Malaysian Journal of Mathematical Sciences **1(1)**: 45 - 61 (2007)

The Effects of Using Graphic Calculators in Teaching and Learning of Mathematics

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ABSTRACT

Although graphic calculators have been developed in mathematics education for nearly two decades, research on the technology's use is not robust. Its use in secondary schools (for example, in Great Britain, France, Sweden, New Zealand, Netherlands, and United States) is not well understood, universally accepted, nor well-documented. In Malaysia, research on the usage of graphic calculators is still in its infancy and therefore its use has yet to be explored. Thus, there is a need to further research in this area especially in the context of teaching and learning of mathematics at secondary school level in Malaysia. This study employs a quasi-experimental with non equivalent control group design. The main objective of the study was to investigate the effects of the use of graphic calculators on Form four secondary school students' mathematics achievement and metacognitive awareness in the learning area of Relation and Function. Students' views about their experiences benefits and difficulties experienced in using graphic calculators in learning of mathematics were sought. Preliminary findings of this study provided pedagogical impact of the use of graphic calculators as a tool in teaching and learning of mathematics in Malaysia.

Keywords: Graphic calculators, mathematics achievement, metacognitive awareness, cognitive load theory, and distributed cognition theory

INTRODUCTION

Technology explosion has inspired various methodologies for the purpose of effective teaching and learning in general and specifically in mathematics. The use of technology in teaching and learning of mathematics has consistently been one of the major emphases in the Malaysian Integrated Curriculum for Secondary School Mathematics. Teachers are encouraged to use the latest technology to help students understand mathematical concepts meaningfully and in detail and to enable them to explore mathematical ideas (Ministry of Education Malaysia, 2005). This emphasis is congruent with the National Council of Teachers of Mathematics' (NCTM) 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 these days. These range from very powerful computer software, such as Mathematica, Maple, and MathLab to much less powerful technologies such as the use of paper and pencil. Currently, mathematics reform has encouraged the use of hand-held technologies such as graphic calculators in the teaching and learning of mathematics (Kissane, 2000). The choice of a graphic calculator is based mainly on its availability and accessibility to essentially all students at all times (Kissane, 2000) with special consideration for cost and ease of use/user friendliness. In fact, a graphic calculator is built as a hand-held mathematics computer that can draw and analyse graphs, computes the values of mathematical expressions, solves equations, performs symbolic manipulation (requires CAS), performs statistical analyses, programmable, and communicates information between devices (Jones, 2003).

Numerous studies in many developed countries have shown positive impacts from the use of graphic calculator in the classrooms and in examinations (Adams, 1997; Burill et al., 2002; Connors & Snook, 2001; 2000; Dunham, 2000; Dunham & Dick, 1994; Gage, 2002; Graham & Thomas, 2000; Hennessey, 2000; Hong et al., 2000; Horton et al., 2004; Noraini Idris, 2004, Noraini Idris et al., 2002, 2003; Kastberg & Leatham, 2005; Keller & Russel, 1997; Penglese & Arnold, 1996; Quesada & Maxwell, 1994; Ruthven, 1990, 1996; Smith & Shortberger, 1997; Waits & Demana, 2000). In Malaysia, the Curriculum Development Centre introduced the graphic calculator in the early of 1990s (Muhd. Khiriltitov Zainudin, 2003). However, the use of graphic calculators in Malaysian schools is still in its infancy (Noraini Idris, 2004), and therefore its use has yet to be fully explored. Thus, there is a need for further research in this area, specifically in the context of teaching mathematics at the Malaysian secondary school level.

THEORETICAL FRAMEWORK OF THE STUDY

Learning theories such as the cognitive load theory and the distributed cognition theory described in the following sections will provide the theoretical framework of the study. The theories provide the background basis for the positive effects of the use and integration of graphic calculators in the teaching and learning of mathematics.

Cognitive Load Theory

Cognitive load theory (Sweller, 1988) is an internationally known and widespread theory which focuses on the role of working memory in the development of instructional methods. The theory originated from the information processing theory in the 1980s and underwent substantial changes and extensions in the 1990s (Pass et al., 2003; Sweller et al., 1998). Research within cognitive load perspective is based on the structure of information and the cognitive architecture that enables learners to process that information. One major assumption of the theory is that a learner's working memory has only limited capacity. Learners will allocate most of their cognitive resources to the learning activities when learning. However, in many cases the instructional format causes an overload on the working memory. Therefore, to enhance learning and promote transfer of learning, cognitive load theory asserts that external load should be reduced, hence providing more working memory capacity for actual learning to take place. For example, suppose we are asked to mentally remember all 18 letters in any order such as ACEEGGIIIILNNNRSTX. Most people cannot remember the entire list, even though the letters are presented in alphabetical order. The number of items exceeds the capacity of their working memories. However, if the same letters presented as LEARNING IS EXCITING, then they are simple to remember. This is because they have been "chunked" into three meaningful words and into a meaningful sentence which requires less working memory space. In short, the more items added on to the list, the higher the cognitive load imposed on the working memory, and the more likely that mental resources are not available. Hence the situation will impede the processing of information.

Cognitive load is a construct that represents the load imposed while performing a particular task on the cognitive system (Sweller, et al., 1998). According to Sweller et al. (1998), cognitive load can arise from three sources: intrinsic, extraneous and germane cognitive load. 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 loads can be reduced.

According to the cognitive load theory, 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 instructional format minimizes extraneous cognitive load and optimizes germane cognitive load. This type of instructional format will promote learning efficiently, provided that the total cognitive load does not exceed the total mental resources during learning.

More and more applications of cognitive load theory have begun to appear recently in the field of technology learning environment. Some researchers also have suggested that the use of calculators can reduce cognitive load when students learn to solve mathematics problems (Jones, 1996; Kaput, 1992; Wheatley, 1980). Thus, in this study, it was hypothesized that 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 format that minimizes extraneous cognitive load.

Distributed Cognition Theory

The traditional view of cognition is that cognition exists solely inside one's head (Solomon, 1993). In addition, Rogers and Scaife (1997) describes that it is a localized phenomenon that can be best explained in terms of information processing at the individual level. In contrast, the distributed cognition theory claims that cognition is better understood as a distributed phenomenon: one that goes beyond the boundaries of a person but to include environment, artifacts, social interaction, and culture (Rogers & Scaife, 1997).

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. Tools can include computers, calculators, graphics calculators, paper and pencil, and others. The system explains how the knowledge within the environment, culture and social interaction is represented; how the knowledge between different individuals and artifacts is transmitted; and how the external structures are transmitted when acted on by individuals and artifacts. Further, the system has goals in which one has to use tools in an appropriate organized manner to achieve learning goals.

The distributed phenomenon perspective is adopted to explain cognitive effect when using technology (Soloman et al., 1992; Jones, 2000). It is the effect obtained during intellectual partnership with the technology, and in terms of the transferable cognitive residue that this partnership leaves behind in the form of better mastery of skills and strategies. In this perspective, 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 (Pea, 1985; Salomon et al., 1992). Further, this will allow users to focus cognitive resources elsewhere. 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.

According to the distributed cognitive theory, it is not enough to account for human cognitive accomplishment by reference only to what is inside our head alone. We must also consider the cognitive roles of the social and material world. 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, the distributed cognition theory is considered as a foundation of performance support in teaching and learning using graphic calculators.

OBJECTIVES OF THE STUDY

The main purpose of this study is to investigate the effectiveness of using graphic calculators (TI-83 Plus) in teaching and learning of mathematics on Form four secondary school students' mathematics achievement and their metacognitive awareness in the learning area of Relation and Function. Students' views about their experiences, benefits and difficulties in using graphic calculators in learning of mathematics were sought. Specifically, the objectives of this study were:

- To compare the effect on students' mathematics achievement during the study of straight lines using graphic calculators and the conventional methods.
- To compare the effect on students' metacognitive awareness during problem solving of straight line problems between the graphic calculator group and the conventional group.
- To describe students' views from the graphic calculator group on:
  i. Their experiences using graphic calculators during the study of the straight line.
  ii. The benefits of using graphic calculators during the study of the straight line.
  iii. The difficulties experienced during the use of graphic calculators during the study of the straight line.

In this study, students' mathematics achievement refers to the overall achievement based on the Straight Line Achievement Test (SLAT) score. Specifically, it shows students' ability to demonstrate their understanding of mathematical concepts in the study of a Straight Line during the experimental period. The mathematical concepts tested in the SLAT include the following: (i) the concept of gradient of a straight line, (ii) the concept of gradient of the straight line in Cartesian Coordinates, (iii) the concept of intercept, and (iv) the concept of the equation of a straight line. In addition, metacognitive refers to how often students think or feel or do or demonstrate an awareness on planning, cognitive strategy, self-checking and awareness while working on tasks or problems related to the Straight Line studies.

METHODOLOGY

Design of the study

This study employed the quasi-experimental, non-equivalent control posttest design. According to Fraenkel and Wallen (2006), this design is most appropriate in investigating the effectiveness of an intervention with availability of intact groups.

Sample

The sample for this study consisted of two classes of Form four students from one of the secondary schools in Pelabuhan Klang. Based on school reports and discussions with the school's principal and mathematics teachers, both groups had comparable socio-economic and ethnic backgrounds, and each class was assigned with mixed ability (high, average and low). Results from the previous monthly test were further analyzed to ascertain that the students were of similar ability. The result of the t-test indicated that there was no significant difference between the mean of monthly test score for the two groups ($t(38) = -0.049$, $p > 0.05$, SE difference =5.351). This suggested that the students' mathematics performance for both groups in this study do not differ significantly. Hence the two classes were randomly assigned, one as the experimental group and the other the control group. The experimental group had 28 students, 7 boys and 21 girls. The control group had 35 students, 15 boys and 17 girls. However, during the posttest a few students from both groups had co-curricular activities thus drop-out from the study. Finally, only 21 students (4 (19%) boys and 17 (81%) girls) in the experimental group and 19 students (7 (37%) boys and 12 (62%) girls) in the control group took the posttest. The experimental group studied the straight line by using the graphic calculators, while the control group used the conventional whole-class instruction. Since this is a preliminary study, the experiment was carried out for only a short period of two weeks.

Materials

The instructional materials for this experiment consisted of six sets of lesson plans of teaching and learning about Straight Lines. The format of each lesson plan includes activities for the following phases: set induction, acquisition, practice, closure and evaluation phases. In the acquisition phase, the experimental group was first introduced to the concept of each subtopic of the straight lines using the TI-83 Plus graphing calculator. The main features of this phase were that they highlighted exploratory and discovery learning of the topic. This was followed by the practice phase: first, they were required to solve the given problems using a graphic calculator, and second, they were not allowed to solve the given problems using the graphic calculator. The practice phase was followed by the closure phase where the important concepts learnt were highlighted. At the end of the lesson, each student was given an evaluation. Two questions were posed. For the first question, the students were asked to solve the problem using a graphic calculator, and for the second question, they were to solve the problem without using the graphic calculator.

The control group was also guided by the same instructional format with one exception. The conventional mathematics instruction method did not incorporate the use of TI-83 Plus graphic calculator. It was a whole-class instruction with the following activities:

- Teacher explains the mathematical concepts using only the blackboard
- Teacher explains how to solve mathematical problems related to the concepts explained
- Students are given mathematical problem solving to solve them individually
- Teacher handles discussion of problems solving
- Teacher gives the conclusion of the lesson.

Instruments

The instruments in this study consisted of a Straight Lines Achievement Test (SLAT), a Metacognitive Awareness Survey (MCAS), and a Graphic Calculator Usage Survey (GCUS). The SLAT was designed by the researchers to measure students' understanding of the Straight Lines. It 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 overall total score for the SLAT was 40. The reliability index using Cronbach's alpha coefficient was 0.57. This index was not an acceptable level based on Nunnally (1978) cut-off point of 0.70. However, according to Ary et al. (1996), a lower reliability coefficient (in the range of 0.50 to 0.60) might be acceptable if the measurement results are to be used in making decisions about a group or even for research purposes. Further, Worthen et al. (1999) stated that a reliability coefficient as low as 0.50 is acceptable if the test is to be used in making decisions about a group. Thus, the reliability of SLAT for this experiment was reasonably acceptable.

The MCAS was adapted from the "State Metacognitive Inventory" by O'Neil and Abedi (1996) to measure students' metacognitive awareness during mathematical problem solving. It consisted of 20 items with four point Likert scale ranks of agreement. The construct encompassed the following subconstructs: awareness, planning, cognitive strategy, and self-checking. Based on the studies of O'Neil and Abedi (1996) for 12th graders, the Cronbach's alpha reliability estimates and factor analysis indicated that their metacognitive subscales are reliable (alpha above 0.70) and uni-dimensional. The reliability coefficient of the MCAS for this study was 0.85. The reliability coefficient for each subscale ranged from 0.61 to 0.69 where 0.69 was for self-checking, 0.63 for cognitive strategy, 0.61 for awareness and 0.63 for planning. Since the Cronbach's alpha coefficient of MCAS for this study was greater than 0.70, the measurement of this construct was considered reliable.

The GCUS was constructed to examine views of students' of the graphic calculator group about the use of graphic calculators during the period of study. There were three open questions in the survey: (i) What are your experiences in using graphic calculators in learning about a Straight Lines (ii) What are the benefits of using graphic calculators in learning about Straight Lines and (iii) What are the difficulties experienced during the use of graphic calculators.

Procedure

This study was carried out from 6th April, 2005 to 26th April, 2005. As part of the preparation for the study, the first two periods were used to introduce and familiarize the experimental group students with the features and functions of the TI-83 Plus graphing calculator. Then, for two weeks, the experimental group learned mathematics by using the graphic calculators while the control group learned mathematics by using conventional whole-class instruction. Both groups have identical conditions in terms of the lessons structure, mathematical tasks and contact hours. Lessons on the straight line topic in the learning area of relation and function were taught to both groups. At the end of the study, the SLAT and the MCAS were administered to both the experimental and control groups. In addition, the experimental group was given the GCUS.

RESULTS

Students' Achievement

Means and standard deviations of the students' achievement based on the posttest given are shown in Table 1. A 5% level of significance was used for the statistical analyses. The posttest mean for the experimental group was 16. 81 (SD = 4.76) and the posttest mean for the control group was 14.05 (SD = 6.86). Using the analysis of covariance, there was a significant difference on the mean performance scores in the SLAT between the experimental and the control groups ($F(1, 37) = 15.14$, $p < 0.05$).

Students' Metacognitive Awareness Level

Means and standard deviations of students' metacognitive awareness level are shown in Table 2. The mean level of metacognitive awareness for the experimental group was 2.94 (SD = 0.37) compared to the control group mean of 3.15 (SD = 0.28). A t-test analysis indicated that there was no significant difference between the experimental and control groups ($t(36) = -1.92$, SE difference = 0.11, $p > 0.05$) on the metacognitive awareness level.

The results from this experiment provided some evidence that the use of graphic calculators can enhance learning performance among students. However, the results also showed that there was insufficient evidence to conclude that the use of graphic calculators in teaching and learning mathematics can boost students' metacognitive awareness level during mathematical problem solving.

Students' GCUS

i. Students' views about their experiences using graphic calculators in learning about of Straight Lines.

TABLE 1: Means and Standard Deviations for Experimental and Control Groups on Straight Line Achievement Test

Test		Group	
		Experimental	Control
Performance on Straight Line Achievement Test	N	21	19
	Mean	16.81	14.05
	Standard Deviation	4.76	6.86

Table 3 provides a summary of students' GCUS for the first question about students' views about their experiences using graphic calculators in learning about Straight Lines.

Overall, students' experience using graphic calculators can be divided into two positive and negative experiences. Most of the students (26 students - 92.9%) expressed their experience using graphic calculator in the learning of Straight Lines as positive. The commonly used words to describe their feelings are "interesting", "exciting",

TABLE 2: Means and Standard Deviations for Experimental and Control Groups on Metacognitive Awareness Level

Test		Group	
		Experimental	Control
Metacognitive Awareness Level	N	21	17
	Mean	2.94	14.05
	Standard Deviation	0.37	0.28

"good", and "impressive". Only two students (7.1%) felt that they had a negative experience. They were not completely convinced that graphic calculator is a useful tool in learning mathematics.

ii. Students' views on the benefits of using graphic calculators in learning about Straight Lines

Table 4 provides a summary of students' GCUS for the second question about students' views on the benefits of using graphic calculators in learning about Straight Lines.

The overall remark made by the respondents was positive and encouraging. Four categories were revealed. Firstly, 12 students (42. 9%) suggest that the use of graphic calculators helped them to understand the straight lines concept better. They claimed that graphic calculators enhanced student performance, helps in determining the value of gradient easier, draws graphs easier, helps in solving problems, and provides information and various graphing capabilities. Secondly, 12 students (42.9%) agree that the use of graphic calculators helped them to get accurate answers faster. In addition, they can save time and papers when doing problem solving. Thirdly, 3 students (10.7%) felt that the use of graphic calculators stimulates their interest in learning about Straight Lines. Finally, one student (3.6%) noted that the graphic calculator provides an opportunity in using new technology.

iii. Students' views on the difficulties experienced during the use of graphic calculators.

Table 5 provides a summary of students' GCUS for the third question about students'

TABLE 3: Students' views about their experiences using graphic calculators in learning about Straight Lines

Item 1	Students' views about their experiences using graphic calculators	
Category	Positive Experience	Negative Experience
No. of Students (%)	29 (92.9%)	2 (7.1%)

views on the difficulties caused by using graphic calculators in practice.

Out of 28 students that responded to this question, four students (14.3%) feel that they are not having difficulties, three students (10.7%) did not answer the question, and 21 students (75%) agree that they are having difficulties. The difficulties caused by using graphic calculators in practice can be summarized due to the first time that graphic calculators were introduced and were used in learning mathematics. Therefore, they don't have enough time to learn the different function keys of the graphic calculator. Majority of the students also claimed that the keys on graphic calculators are difficult to remember, many steps to follow in the instructions of using a graphic calculator, and they have to be very cautious in using the cursor to trace the coordinates on the straight line.

TABLE 4: Students' views on the benefits of using graphic calculators in learning about Straight Lines

Item 2	Students' views on the benefits of using graphic calculators			
Category	understand the straight line concept better	get the answer faster and accurate	save time and papers when doing problem solving	provides opportunity in using new technology
No. of student (%)	12 (42.9%)	12 (42.9%)	3 (10.7%)	1 (3.6%)

DISCUSSION

The results of the above experiment indicated that the use of graphic calculators in teaching and learning of mathematics could be helpful in improving students' achievement. These results support the findings from previous studies on the effects of using graphic calculators in teaching and learning of mathematics (Acelajado, 2004; Adams, 1997; Connors & Snook, 2001; Graham & Thomas, 2000; Hong et al., 2000; Horton et al., 2004; Noraini Idris, 2004, Noraini Idris et al., 2002, 2003; Quesada & Maxwell, 1994; Ruthven, 1990; Smith & Shotberger, 1997). They reported that the treated group outperformed the control group, suggesting that the use of graphing calculators significantly improved the students' achievement in mathematics.

The result of the analysis of the metacognitive awareness indicated there is insufficient evidence to prove that using graphic calculators in teaching and learning of mathematics can improve students' metacognitive awareness. This result could not prove some of the results from previous studies (Gage, 2002; Hylton-Lindsay, 1998; Keller & Russel, 1997). Gage (2002) reported that the use of graphic calculators formed a focus for reflective discussion which led to cognitive change. Students in the

TABLE 5: Students' views on the difficulties experienced during the use of graphic calculators

Item 3	Students' views on the difficulties experienced during the use of graphic calculators		
Category	not having difficulties	not answering the question	having difficulties
No. of Students (%)	4 (14.3%)	3 (10.7%)	21 (75%)

experimental group should have been asked to work in pairs to encourage reflective discussion and hence shaping the higher mental processes of the students such as their metacognitive awareness. In Hylton-Lindsay (1998), analysis of students' scores indicated that the use of graphic calculators enhanced the metacognitive aspect of students' performance, particularly students' thought processes and their ability to self-regulate. In the study by Keller and Russel (1997), students using CAS technology were more able to concentrate on developing their conceptual understanding of calculus and development of metacognitive behaviors which support problem solving. Another reason for the results not showing any differences was because the questions used in the test did not pose a high enough metacognitive awareness, the students were not able to demonstrate these skills in the test without the aid of graphic calculator, and that the short-term use of the graphic calculator was insufficient in establishing the metacognitive awareness. It is also possible that the MCAS instrument used in the study to measure general metacognitive awareness was not suitable to show the effect of the graphic calculator intervention on metacognitive awareness. These assertions merit further consideration.

Even though a few students had difficulties due to the first time that graphic calculators were introduced and used in learning mathematics, the survey findings were encouraging. Majority of the students responded positively and favorably towards using graphic calculators in teaching and learning about Straight Lines. The findings here concur with many other studies such as Forster (2001), Hennesey et al., (2001), Kee and Sam (2003), and Smith and Shortberger (1997). For example, from the cognitive domain study by Smith and Shortberger (1997) it was found that "more than 70% of the students specifically identified the calculator as helping them to "understand more fully" or to see certain ideas "better" (p. 373). The survey and the case study of

Hennesey et al. (2001) support the conclusion that graphic calculators facilitated graphing using visual representation, by making the process less time-consuming, and encouraging translation. An interesting result from the study by Kee and Sam (2003) was that students "looked upon themselves as technological-able and valued themselves as more marketable in the society" (p. 23). However, a few studies also demonstrated that there are some difficulties associated with the use of graphic calculators such as using an incorrect syntax for formula entry leading to incorrect answers (Hong et al., 2000) and the top-down character of a CAS, its black-box style and its idiosyncrasies of syntax produced obstacles during the performance of instrumentation schemes and during the interpretation of the results (Drijvers, 2000).

CONCLUSION

The findings of this study provide enough evidence to conclude that there are pedagogical impacts of the use of graphics calculator technology as a tool in teaching and learning of mathematics in Malaysia. The study revealed that the use of graphic calculators improved students' achievement in studying about Straight Lines. However, a number of students had difficulties in using graphic calculators because it was the first time the graphic calculator was introduced to them as a mathematics learning tool. The study also showed that there is not enough evidence to conclude that using graphic calculators in teaching and learning of mathematics can improve students' metacognitive awareness. This finding is a reminder to researchers to emphasize on the need to give due considerations when designing future experiments. It is noteworthy to observe that the results of this experiment were achieved under certain conditions and limitation and thus may not be applicable to all situations.

REFERENCES

ACELAJADO, M.J. 2004. Use of graphing calculator: Effect on students' achievement in ANMATH1 and anxiety in mathematics. In *USM Proceeding Series, Integrating Technology in the Mathematical Sciences*, ed. Yahya Abu Hassan, Adam Baharum, Ahmad Izani Mohd. Ismail, Koh Hock Lye and Low Heng Chin. Pulau Pinang, Malaysia: Universiti Sains Malaysia.

ADAMS, T.L. 1997. Addressing students' difficulties with the concept of function: applying graphing calculators and a model of conceptual change. *Focus on Learning Problems in Mathematics* **19(2):** 43-57.

ARY, D., L.C. JACOBS and A. RAZAVIEH. 1996. *Introduction to Research in Education.* Florida: Harcourt Brace College Publishers.

BOTTINO, R.M. 2004. The evolution of ICT-based learning environment: which perspectives for the school of the future. *British Journal of Educational Technology* **35(5):** 553-567.

Brunning, R.H., G. J. Schraw, M.M. Norby and R.R. Ronning. 2004. *Cognitive Psychology and Instruction*. 4th Ed. Upper Saddle River, New Jersey: Merrill Prentice Hall.

Burill, G., J. Allison, G. Breaux, S. Kastberg, K. Leatham and W. Sanchez. 2002. Handheld graphing technology in secondary mathematics: Research findings and implications for classroom practice. Dallas, TX: Texas Instruments Corp.

Byrnes, J.P. 2001. *Cognitive Development and Learning in Instructional Contexts*. 2nd Ed. Needham Height, Maryland: Allyn and Bacon.

Confrey, J. 1990. What constructivism implies for teaching. In *Constructivist Views on the Teaching and Learning of Mathematics*, JRME Monograf, No. 4, ed. R. Davis, C. Maher and N. Nodings. Reston, VA: NCTM.

Connors, M.A. and K.G. Snook. 2001. The effects of hand-held CAS on students achievement in a first year college core calculus sequence. *The International Journal of Computer Algebra in Mathematics Education* **8(2):** 99-114.

Cook, T.D. and J.D. Campbell. 1979. *Quasi-Experimentation: Design & Analysis Issues for Field Settings*. Boston, Mass. : Houghton Mifflin.

Dofler, W. 1993. Computer use and views of the mind. In *Learning from Computers: Mathematics Education and Technology*, ed. C. Keitel and K. Ruthven, p. 159-186. NATO ASI Series, Series F and Systems Sciences. London: Springer-Verlag.

Doerr, H.M. and R. Zangor. 2000. Creating meaning for and with the graphing calculator. *Educational Studies in Mathematics* **41:** 143-163.

Drijvers, P. 2000. Students encountering obstacle using a CAS. *International Journal of Computers for Mathematical Learning* **5(3):** 189-209.

Dunham, P. H. and T. Dick. 1994. Research on graphing calculators. *The Mathematics Teacher* **87(6):** 440-445.

Dunham, P. H. 2000. Hand-held calculators in mathematics education: A research perspective. In *Hand-Held Technology in Mathematics and Science Education: A Collection of Papers*, ed. E. D. Laughbaum, p. 39–47. Ohio: Ohio State University.

Fraenkel, J.R. and N.E. Wallen. 2006. *How to Design and Evaluate Research in Education*. 7th ed. Forth Worth: Holt Rinehart and Winston Inc.

Forster, P. A. 2000. Process and object interpretations of vector magnitude mediated by use of the graphics calculator. *Mathematics Education Research Journal* **12(3):** 269-285.

Gage, J. 2002. Using the graphic calculator to form a learning environment for the early teaching of algebra. *The International Journal of Computer Algebra in Mathematics Education* **9(1):** 3-28.

GRAHAM, A.T. and M.O.J. THOMAS. 2000. Building a versatile understanding of algebraic variables with a graphic calculators. *Educational Studies in Mathematics* **41:** 265-282.

HENNESSY, S. 2000. Graphing investigations using portable (palmtop) technology. *Journal of Computer Assisted Learning* **17:** 243–258.

HENNESEY, S., P. FUNG and E. SCANLON. 2001. The role of graphic calculator in mediating graphing activity. *International Journal of Mathematical Education in Science and Technology* **32:** 267-290.

HONG, Y., M. TOHAM and C. KIERNAN. 2000. Supercalculators and university entrance calculus examinations. *Mathematics Education Research Journal* **12(3):** 321-326.

HORTON, R.B., J. STORM and W.H. LEORNARD. 2004. The graphing calculator as an aid to teaching algebra. *Contemporary Issues in Technology and Teacher Education* **4(2):** 152-162.

HYLTON-LINSAY, A.A. 1998. The effect of the graphing calculator on metacognitive aspects of student performance in precalculus for business (Columbia University Teachers College 1997). Digital Dissertation ProQuest (AAT 9810960).

JONES, P. 1996. Handheld technology and mathematics: Towards the intelligent partnership. In Roles of Calculators in the Classroom, ed. P. Gomez and B. Waits, p. 87-96. Retrieved October 22nd, 2004 from http:www.ued.uniandes.edu.co/servidor/em/recinf/tg18/Base/WWWfiled-1.html.

JONES, P. 2000. Realizing the educational potential of the graphics calculator. In *Hand-Held Technology in Mathematics and Science Education: A Collection of Papers*, ed. E. D. Laughbaum, p. 68 – 71. Ohio State University.

JONES, P. 2003. The graphics calculator: Education potential & challenges. In *Proceeding of 1st National Conference on Graphing Calculators*, p. 46-55, 11 – 12 July , Hotel Singgahsana, Petaling Jaya. Kuala Lumpur, Malaysia: Universiti Malaya.

KASTBERG, S. and K. LEATHEAM. 2005. Research on graphing calculators at the secondary level: Implications for mathematics teacher education. *Contemporary Issues in Technology and Teacher Education* **5(1):** 25-37.

KAPUT, J.J. 1992. Technology and mathematics education. In *Handbook on Research on Mathematics Teaching & Learning*, ed. D.A. Grouws, p. 515-574. New York: Macmillan.

KELLER, B. and C. RUSSELL. 1997. Effects of the TI-92 on calculus students solving symbolic problems. *International Journal of Computer Algebra in Mathematics Education* **4:** 77-97.

KISSANE, B. 2000. Technology and the curriculum: The case of the graphics calculator. *In Proceeding of TIME 2000: An International Conference on Teaching in Mathematics Education*, ed. M. J. Thomas, p. 60-71). Auckland, New Zealand. Retrieved July 16th, 2004 from http://www.staf.murdoch.edu.au/~kissane/papers/ATCM99.pdf

KOR LIEW KEE and LIM CHAP SAM. 2003. Learning statistics with graphics calculator: A case study. In *Proceeding of 1st National Conference on Graphing Calculators*, p. 18-26, 11 – 12 July, Hotel Singgahsana, Petaling Jaya. Kuala Lumpur, Malaysia: Universiti Malaya.

MEIRA, L. 1995. The microevolution of mathematical representations on children's activities. *Cognition and Instruction* **13:** 269-313.

MEIRA, L. 1998. Making sense of instructional devices: The emergence of transparency in mathematical activity. *Journal for Research in Mathematics Education* **29(2):** 121-143.

MERRIWEATHER, M. and M.L. THARP. 1999. The effect of instruction with graphing calculators on how general mathematics students naturalistically solve algebraic problems. *Journal of Computers in Mathematics and Science Teaching* **19(1):** 7 – 22.

MINISTRY OF EDUCATION MALAYSIA. 2005. Integrated curriculum for Secondary Schools, Curriculum Specification, Mathematics Form 4, Kuala Lumpur, Malaysia: Curriculum Development Centre.

MUHD. KHAIRILTITOV ZAINUDDIN. 2003. Penggunaan kalkulator grafik di sekolah-sekolah di Malaysia: Penerokaan dan cabaran. In *Proceeding of 1st National Conference on Graphing Calculators*, p. 133, 11 – 12 July, Hotel Singgahsana, Petaling Jaya. Kuala Lumpur, Malaysia: Universiti Malaya.

NATIONAL COUNCIL FOR TEACHERS OF MATHEMATICS. 2000. *Principles and Standards for School Mathematics*. Reston, VA: NCTM.

NORAINI IDRIS. 2003. Communication in mathematics: Usage of graphing calculator. In *Proc. of 1st National Conference on Graphing Calculators*, p. 91- 107, 11 – 12 July, Hotel Singgahsana, Petaling Jaya. Kuala Lumpur, Malaysia: Universiti Malaya.

NORAINI IDRIS. 2004. Exploration and entertainment mathematics: Why graphics calculator? In *Proc. of 2nd National Conference on Graphing Calculators*, 4 – 6 October , Penang. Malaysia: Universiti Sains Malaysia.

NORAINI IDRIS, TAY BEE LIAN, DING HONG ENG, GOH LEE SIEW and NILAWATI MAHFUD. 2003. A graphing calculator-based instruction and its impact on the teaching and learning of mathematics. In *Proc. of 1st National Conference on Graphing Calculators*, p. 1-17, 11– 12 July, Hotel Singgahsana, Petaling Jaya. Kuala Lumpur, Malaysia: Universiti Malaya.

NUNNALLY, J.C. 1978. *Psychometry Theory*. 2nd Ed. New York: McGraw Hill Book Company.

O'NEIL, H.F. and J. ABEDI. 1996. Reliability and validity of a state metacognitive inventory: Potential for alternative assessment. *Journal of Educational Research* **89:** 234-245.

PAAS, F., A. RENKL and J. SWELLER. 2003. Cognitive load theory and instructional design: Recent developments. *Educational Psychologist* **38:** 23-32.

PEA, R.D. 1985. Beyond amplification: using the computer to recognize mental functioning, Special issue: Computers and education. *Educational Psychologist* **20(4):** 167 – 182.

PENGLASE, M. and S. ARNOLD. 1996. The graphics calculator in mathematics education: a critical review of recent research. *Mathematics Education Research Journal* **8(1):** 58-90.

QUESADA, A.R. and M.E. MAXWELL. 1994. The effects of using graphing calculators to enhance college students' performance in precalculus. *Educational Studies in Mathematics* **27:** 205-215.

ROGERS, Y. and M. SCAIFE. 1997. *Distributed Cognition COGS.* University of Sussex.

RUTHVEN, K. 1990. The influence of graphic calculator use on translation from graphic to symbolic forms. *Educational Studies in Mathematics* **21:** 431-450.

RUTHVEN, K. 1996. Calculators in the mathematics curriculum: The scope of personal computational technology. In *International Handbook of Mathematics Education*, ed. A. J. Bishop, K. Clements, C. Keitel, J. Kilpatrick, and C. Laborde, p. 435-468. Netherlands: Kluwer Academic Publishers.

SALOMON, G. 1990. On the cognition effects of technology. In *Psychological Development Culture, Schooling*, ed. L.T. Landsman, p. 91-100. Norwood, New Jersey: Ablex Publishing.

SALOMON, G., D.N. PERKINS and T. GLOBERSON. 1992. Partners in cognition: Extending human intelligence with intelligent technologies. *Educational Researcher* **20(3):** 2-9.

SMITH, K.B. and P.G. SHOTSBERGER. 1997. Assessing the use of graphing calculators in college algebra: Reflecting on dimensions of teaching and learning. *School Science and Mathematics* **97:** 368-376.

SWELLER, J. 1988. Cognitive load during problem solving: Effects on learning. *Cognitive Science* **12:** 257-285.

SWELLER, J., J. VAN MERRIENBOER and F. PASS. 1998. Cognitive architecture and instructional design. *Educational Psychology Review* **10(3):** 251-296.

VYGOTSKY, L.S. 1978. *Mind in Society.* Cambridge, MA: Cambridge University Press.

WAITS, B. and F. DEMANA. 2000. Calculators in mathematics teaching and learning: Past, present and future. In *Learning Mathematics for a New Century: 2000 Yearbook*, ed. M.J. Burke and F.R. Curcio, p. 52-66. Reston, VA: National Council of Teachers of Mathematics.

WHEATLEY, C.L. 1980. Calculator use and problem-solving performance. *Journal for Research in Mathematics Education* **80(7):** 620-624.

WORTHEN, B. R., K.R. WHITE, X. FAN and R.R. SUDWEEKS. 1999. *Measurement and Assessment in Schools*. New York: Longman.