load and instructional efficiency.

The research hypotheses were:

1. There is significant difference in the mean overall test performance in the learning of Straight Lines topic between the GC strategy group and the CI strategy group.

2. There is significant difference in the mean conceptual knowledge performance during the test phase in the learning of Straight Lines topic between the GC strategy group and the CI strategy group.

3. There is significant difference in the mean procedural knowledge performance during the test phase in the learning of Straight Lines topic between the GC strategy group and the CI strategy group.

4. There is significant difference in the mean performance on solving similar problems during the test phase in the learning of Straight Lines topic between the GC strategy group and the CI strategy group.

5. There is significant difference in the mean performance on solving transfer problems during the test phase in the learning of Straight Lines topic between the GC strategy group and the CI strategy group.

6. There is significant difference in the mean overall level of students' meta-cognitive awareness, cognitive strategy subscale, planning subscale and self-checking subscale while solving problems related to the Straight Lines topic between the GC strategy group and the CI strategy group.

7. There is significant difference in the mean mental effort per problem invested during the test phase in the learning of Straight Lines topic between the GC strategy group and the CI strategy group.

8. There is significant difference in the mean instructional efficiency index in the learning of Straight Lines topic between the GC strategy group and the CI strategy group.

Methodology of the Study

This study focused on the effects of integrating the use of graphing calculator strategy (GCS) and using conventional instruction strategy (CIS) in the teaching and learning of mathematics on Form Four secondary schools students on measures of mathematics performance and meta-cognitive awareness. Thus, the experimental design is considered most apt for this purpose. It is important to note that only experimental data can conclusively establish cause-and-effect relationships (Gay & Airasian, 2003).

This quasi-experimental design fulfils the criterion of a strong experimental design whereby there must be at least two comparison groups: one treatment group and one control group. The purpose of having different experimental and control groups is to control any confounding extraneous variables that will threaten the internal validity of the design. Even though the quasi-experimental design does not provide full control, Campbell and Stanley (1963) state that the quasi-experimental studies are "well worth employing where more efficient probes are unavailable" (p. 205). Further, these designs permit one to reach reasonable cause and effect of the intervention provided on the investigated variables conclusion (Ary, Jacob & Razavieh, 1996). In addition, another advantage of this design is that since classes are selected "as is", possible effects from reactive arrangements are minimised (Gay & Airasian, 2003).

The quasi-experimental non-equivalent control-group post-test only design (Creswell, 2002; Cook & Campbell, 1979) was employed. Figure 1 shows the diagrammatic representation of the non-equivalent control-group post-test only design. An X indicates an experimental treatment, and a "dash" indicates no experimental treatment. The Os indicate the measurements made during the post-test.

Figure 1. Non-equivalent Control-Group Post test Only Design

Group	*Treatment*	*Post test Measures*
Experimental	X	O
Control	-	O

In this study, well-designed activities integrating the use of the TI-83 Plus graphing calculators were prepared as modular lessons. These modular lessons were used by the experimental group teacher in helping the students to build mathematical understanding. On the other hand the conventional instruction strategy was a whole-class instruction. Students were not allowed to use the TI-83 Plus graphing calculator.

Variables Studied

The overall test performance refers to students' overall achievement based on the Straight Lines Achievement Test (SLAT) score which indicated the students' ability to demonstrate their understanding of mathematical concepts in Straight Lines topic learnt during the experimental period of time. The mathematical concepts that will be tested in the SLAT include the concept of the gradient of a straight line, the concept of the gradient of the straight line in Cartesian Coordinates, the concept of intercept, the concept of the equation of a straight line, and the concept of parallel lines.

The conceptual knowledge performance were students' performance in interpreting, explaining, and applying mathematical concepts in Straight Lines topic to a variety of situations and translate between verbal statements and mathematical expressions. Evidence is communicated through making connection between the problem situation, relevant information, appropriate mathematical concepts and logical or reasonable responses.

On the other hand, the procedural knowledge performance is the ability of students to solve mathematical problems which requires algorithm-based method. Evidence includes the verifying and justifying of a procedure using concrete models, or the modifying of procedures to deal with factors inherent in the problem.

Meta-cognitive awareness refers to how often students think or feel or do or demonstrate an awareness of their ability to monitor their own thought while working on tasks or mathematics problems (Flavell, 1976). Thus, levels of students' awareness were measured on three meta-cognitive subscales namely, planning, cognitive strategy and self-checking while solving Straight Lines problems. This instrument comprised of 33 items based on the three subscales. Examples of items are as follows. Planning: "I made sure I understood what had to be done when I have to determine the gradient of a straight line passing two points in Cartesian coordinates"; Cognitive strategy: "I used an appropriate formula to determine the gradient of a straight line passing through two points in Cartesian coordinates; Self-checking: "I corrected my errors if I used the wrong formula in determining the gradient of a straight line passing through two points in Cartesian coordinates".

Mental effort can be considered to reflect the actual cognitive load which refers to the cognitive capacity that is actually allocated to accommodate the demands imposed by the task (Paas, Tuovinen, Tabbers & van Gerven, 2003, Sweller et. al., 1998; Paas & van Merrienboer, 1994). According to Pass et al. (2003b), mental effort can be considered to reflect the actual cognitive load. In this study, mental effort will be measured by a rating scale technique. The nine-point symmetrical rating-scale, ranging from very, very low mental effort (1) to very, very high mental effort (9), designed by Pass and van Merrienboer (1994) and Pass (1992) was used in this study. Subjects were asked to report their invested mental effort on a nine-point symmetrical category scale by translating the perceived amount of mental effort into the numerical value, 1 to 9. The intensity of effort being expended by subjects can be considered the essence of a reliable estimate of cognitive load (Paas & van Merrienboer, 1994).

Instructional efficiency is a diagnostic instrument to identify and differentiate the efficiency of instructional conditions. It is measured by the 3-dimensional (3-D) instructional efficiency, which combines the measures of learning effort, test effort and test performance. The approach used to achieve the desired three factors combination was adopted from Tuovinen and Paas (2004), which was an extension of the original formulation by Paas and van Merrienboer (1993) method. The 3-D Efficiency is calculated using the following formula:

$$\text{3-D Efficiency} = \frac{P - E_L - E_T}{\sqrt{3}},$$

where P = performance, E_L = learning effort, and E_T = test effort.

RESULTS

The subjects for this experiment were 99 students from four intact classes of Form Four in one randomly selected school in the Alor Gajah District in Malacca. Two classes were randomly assigned to be the GC strategy groups and the other two were assigned to be the CI strategy groups. The GC strategy groups comprised of 41 students, 14 boys and 27 girls, while the control groups comprised of 58 students, 28 boys and 30 girls. However, during the post-test a few students from both groups had to participate in co-curricular activities and also a few of them were absent from school. Hence, a total of 33 students in the GC strategy group and 32 students in the CI strategy group took the post-test.

Performance measures

The means and standard deviations of the overall test performance for both the GC and the CI strategy groups were presented in Table 1 below. The mean overall test performance of GC strategy group was 24.21 (SD=9.69) while the mean for the CI strategy group was 17.75 (SD=10.54). An independent t-test analysis showed that the difference in the means was significant, t(63)=2.57, *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 means was considered moderate based on Cohen (1988) with eta-squared =.09. Further, planned comparison test showed that the mean overall test performance of the GC strategy group was significantly higher than those of the CI strategy group, F(1,63)=6.60, *p*<.05. This finding suggested that the GC strategy group had performed significantly better for the test phase than the CI strategy group.

Table 1. Means, standard deviations for overall test performance

	Group	*n*	*M*	*SD*	*SEM*	*t*	*df*	*p*
Overall test performance	GC strategy	33	24.21	9.69	1.69	2.57	63	.012
	CI strategy	32	17.75	10.54	1.86			

Table 2 illustrates further analyses. Based on the conceptual knowledge performance for both the GC and the CI strategy groups, the GC strategy group obtained a mean score of 15.70 (SD=4.81) while that the CI strategy group obtained a mean score of 9.59 (SD=6.48). It is to be noted that Levene's test indicated that the assumption for equal variance has been violated, F= 4.51, $p<.05$. Therefore the reading for the output for the independent t-test is based on the reading for equal variance not assumed. An independent t-test showed the difference in means was significant, t(57.18)=4.30, $p<.05$. The effect size was .23 using eta-squared value which was large based on Cohen (1988). Further, planned comparison test showed that the mean conceptual knowledge performance of the GC strategy group was significantly higher than those of the CI strategy group, F(1,57.18)=18.49, $p<.05$. This finding suggested that the GC strategy group had performed better on the conceptual knowledge performance than the CI strategy group.

The means and standard deviations of procedural knowledge performance for both the GC and the CI strategy groups are illustrated in Table 2. The mean procedural knowledge performance of the GC strategy group was 8.18 (SD=5.58) while that of the CI strategy group was 8.16 (SD=4.59). An independent t-test showed that the difference in means was not significant, t(63)=.02, $p>.05$. This finding suggested that the GC strategy group performed as well as the CI strategy group on the procedural knowledge performance.

Findings from Table 2 indicated that the mean performance on solving similar problems of the GC strategy group was 8.82 (SD=5.46) while that of the CI strategy group was 9.66 (SD=5.40). An independent t-test showed the difference in the means was not significant, t (63)=−.62, $p>.05$. The results showed that there was no significant difference in the mean performance on similar problems during the test phase in the learning of the Straight Lines topic between the GC strategy group and the CI strategy group. The effect size was .006 using eta-squared value which was considered very small based on Cohen (1988).

Table 2. Means, standard deviations, independent sample t-test results

	Group	*n*	*M*	*SD*	*SEM*	*t*	*df*	*p*
Conceptual knowledge performance	GC	33	15.70	4.81	.84	4.30	57.18	.000
	CI	32	9.59	6.48	1.15			
Procedural knowledge performance	GC	33	8.18	5.58	.97	.02	63	.984
	CI	32	8.16	4.59	.81			
Similar problems performance	GC	33	8.82	5.46	.95	−.62	63	.536
	CI	32	9.66	5.40	.96			
Transfer problems performance	GC	33	15.09	5.33	.93	.30	63	.000
	CI	32	8.41	5.87	1.04			

Table above illustrates the mean performance on solving transfer problems of the GC strategy group which was 15.09 (SD=5.33) while that of the CI strategy group was 8.41 (SD=5.87). An independent t-test showed that the difference in the means was significant, t (63)=4.81, $p<.05$. The results showed that there was a significant difference in the mean performance on solving transfer problems during test phase in the learning of the Straight Lines topic between the GC strategy group and the CI strategy group. An eta-squared obtained was .27 where the magnitude of difference between the two means was considered large based on Cohen (1988). Further, planned comparison test showed that the mean performance on solving transfer problems of the GC strategy group was significantly higher than those of the CI strategy group, F (1,63)=23.14, $p<.05$. This finding indicated that the GC strategy group had performed better on solving transfer problems during the test phase as compared to the CI strategy group.

Meta-cognitive Awareness Level

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

The mean of each item for the GC strategy group ranged from 2.06 (SD=.79) to 3.12 (SD=.70) while the CI strategy group ranged from 2.00 (SD=.80) to 2.97 (SD=.90). This showed that both group scored above moderate level of meta-cognitive awareness. The total score of each subscale for the GC strategy group ranged from 2.59 (SD=.41) to 2.66 (SD=.44) whereas the CI strategy group ranged from 2.34 (SD=.40) to 2.54 (SD=2.54). The GC strategy group obtained the highest mean score for the cognitive strategy subscale whilst the CI strategy group scored highest for the planning subscale. This indicates that the two groups differ in their meta-cognitive awareness.

As shown in Table 3, the overall mean level of students' meta-cognitive awareness of the GC strategy group was 2.63 (SD=.40) while the CI strategy group was 2.44 (SD=.37). An independent t-test revealed that the difference in means was significant, t(63)=2.05, $p<.05$. Results showed that there was a significant difference in the mean level of students' meta-cognitive awareness between the GC strategy group and the CI strategy group. The effect size for the treatment was .06 using eta-squared value which was considered moderate based on Cohen (1988). Further, planned comparison test showed that the mean level of students' meta-cognitive awareness of the GC strategy group was significantly higher than those of the CI strategy group, F (1,63)=4.22, $p<.05$. This finding indicated that the GC strategy group had better level of meta-cognitive awareness while solving problem related to the Straight Lines topic as compared to that of CI strategy group.

Table 3. Means, standard deviations of students' meta-cognitive awareness

	Group	*n*	*M*	*SD*	*SEM*	*t*	*df*	*p*
Overall meta-cognitive awareness	GC strategy	33	2.63	.40	.07	2.05	63	.044
	CI strategy	32	2.44	.37	.07			

Table 4 showed that the mean score for cognitive strategy subscale for the GC strategy group which ranged from 2.24 (SD=.83) to 3.12 (SD=.70) while that of the CI strategy group ranged from 2.00 (SD=.80) to 2.97 (SD=.90). The mean level of students' meta-cognitive awareness for cognitive strategy subscale of the GC strategy group was 2.66 (SD=.44) while that of the CI strategy group was 2.43 (SD=.45). An independent t-test further showed the difference in the means was significant, t (63)=2.10, $p<.05$. The effect size for the treatment was .07 using eta-squared value which was moderate based on Cohen (1988). Further, planned comparison test showed that the mean level of students' meta-cognitive awareness for cognitive strategy subscale for GC strategy group was significantly higher than those of the CI strategy group (F (1,63)=4.40, $p<.05$). These findings indicated that the use of graphing calculator induced higher level of meta-cognitive awareness for cognitive strategy subscale while solving problems related to the Straight Lines topic than that of the conventional instruction.

Table 4. Comparison of three meta-cognitive subscales

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

Both groups scored above moderate meta-cognitive awareness level of planning subscale. The mean level of students' meta-cognitive awareness for planning subscale of the GC strategy group was 2.65 (SD=.44) while the CI strategy group was 2.54 (SD=.37). From the analysis of an independent t-test, it was found that the difference in the means was not significant, t (63)=1.12, p>.05. Results showed that there was no significant difference in the mean level of students' meta-cognitive awareness for planning subscale between the GC strategy group and the CI strategy group. The effect size for the treatment was .02 using eta-squared value which was small based on Cohen (1988). This indicated that only 2% of the variance of planning subscale was accounted for by the strategy imposed on the group.

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

Mental effort and instructional efficiency

As shown in Table 5 the mean mental effort per problem invested during learning phase of GC strategy group was 2.93 (SD=.78) while mean mental effort per problem during invested learning phase of CI strategy group was 4.13 (SD=.91). An independent t-test showed that the difference in means was significant, t(63)=−5.72, $p<.05$. The results showed that there was a significant difference in the mean mental effort per problem invested during the learning phase between the GC strategy group and the CI strategy group. The effect size of the GC strategy group as compared to the CI strategy group was .34 using eta-squared value which was large based on Cohen (1988). Planned comparison test showed that the mean mental effort per problem invested during learning phase for CI strategy group was significantly higher than those of the GC strategy group, F(1,63)=32.72, $p<.05$. This finding indicated that the GC strategy group had expanded less mental effort per problem than that of the CI strategy group during learning phase.

Table 5. Comparison of mental effort and instructional efficiency

	Group	*n*	*M*	*SD*	*SEM*	*t*	*df*	*p*
Mental effort	GC	33	2.93	.78	.14	−5.72	63	.000
	CI	32	4.13	.91	.16			
3-D instructional efficiency	GC	33	.70	1.31	.23	4.46	63	.000
	CI	32	.73	1.28	.23			

Instructional efficiency measures were calculated using Tuovinen and Paas (2004) procedure of 3-Dimensional instructional efficiency index. It is an extension of the original Paas and van Merrienboer (1993), 2-dimensional instructional efficiency. According to Tuovinen and Paas (2004), the 3-D instructional condition efficiency takes into account the three dimensions: learning effort, test effort and test performance.

The means and standard deviations of the instructional condition efficiency index for both the GC and the CI strategy groups were shown in Table 5. The mean instructional efficiency index of GC strategy group was .70 (SD=1.31) while mean instructional efficiency index of the CI strategy group was −.73 (SD=1.28). Analysis of an independent t-test showed that the difference in mean was significant, t (63)=4.46, $p<.05$. The effect size was .34 using eta-squared value which was large based on Cohen (1988). Planned comparison test showed that the mean 3-D instructional efficiency index for the GC strategy group was significantly higher than those of the CI strategy group, F (1,63)=19.89, $p<.05$. These findings confirmed that learning by integrating the use of graphing calculators was more efficient than learning using CI strategy.

CONCLUSION AND DISCUSSION

In summary, the results showed that there were significant differences in the mean for almost all important performance variables such as the overall test performance, 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 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.

It was also found that the GC strategy group obtained better level of meta-cognitive awareness than the CI strategy group. This suggested that the instruction using the graphing calculators induced better meta-cognitive awareness as compared to conventional instruction.

The results also revealed that the GC strategy group had invested less mental effort per problem during the learning and the test phases. This suggested that the instruction using graphing calculators imposed less mental effort during the learning and the test phases as compared to conventional instruction. In addition, the findings also indicated that learning by integrating the use of graphing calculators was instructionally more efficient than learning using conventional strategy.

The findings from this study confirmed other earlier findings about the positive effects of graphing calculators' usage in mathematics classroom (Horton et al., 2004; Connors & Snook, 2001; Graham & Thomas, 2000). This study has also provided empirical evidence and confirmed earlier studies about the advantages of using graphing calculators as facilitative tool for improving level of students' meta-cognitive awareness (Gage, 2002; Hylton-Lindsay, 1998).

The GC strategy group imposed lower cognitive load and resulted in less effort-demanding transfer performance than that of the CI strategy group. Furthermore, the new 3-D instructional efficiency approach of Tuovinen and Paas (2004) was used as diagnostic instrument to identify different aspect of efficient or inefficient instructional conditions based on assessments of mental effort during instructions, mental effort during test phase, and test performance. The 3-D method appears to provide a more robust way of investigating and expressing the reasons behind a given instructional condition's total efficiency and may suggest more beneficial ways to improve instruction than previous measures used (Tuovinen & Paas , 2004).

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