Effects of Integrating the Use of Graphic Calculators on Mathematics Performance from the Cognitive Load Perspective

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ABSTRACT

Cognitive load theory assumes that some learning environment impose greater demands than others, consequently impose a higher information processing load on limited cognitive resources in working memory. The theory holds that if an instructional strategy reduces extraneous cognitive load and/or increases germane cognitive load during learning as compared to another instructional strategy, then it will be more efficient in promoting learning, provided that the total cognitive load does not exceed the total mental resources. Based on this premise, three phases of quasi-experimental studies were conducted to investigate the effects of integrating the graphic calculator in mathematics teaching and learning on Form Four Malaysian secondary school students' performance. The findings from this study indicated that integrating the use of graphic calculator can reduce cognitive load and lead to better performance in learning of Straight Lines topic and increase 3-dimensional instructional efficiency index. Thus the graphic calculator strategy is instructionally more efficient than the conventional instructional strategy. Overall, this study has shown promising implications for the potential of the tool in teaching mathematics at Malaysian secondary school level.

1. Introduction

Recently, technology tools are increasingly available to enhance and promote mathematical understanding. Among those, there has been a steady increase in interest in using hand-held technologies, in particular the graphic calculator. Generally, this tool has gained widespread acceptance as a powerful tool for learning mathematics. As this technology is commonplace in classroom, consideration of the extent to which its usage can impact students' understanding of mathematical concepts within particular course content is vital. Kastberg and Leatheam [1] in reporting research studies on the use of graphic calculator up to this time, argue that the maximum potential for this technology has not been explored. Those studies provide a starting point for effort to be better understanding how to effectively use the technology in the classroom. Thus, further rigorous research is needed. This study directly responds to the need for empirical evidence regarding the effects of integrating the use of graphic calculator in mathematics instruction at the Malaysian secondary school level. Apart from studying the effectiveness of integrating the use of graphic calculator in teaching and learning of mathematics on performance measures, this research attempts to provide explanation on the benefit of graphic calculator as a tool for learning from the cognitive load perspectives.

2. Cognitive Load Theory

More and more applications of cognitive load theory (CLT, [2], [3]) have begun to appear in the field of technology learning environment recently ([4], [5], [6]). Research within cognitive load perspective is based on the structure of information and the cognitive architecture that enables learners to process that information. Specifically, CLT emphasizes structures that involve interactions between long term memory and short term memory or working memory which play a significant role in learning. One major assumption of the theory is that a learner's working memory has only limited in both capacity and duration. Under some conditions, these limitations will somehow impede learning.

Cognitive load is a construct that represents the load which performing a particular task imposes on the cognitive system [7]. CLT researchers have identified three sources of cognitive load during instruction: intrinsic, extraneous and germane cognitive load (e.g. [6], [7], [8]). Intrinsic cognitive load is connected with the nature of the material to be learned, extraneous cognitive load has its roots in poorly designed instructional materials, whereas germane cognitive load occurs when free working memory capacity is used for deeper construction and automation of schemata. Intrinsic cognitive load cannot be reduced. However, both extraneous and germane cognitive load can be reduced.

According to CLT, learning will fail if the total cognitive load exceeds the total mental resources in working memory. With a given intrinsic cognitive load, a well-designed instruction minimizes extraneous cognitive load and optimizes germane cognitive load. This type of instructional design will promote learning efficiently, provided that the total cognitive load does not exceed the total mental resources during learning.

Some researchers have suggested that the use of calculators can reduce cognitive load when students learn to solve mathematics problems ([9], [10], [11]). Thus, in this study, it was hypothesized that integrating the use of graphic calculators in teaching and learning of mathematics can reduce cognitive load and lead to better performance in learning. Specifically, this method uses an instructional strategy that minimizes extraneous cognitive load and hence optimizes germane cognitive load.

3. Purpose of the Study

The purpose of this study is to investigate the effects of integrating the use of graphic 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 graphic 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 three weeks. Phase II was partly replication of experiment in Phase I. In addition, the possibility that the use of graphic calculators can reduce cognitive load was tested in this phase. Finally, Phase III was conducted to investigate that the effectiveness of using graphic calculator may well depend on different levels of mathematics ability. Both experiments in Phases II and III were carried out for 6 weeks.

4. Methodology

4.1 Design

The quasi-experimental nonequivalent control-group posttest only design ([12], [13]) 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 (graphic 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.

4.2 Population and Sample

The target population for this study was Form Four (11^{th} grade level) students in National secondary schools in Malaysia whilst the accessible population was Form Four students from one selected school in Selangor and 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 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.

4.3 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 understand the concept of gradient of a straight line, understand the concept of gradient of a straight line in the Cartesian coordinates, understand the concepts of intercepts, understand and use equation of a straight line, and understand and use the concept of parallel lines. The main feature of the acquisition phase for the GC strategy group was that students used "balanced approach" in learning of Straight Lines topic. Waits and Demana [14] illustrated that the "balanced approach" is an appropriate use of paper-and-pencil and calculator techniques on regular basis (p.6). 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 graphic calculator.
ii. Solves using a graphic calculator, and then confirms analytically the result using traditional paper and pencil algebraic methods.
iii. Solves using graphic 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 graphic calculator in the "extension" and "generalizing" phase.
v. Approach and solve problems numerically using tables on graphic calculator.
vi. Model, simulate and solve problem situations using graphic calculator and then confirm, when possible using analytic algebraic paper and pencil methods.

Appendix A shows a sample of one lesson plan that was used in Phases II and III.

The CI strategy group was also guided by the same instructional format with conventional whole-class instruction without incorporating the use of graphic 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 [15] 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 of seven questions based on the Straight Lines topic covered in the experiment. The time allocated to do the test was 40 minutes. The scores for each problem solution were allotted one mark for each correct step in the solution. 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 [16] cut-off point of .70. However, according to Ary, Jacobs and Razavieh [17], 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 of 12 questions and the total test score was 60. The time allocated to do the test was one hour and 30 minutes. Similarly, the scores for each problem solution were allotted one mark 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 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, the scores for each problem solution were allotted one mark 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. Appendix B shows the example of SLAT that was used in this phase.

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 [15] and Paas and Van Merrienboer [18]. 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.

5. Results

The exploratory data analysis was conducted for all the data collected in all phases. 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, number of problems solved and transfer problems performance. 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 [19] 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 [19]. The greatest instructional condition efficiency would be occurred when the performance score was the greatest and the effort scores were the least. On the other hand, the worst instructional efficiency condition would occur when the performance score was the least and the effort scores were the greatest.

For Phases I and II, comparative analyses using independent samples t-tests were used to explained differences exist in means of dependent variables between GC strategy 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 from those of CI instruction strategy groups. 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.

5.1 Phase I

5.1.1 Effect of GC Strategy and CI Strategy on Performance

The SLAT comprised of seven problems based on the subtopic of Straight Lines topic covered in experiment in Phase I. The time allocated to do the test was 40 minutes. The scores for each problem solution were allotted one mark for each correct step in the solution. 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 means, standard deviations of the variables under analysis and the results of the independent samples t-test are provided in Table 1. As can be seen from Table 1, the mean overall test performance of GC strategy group was 16.81 (SD=4.76) and mean overall test performance for CI strategy group was 12.53(SD=4.99). Independent samples t-test results showed that there was a significant difference in mean test performance between GC strategy group and the CI strategy group, $t(38)=2.78$, $p<.05$. The magnitude of the differences in the means was large based on Cohen [20] with eta squared =.17. Further, planned comparison test showed that mean overall test performance of GC strategy group was significantly higher from those of CI strategy group, $F(1, 38)= 7.71$, $p<.05$. This finding indicated that the GC strategy group had performed better for test phase than the CI strategy group.

An independent t-test analysis on mean number of problems solved also revealed a significant difference between GC strategy group (M=2.19, SD=1.12) and CI strategy group (M=1.53. SD=.84), $t(38)=2.10$, $p<.05$. The magnitude of the differences in the means was moderate based on Cohen [20] with eta squared =.10. Planned comparison test showed that mean number of problems solved of GC strategy group was significantly higher from those of CI strategy group, $F(1, 38)=4.40$, $p<.05$. This finding suggested that the GC strategy group had solved significantly more problems than that of CI strategy group during the test phase.

For transfer problems performance, the results of independent t-test showed that there was no significant difference in means between the GC strategy group and CI strategy group, $t(38)=1.92$, $p>.05$. The effect size was 0.9(moderate) using eta squared value based on Cohen [20]. Planned comparison tests showed that means of GC strategy group was not significantly higher from those of CI strategy group. This finding suggested that GC strategy group performed as well as the CI strategy group on transfer problems during test phase.

Table 1. Independent samples t-test for overall test performance in Phase I

Performance	Group	N	M	SD	SEM	t	df	p
Test performance	Experimental	21	16.81	4.76	1.04	2.78	38	.008
	Control	19	12.53	4.99	1.15			
No. of problems solved	Experimental	21	2.19	1.12	.25	2.10	38	.043
	Control	19	1.53	.84	.19			
Transfer problems performance	Experimental	21	7.14	5.00	1.09	1.92	38	.062
	Control	19	4.32	4.22	.97			

5.2 Phase II

5.2.1 Effect of GC Strategy and CI Strategy on Performance

The means, standard deviations of the variables under analysis and the results of the independent samples t-test are provided in Table 2. 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 [20] using eta squared =.64. Planned comparison test showed that the mean test performance of GC strategy group was significantly higher from 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.

For number of problems solved, the results of the independent t-test showed that there was no significant difference in means between the GC strategy group (M=2.73, SD=1.96) and the CI strategy group (M=2.22, SD=1.85), $t(63)=1.08$, $p>.05$. The effect size was .02 using eta squared value which was small based on Cohen [20]. Planned comparison test showed that mean number of problems solved for test phase of GC strategy group was not significantly higher from those of CI strategy group, $F(1, 63)= 1.17$, $p>.05$. This finding suggested that both groups did not differ significantly in their ability to solve problems related to Straight Lines.

Further, there was a significant difference in mean transfer problems performance between the GC strategy group (M=15.09, SD=5.33) and the CI strategy group (M=8.41, SD=5.87); $t(63)=4.81$, $p<.05$. The effect size was .27 using eta squared value which was large based on Cohen [20]. Planned comparison tests showed that means of GC strategy group was significantly higher from those of CI strategy group, $F(1, 63)=23.14$, $p<.05$. This suggested that the GC strategy group performed better on solving transfer problems during the test phase compared to CI strategy group.

Table 2. Independent samples t-test for performance

Performance	Group	N	M	SD	SEM	t	df	p
Test performance	Experimental	33	24.21	9.69	1.69	2.57	63	.012
	Control	32	17.75	10.54	1.86			
No. of problems solved	Experimental	33	2.73	1.96	.34	1.08	63	.285
	Control	32	2.22	1.85	.33			
Transfer problems solved	Experimental	33	15.09	5.33	.93	.30	63	.000
	Control	32	8.41	5.87	1.04			

5.2.2 Effect 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 [20]. Planned comparison showed that the mean mental effort for CI strategy group was significantly higher from 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 [20]. 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)	Experimental	33	2.93	.78	.14	-5.72	63	.000
	Control	32	4.13	.91	.16			
Mental effort (Test phase)	Experimental	33	5.41	1.45	.25	-3.03	63	.004
	Control	32	6.44	1.27	.22			

5.2.3 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 3D 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 [20]. 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 from that of CI strategy group, $F(1, 63)=19.89$, $p<.05$. This finding indicated that learning by integrating the use of graphic calculator 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	Experimental	33	.70	1.31	.23	4.46	63	.000
	Control	32	.73	1.28	.23			

5.3 Phase III

5.3.1 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 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 [20]. Similarly, the main effect of type of instructional strategy also yielded a significant differences (($F(1, 66)=23.82$, $p<.05$) with large effect size (partial eta squared=.27). However, the interaction effect between mathematics ability and instructional strategy did not reach statistical significant ($F(1,66)=.87$, $p>.05$, 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 from that of CI strategy group. As can be seen from Table 6, the GC strategy group ($M=23.97$, $SD=9.58$) 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 from that of CI strategy group, $F(1,68)=13.18$, $p<.05$. The results indicated that the GC strategy is significantly better than the CI strategy.

5.3 2 Effect 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 learning phase as a function of the level of mathematics ability and type of instructional strategy are provided in Table 6. The ANOVA performed on mean amount of mental effort invested during 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 type of instructional strategy ($F(1,66)=4.46$, $p<.05$) 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 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 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 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 type of instructional strategy 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 from 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 test phase of the GC strategy decreased. For low mathematics ability, this strategy was less beneficial, but, for average mathematics ability group, it led to decrease about 2.16 points (6.69 – 4.53) which is doubled mean amount of mental effort than the low mathematics ability group which reported decreased in mean amount of mental effort of about 7.06 – 6.06= 1.00 points.

Further planned comparison results showed that the mental effort invested during 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 test phase as compared to that students in CI strategy group. This finding suggested that the GC strategy had invested less mental effort during 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

Mathematic 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

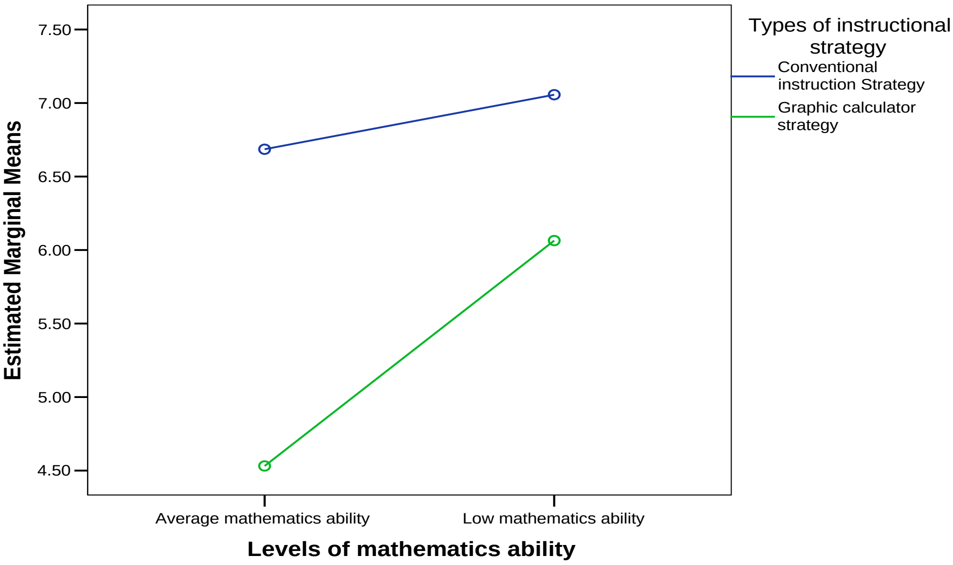

Figure 1. Interaction between levels of mathematics ability and types of instructional strategy on mental effort during test phase

5.3.3 Effect 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 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 were 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 from 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 from 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

Mathematic 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

6. Discussions

Past studies on effects of the use of graphic calculators offers different results. Generally the results have favored the use of this technology in mathematics classroom (for example, [21], [22], [23], [24], [25], [26], [27], [28], [29]). Those studies reported that use of graphic calculators improved students' mathematics performance.

The findings from this study suggest that integrating the use of graphic calculator can reduce cognitive load and lead to better performance in learning, thus increase instructional efficiency when Form Four students learn Straight Lines topic. In addition, the findings form the second and third phases provide empirical evidence to support the contention by Jones [9], Kaput [10] and Wheatley [11] that the use of calculators can reduce cognitive load and hence facilitate learning.

The findings provide a possible explanation from the cognitive load theory perspectives why GC strategy is 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 graphic calculator freed students' mental resources from the tedious computation, algebraic manipulation and graphing skills and hence enabled them to redirect their attention from irrelevant cognitive processes to relevant germane processes of schema construction. This was evident from the significantly lower levels of mental effort reported which theoretically would indicate a lower cognitive load and the significantly higher performance achieved by the students from the GC strategy group in Phases II and III.

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 Malaysian Mathematics syllabus.

It is also pertinent to note that the results of Phase I showed the difference were not significant in several instances important performance variables particularly the transfer problems performance. The findings indicate that the interventions of very brief duration (about three weeks) was not enough to show that the GC strategy is an effective instructional strategy for obtaining schema acquisition. Dunham [30] noted that a few studies that produced negative results due to treatment of very brief duration such that the learning of graphic calculator may have interfered with learning of content (for example, [31], [32]). However, for Phases II and III, the treatment was conducted for about six weeks and the findings were in favor for GC strategy. More importantly, the GC strategy group performed better on transfer problems performance as compared to the control group that executing the CI strategy. Such findings suggest that the GC strategy group have acquired effective schemas that enabled transfer to be enhanced [33].

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 graphic calculator instructions) and the graphic calculator screen. The results showed that if the split attention effect exists, its negative consequences are far outweighed by the reduction in cognitive load. In both phases, students in GC strategy group were found to be sufficiently proficient enough in graphic calculator use because besides having the pre-experiment training of introducing the graphic calculator and learning how to use the graphic calculator, they had longer duration of intervention. Thus, this explanation confirms the results for phase I such that the difference were not significant in the transfer problems performance could be due to any advantage of using graphic calculator was negated by the split attention effect.

Hence, it is pertinent to note that if students who had hardly knew how to use the graphic calculator had been selected, the results might have been different. The negative consequences of the split attention effect might have outweighed the positive effects of cognitive load reduction. On the other hand, the results on performance might have been further magnified if students very proficient with the use of graphic calculator had been selected in this phase.

Another important finding in this study namely Phase III was that both factors mathematics ability and instructional strategy separately influence test performance, mental effort invested during learning and instructional efficiency. However, there was a significant interaction between levels of mathematics ability and types of instructional strategy for amount of mental effort invested during test phase. It was found that as mathematics ability increased, the effectiveness of GC strategy increased. The average mathematics ability group was greatly beneficial from the GC strategy as it led to doubled decrease mean amount of mental effort than that of low mathematics ability group. However, it is pertinent to note that even though there was no significant interaction between mathematics ability and instructional strategy for test performance, practically the average ability group of GC strategy had performed better on test performance**.**

7. Conclusion

The findings from this study reaffirm Sweller's ([2], [3]) contention that the limited capacity of working memory is very important consideration 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 graphic calculator strategy is instructionally more efficient and thus is superior to conventional instruction strategy. This study shows promising implications for the potential of the tool in teaching mathematics at Malaysian secondary school level.

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APPENDIX A

LESSON 6
MATHEMATICS
TOPIC 5: THE STRAIGHT LINES

SUBTOPIC 5.4: Understand and use equation of a straight line

Time : 40 minutes

Learning outcomes:
Students will be able to
(i) draw the graph given an equation of the form $y = mx + c$.
(ii) determine the effects of changing the value of *m* while keeping *c* a constant.
(iii)determine the effects of changing the value of *c* while keeping *m* a constant.

Materials:
1. Short notes 1 and 2
2. Graphic Calculator TI-83 Plus
3. Worksheet 1 and Worksheet 2
4. Evaluation sheet

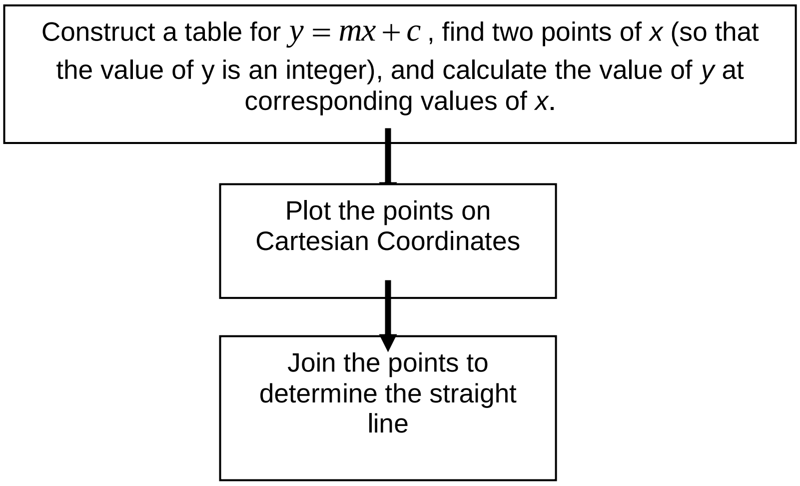
Time/Phase	Teacher Activity	Student Activity	Materials
Induction Set (3 min)	• Ask students to recall previous lesson about concept of gradient and intercept. • Give the lesson objectives.	• Recall previous lesson.	
Instructional Development (27 min) Acquisition Phase (15 min)	• Using worksheet 1, teacher guides the students to draw the graph of equation $y = mx + c$ using GC (using Y- editor and 'LIST and PLOT'. • Emphasizes how to draw graph without using GC using short notes 1. • Help students in carrying out activity as in worksheet 1 using GC to make inference on the effects of changing the values of *m* and *c* of $y = mx + c$. • Using short notes 2 to emphasize the concept learned.	• Work in pairs and using worksheet 1 to perform activity. • Draw graphs using GC (using Y- editor and 'LIST and PLOT'). • Compare the linear graphs with coordinates of each point on the line. • Make inference on the difference between positive and negative gradients while keeping c a constant. • Make inference on the difference between positive and negative value of *c* while keeping *m* a constant.	Worksheet 1 Short notes 1 Short notes 2
Practice Phase (10 min)	• Reinforce students' understanding with practice	• Work in pairs and perform activity for	Worksheet 2

	phase using worksheet 2.	practice phase using worksheet 2. • Using GC to draw straight lines of the form $y = mx + c$. • Identify the sketch of straight lines when the values of *m* and *c* are changed. • Using GC to check the answer.	
Closure Phase (2 min)	• Ask students to summarize the lesson learned.	• Volunteer to summarize the lesson learned.	
Evaluation (10 min)	• Evaluate students' understanding.	• Try out to answer questions on the evaluation sheet.	Evaluation sheet

Homework:
Ex. 5.4A:
No. 1b, d, and f.

Short Notes 1

Drawing the graph of equation $y = mx + c$:

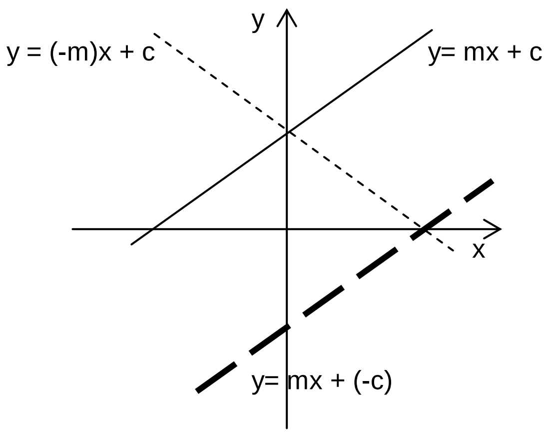


Short Notes 2

For a positive value of m and c in the equation of $y = mx + c$:

(i) If the value of m is changed to -m (while keeping c a constant), then the same straight line will change to incline downwards to the right.

(ii) If the value of c is changed to -c (while keeping m a constant), then the same straight line will change to move downwards below the x-axis with an equal length above and below the x-axis.



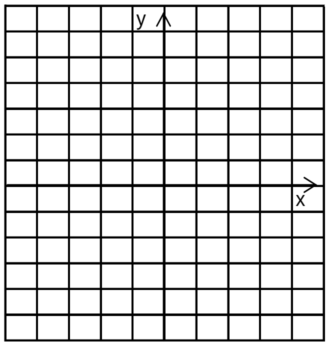
NAME:____
FORM:___________________

Worksheet 1

Work in pairs.
Drawing the graph of equation $y = mx + c$ using GC (using Y- editor and 'LIST and PLOT')

(i)Draw a graph for $y = 2x + 1$ using LIST and PLOT

1. Make sure all previous data are cleared.
2. Press 'STAT' and select '1: Edit', then press 'ENTER'.
3. Use arrow key to move the cursor to L_1.
4. Enter values of x in column L_1 and values of y that satisfies the equation $y = 2x + 1$.
5. Press '2nd', [STAT PLOT], select '1: Plot 1…Off', ENTER ENTER ▼ ▶ ENTER ▼ 2nd [L1] ENTER [L2] ENTER.
6. Press 'GRAPH'.
7. Sketch the graph on the following Cartesian Coordinates.



(ii)Draw a graph for $y = 2x + 1$ using Y-editor

1. Clear the plot by moving the cursor to Plot 1 and press ENTER ▼.
2. Enter the equation of the straight line in the form of $y = 2x + 1$:
   Press :

   | Y= | 2 | X, T, Θ, *n* | + | 1 |

3. Press 'GRAPH'.

Determine the effects of changing the value of m while keeping c a constant, and the effects of changing the value of c while keeping m a constant.

1. Make sure all previous data are cleared.
2. Using Y-editor, draw a graph for $y = 2x + 3$.
3. Then, draw another graph for $y = -2x + 3$.
4. Make inference on the difference between positive and negative value of m while keeping c a constant on the form of the straight line.

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5. On the same Cartesian Coordinates, draw another graph for $y = -2x + 3$.

6. Make inference on the difference between positive and negative value of c while keeping m a constant on the form of the straight line.

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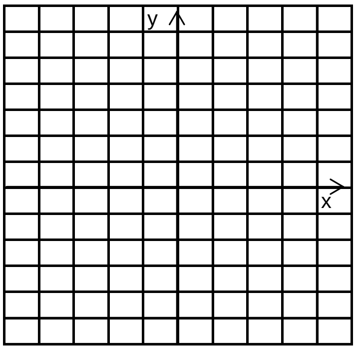
7. Sketch all the three graphs on the following Cartesian Coordinates.



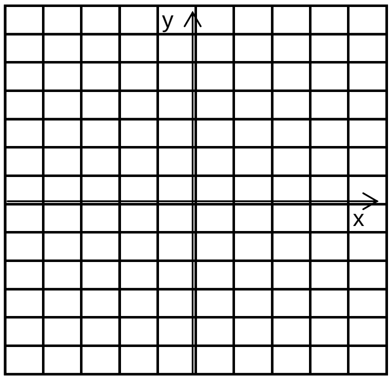
Worksheet 2

NAME:____

FORM:__________________

Work in pairs.

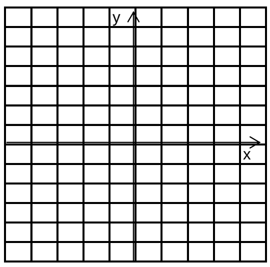
1. Using GC, draw a graph for a straight line $y = -2x - 1$. Without using GC, draw a graph for a straight line $y = 2x - 1$ and $y = 2x - 1$. Check your answer using GC.



2. (i) Complete the table below:

x	0	2
y = ½ x +1		

(ii) Draw the graph for a straight line y = ½ x +1 on the following Cartesian Coordinates.

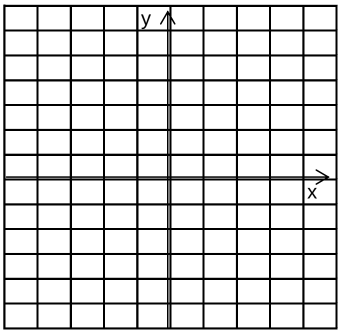


(iii) On the same Cartesian Coordinates, draw the graph for y = -½ x +1 and y = ½ x-1. Using GC check your answer.

NAME:____
FORM:____________________

Evaluation Sheet

(1) Draw a graph for $y = \frac{2}{3}x + 1$ on the following Cartesian Coordinates. On the same Cartesian Coordinates, draw a graph for $y = -\frac{2}{3}x + 1$ and $y = \frac{2}{3}x - 1$. Use a GC to check the answer.



APPENDIX B

STRAIGHT LINE ACHIEVEMENT TEST

PHASE III

Time: 1 ¾ hours

NAME:_______________________________________

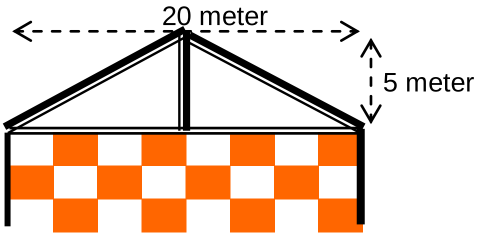
FORM:_______________________________________

Instructions (*Arahan*):

1. This question paper consists of 14 subjective questions.
   (*Kertas soalan ini mengandungi 12 soalan subjektif*)
2. Answer all questions.
   (*Jawab semua soalan*)
3. After each question, you are required to indicate the amount of mental effort expended for that question by responding to the nine-point symmetrical scale as follow:
   (*Selepas setiap soalan, anda dikehendaki menyatakan jumlah daya mental yang telah digunakan bagi soalan itu dengan memberi respon kepada skala simetri sembilan-poin seperti berikut:*)
   1. Very, very low mental effort
      (*Daya mental yang sangat-sangat rendah*)
   2. Very low mental effort
      (*Daya mental yang sangat rendah*)
   3. Low mental effort
      (*Daya mental yang rendah*)
   4. Rather low mental effort
      (*Daya mental yang agak rendah*)
   5. Neither low or high mental effort
      (*Daya mental yang tidak rendah dan tidak tinggi*)
   6. Rather high mental effort
      (*Daya mental yang agak tinggi*)
   7. High mental effort
      (*Daya mental yang tinggi*)
   8. Very high mental effort
      (*Daya mental yang sangat tinggi*)
   9. Very, very high mental effort
      (*Daya mental yang sangat-sangat tinggi*)

1. Based on the diagram below, determine the gradient of the roof.

(5 marks)



Solution:

In solving or studying the preceding problem I invested (Circle the appropriate scale):
(*Dalam menyelesaikan atau mengkaji penyelesaian masalah di atas, saya telah menggunakan* (*Bulatkan skala yang bersesuaian*):)

1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Very, very low mental effort								Very, very high mental effort
(*Daya mental yang sangat-sangat rendah*)								(*Daya mental yang sangat-sangat tinggi*)

2. Draw a straight line *A* that passes through points (-1, 2) and (3, -3) and a straight line B that passes through points (-5, -1) and (2, 2) on the same Cartesian plane. Then, determine the line with the negative gradient.
(5 marks)

Solution:

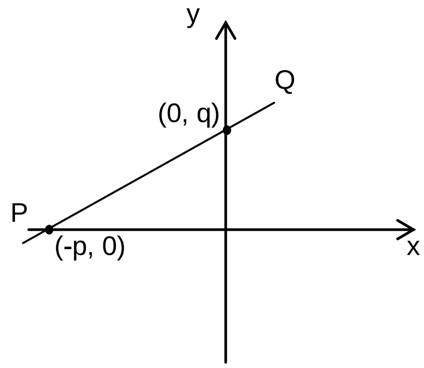
In solving or studying the preceding problem I invested (Circle the appropriate scale):
(*Dalam menyelesaikan atau mengkaji penyelesaian masalah di atas, saya telah menggunakan* (*Bulatkan skala yang bersesuaian*):)

1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Very, very low mental effort								Very, very high mental effort
(*Daya mental yang sangat-sangat rendah*)								(*Daya mental yang sangat-sangat tinggi*)

3. The diagram below shows a straight line *PQ*.

   (a) State the *x*-intercept and *y*-intercept of the line *PQ*. (2 marks)

   (b) Find the gradient of the line *PQ*. (3 marks)



Solution:

In solving or studying the preceding problem I invested (Circle the appropriate scale):
(*Dalam menyelesaikan atau mengkaji penyelesaian masalah di atas, saya telah menggunakan* (*Bulatkan skala yang bersesuaian*):)

1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Very, very low mental effort								Very, very high mental effort
(*Daya mental yang sangat-sangat rendah*)								(*Daya mental yang sangat-sangat tinggi*)

4. A set of discrete data points such as (10, 4), (20, 6), and (30, 8) represents the cost of a certain number of note books versus the number of note books purchased.
   (a) Using an x-axis to represent the cost of note book and a y-axis to represent the number of book purchased, draw a straight line based on the data given.
   (b) Calculate the gradient of the straight line.
   (c) Interpret the gradient of the straight line.

(5 marks)

Solution:

In solving or studying the preceding problem I invested (Circle the appropriate scale):
(*Dalam menyelesaikan atau mengkaji penyelesaian masalah di atas, saya telah menggunakan* (*Bulatkan skala yang bersesuaian*):)

1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Very, very low mental effort								Very, very high mental effort
(*Daya mental yang sangat-sangat rendah*)								(*Daya mental yang sangat-sangat tinggi*)

5. $A(3, 0)$, $B(1, -4)$, and $C(2, k)$ are three points on a straight line. Find the value of k.

(5 marks)

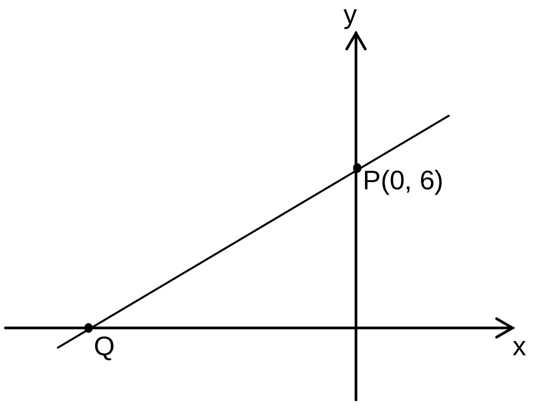
Solution:

In solving or studying the preceding problem I invested (Circle the appropriate scale):
(*Dalam menyelesaikan atau mengkaji penyelesaian masalah di atas, saya telah menggunakan* (*Bulatkan skala yang bersesuaian*):)

1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Very, very low mental effort (*Daya mental yang sangat-sangat rendah*)								Very, very high mental effort (*Daya mental yang sangat-sangat tinggi*)

6. In the following diagram, *PQ* is a straight line with gradient $\frac{2}{3}$. Find the *x*-intercept of line *PQ*.

(5 marks)



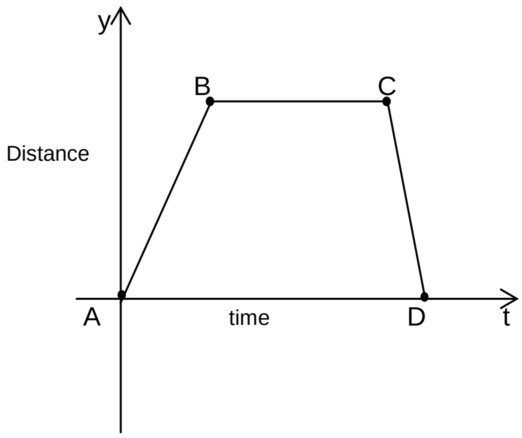
Solution:

In solving or studying the preceding problem I invested (Circle the appropriate scale):
(*Dalam menyelesaikan atau mengkaji penyelesaian masalah di atas, saya telah menggunakan* (*Bulatkan skala yang bersesuaian*):)

1	2	3	4	5	6	7	8	9
Very, very low mental effort (*Daya mental yang sangat-sangat rendah*)								Very, very high mental effort (*Daya mental yang sangat-sangat tinggi*)

7. The following diagram shows a graph of distance (y) versus time (t). It gives information on a person's walk from a house to a mosque and back to the house. The graph is composed of three line segments: segment AB represents the walk from home to the mosque, segment BC represents the period of time at the mosque, and segment CD represents the walk from the mosque back to the house.
   (a) Which segment of lines represents the biggest gradient? Explain your answer.
   (b) Determine when the person was walking the fastest. Explain your answer.

(5 marks)



Solution:

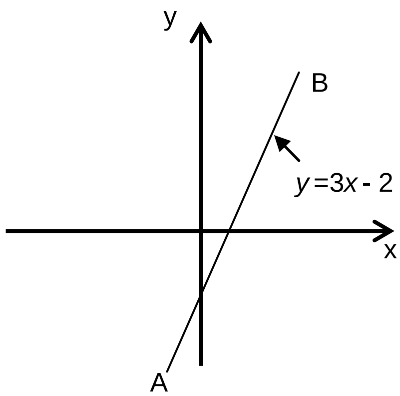
In solving or studying the preceding problem I invested (Circle the appropriate scale):
(*Dalam menyelesaikan atau mengkaji penyelesaian masalah di atas, saya telah menggunakan* (*Bulatkan skala yang bersesuaian*):)

1	2	3	4	5	6	7	8	9

Very, very low mental effort (*Daya mental yang sangat-sangat rendah*)

Very, very high mental effort (*Daya mental yang sangat-sangat tinggi*)

8. The diagram below shows a straight line AB, $y = 3x - 2$. On the same Cartesian coordinates, draw the graphs for $y = -3x - 2$ and $y = 3x + 2$.
(5 marks)



Solution:

In solving or studying the preceding problem I invested (Circle the appropriate scale):
(*Dalam menyelesaikan atau mengkaji penyelesaian masalah di atas, saya telah menggunakan* (*Bulatkan skala yang bersesuaian*):)

1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Very, very low mental effort								Very, very high mental effort
(*Daya mental yang*								(*Daya mental yang*

sangat-sangat rendah) *sangat-sangat tinggi*)

9. Determine the point of intersection of the two straight lines, $y = -2x + 3$ and $y = 2x - 1$.

(5 marks)

Solution:

In solving or studying the preceding problem I invested (Circle the appropriate scale):
(*Dalam menyelesaikan atau mengkaji penyelesaian masalah di atas, saya telah menggunakan* (*Bulatkan skala yang bersesuaian*):)

1	2	3	4	5	6	7	8	9
Very, very low mental effort (*Daya mental yang sangat-sangat rendah*)								Very, very high mental effort (*Daya mental yang sangat-sangat tinggi*)

10. Determine whether a point (2, 0) lies on the straight line $y = 2x - 4$.
(5 marks)

Solution:

In solving or studying the preceding problem I invested (Circle the appropriate scale):
(*Dalam menyelesaikan atau mengkaji penyelesaian masalah di atas, saya telah menggunakan* (*Bulatkan skala yang bersesuaian*):)

1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Very, very low mental effort (*Daya mental yang sangat-sangat rendah*)								Very, very high mental effort (*Daya mental yang sangat-sangat tinggi*)

11. Find the equation of a straight line that passes through points (3, 1) and (-6, -5).

(5 marks)

Solution:

In solving or studying the preceding problem I invested (Circle the appropriate scale):
(*Dalam menyelesaikan atau mengkaji penyelesaian masalah di atas, saya telah menggunakan* (*Bulatkan skala yang bersesuaian*):)

1	2	3	4	5	6	7	8	9
Very, very low mental effort (*Daya mental yang sangat-sangat rendah*)								Very, very high mental effort (*Daya mental yang sangat-sangat tinggi*)

12. Given that the two straight lines, $3x-2y=\frac{3}{4}$ and $2y-mx=4$ are parallel.

Find the value of *m*.

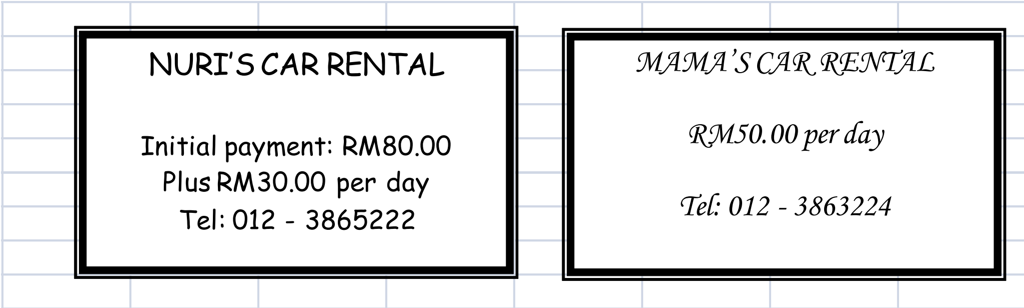
(5 marks)

Solution:

In solving or studying the preceding problem I invested (Circle the appropriate scale):
(*Dalam menyelesaikan atau mengkaji penyelesaian masalah di atas, saya telah menggunakan* (*Bulatkan skala yang bersesuaian*):)

1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Very, very low mental effort (*Daya mental yang sangat-sangat rendah*)								Very, very high mental effort (*Daya mental yang sangat-sangat tinggi*)

13.



Based on the above advertisements, find the number of days when the rental charges are the same for both car rental companies.

(5 marks)

Solution:

In solving or studying the preceding problem I invested (Circle the appropriate scale):
(*Dalam menyelesaikan atau mengkaji penyelesaian masalah di atas, saya telah menggunakan* (*Bulatkan skala yang bersesuaian*)*:*)

1	2	3	4	5	6	7	8	9
Very, very low mental effort (*Daya mental yang sangat-sangat rendah*)								Very, very high mental effort (*Daya mental yang sangat-sangat tinggi*)

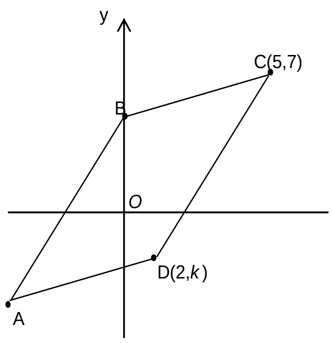
14. In the following diagram, *ABCD* is a parallelogram. Given that the equation of the straight line *CD* is $y = 3x - 8$.

    (a) State the gradient of the straight line CD and then find the value of *k*.

    (5 marks)

    (b) Given that the gradient of the straight line *AD* is $\frac{2}{5}$, determine the equation of the straight line *BC*.

    (5 marks)



Solution:

In solving or studying the preceding problem I invested (Circle the appropriate scale):
(*Dalam menyelesaikan atau mengkaji penyelesaian masalah di atas, saya telah menggunakan* (*Bulatkan skala yang bersesuaian*):)

1	2	3	4	5	6	7	8	9
Very, very low mental effort								Very, very high mental effort
(*Daya mental yang sangat-sangat rendah*)								(*Daya mental yang sangat-sangat tinggi*)