Effects of Use of Graphic Calculators on Performance in Teaching and Learning Mathematics

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ABSTRAK

Ada peningkatan minat dalam menggunakan teknologi genggam, terutama kalkulator grafik, oleh para guru matematika, pengembang kurikulum, dan guru pada umumnya seperti dijelaskan dalam beberapa studi. Meskipun teknologi grafik genggam sudah ada sejak hampir dua dekade, penggunaan kalkulator grafik dalam ruangan kelas sekolah menengah belum berterima, dipahami, dan didokumentasikan secara baik dan universal. Di Malaysia, penelitian tentang penggunaan kalkulator grafik masih sangat baru dan memerlukan kajian lebih lanjut, terutama dalam konteks pembelajaran matematika di sekolah menengah. Penelitian ini menggunakan metode quasi-experimental dengan desain kelompok kontrol non-equivalent yang menggunakan dua kelompok utuh empat siswa. Tujuan utama penelitian adalah untuk menginvestigasi pengaruh penggunaan kalkulator grafik terhadap kinerja siswa dalam bidang pembelajaran relasi dan fungsi. Temuan dari penelitian ini memiliki pengaruh pedagogis penting terhadap penggunaan teknologi kalkulator grafik sebagai alat pengajaran dan pembelajaran matematika.

Kata Kunci: teknologi genggam, kalkulator grafik, pengaruh pedagogis

Technology has become the core feature in the Malaysian Smart School Curriculum especially mathematics curriculum. One of the emphases in teaching and learning of mathematics for secondary schools is the application of technology. The use of technology such as calculators, computers, educational software, websites in the Internet and relevant learning packages can help to upgrade the pedagogical approach and thus promote the understanding of mathematical concepts in depth, meaningfully and precisely (Ministry Of Education Malaysia, 2005). This is in agreement with the aim of the mathematics curriculum: to develop individual that enable him/her to face challenges in everyday life that arise due to the advancement of science and technology (Ministry Of Education Malaysia, 2005).

The significance of using technology in studying mathematics which supports the aim of Integrated Curriculum for Secondary Schools is captured in "The Technology Principle" as stated in Principles and Standards for School Mathematics, "Technology is essential in teaching and learning mathematics, it influences the mathematics that is taught and enhances students' learning" (National Council for Teachers of Mathematics, 2000, p.24]. Thus, in parallel with the growth of technological, educators are responsible to design and develop mathematics instructional methods and strategies that employ the latest technology which could enhance students' mathematical power.

As in many other countries, schools in Malaysia are equipped with computers in computer laboratories but not all students could have access to them regularly. Those computers are used for all subjects taught in school. Hence, access to computers would be irregular for mathematics' lesson. To make the national agenda of introducing technology in the classroom a reality, another form of classroom technology is needed.

There are many kinds of technology that are considered relevant to schools mathematics these days. These range from very powerful computer system, such as Mathematica, Maple, and MathLab to much less powerful technologies such as paper and pencil. Among those, there has been a steady increase in interest in using hand-held technologies, in particular graphics calculators, by mathematics educators and curriculum developers and teachers. The choice of graphic calculators is motivated mainly by the potential for them to be available to essentially all students all of the time (Kissane, 2000). In fact, graphic calculators are purpose built hand-held battery powered mathematics computers that are equipped with functions to draw and analyses graphs, computes the values of mathematical expression, solves equations, perform symbolic manipulation (requires CAS), performs statistical analyses, programmable, and communicates information between devices (Jones, 2003).

To date, there is a substantial body of research into the use of graphics calculators that have shown positive impact on students' achievement (Burill et al., 2002; Dunham, 2000; Dunham, 1994; Kastberg & Leatheam 2005; Penglase & Arnold, 1996; Ruthven, 1996). However, research on the use of the technology is not robust although handheld graphing technology has been available for nearly two decades (Burill et al., 2002). Its' use in secondary classrooms is not well understood, universally accepted, nor well-documented. In Malaysia, research on the usage of graphics calculators is still in its infancy and therefore its use has yet to be explored (Zainuddin, 2003; Idris, 2004). Thus, there is a need to further research in this area in the context of teaching mathematics at the Malaysian secondary school level.

Dunkin and Biddle (1974) present a model to guide the study of teaching and learning. The model is based on the original work of Mitzel's (1960) Model of Teaching. While the model is somewhat dated, it still provides a good background for a discussion of teaching and learning. Dunkin and Biddle propose that the study of teaching and learning involved four major variable types: presage variables, context variables, process variables, and product variables. Figure 1 displays the model reflecting those variables.

Presage variables are variables that influence teachers and their teaching behaviors such as teacher formative experiences, teacher training experiences and teacher properties. Context variables represent conditions to which the teacher must adjust including the population and the background of the learners, classroom, school and the community. Process variables describe the actual activities of classroom teaching. These variables involve the interactions of the teacher and student behaviors in the teaching-learning process. The instructional activities planned and carried out in the classroom are categorized as process variables. Finally, product variables are simply the desired outcomes of education. They are including the immediate pupil growth such as subject matter-learning and attitude toward the subject, and also concerned with long-term effects of education such as the development of a person's adult personality, the development of professional competence, and etc.

Throughout the model, each arrow presumes a causative relationship. According to the model, the presage and the context variables have a causative effect on the classroom events. As indicated by the model, the classroom behavior of the teacher, as well as the teacher-student interaction, plays a significant role in students' outcomes. This study will investigate the effect of instructional strategy (process variable) such as using graphic calculator strategy on students' performance (product variables). The design of the study will control for presage and context variables.

Cognitive load theory (CLT) (Sweller, 1988; 1994) is an internationally well known and widespread theory which focuses on the role of working memory in the development of instructional methods. The theory originated from the information processing theory in the 1980s and underwent substantial changes and extensions in the 1990s (Pass, Renkl & Sweller, 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. Specifically, CLT emphasizes structures that involve interactions between LTM and STM or working memory which play a significant role in learning. One major assumption of the theory is that a learner's working memory has only limited in both capacity and duration. Under some conditions, these limitations will somehow impede learning.

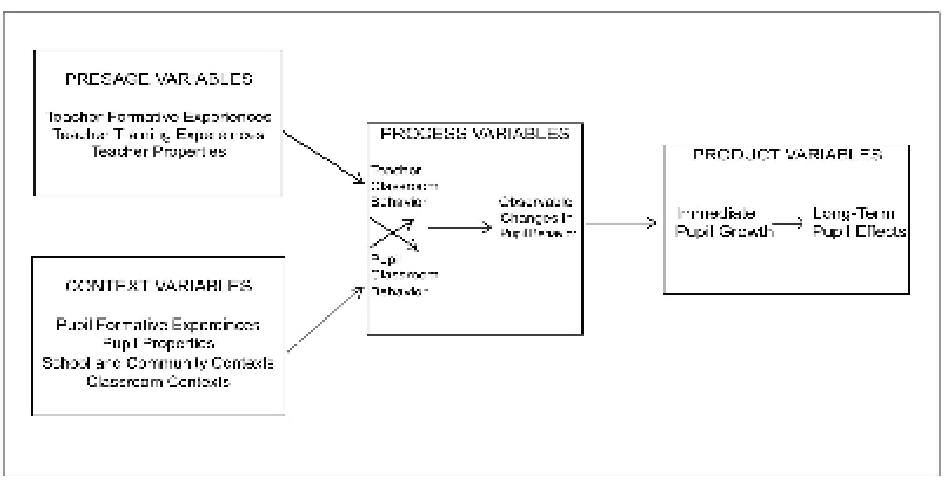

Figure 1: A Model for the Study of Classroom Teaching (Source: Adapted from Dunkin, M. J. and Biddle, B. J. (1974). The Study of Teaching; p. 3)

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

According to CLT, learning will fail if the total cognitive load exceeds the total mental resources in working memory. With a given intrinsic cognitive load, a well-designed instruction minimizes extraneous cognitive load and optimizes germane cognitive load. This type of instructional design will promote learning efficiently, provided that the total cognitive load does not exceed the total mental resources during learning. Since little consideration is given to the concept of CLT, that is, without any consideration or knowledge of the structure of information or cognitive architecture, many conventional instructional designs are less than effective (Pass, Renkl & Sweller, 2003). Further, many of these methods involve extraneous activities that are unrelated to the acquisition of schemas and rule automation. In addition, Bannert (2002) and Sweller et al. (1998) argue that in many cases it is the instructional design which causes an overload, since humans allocate most of their cognitive resources to working memory activities when learning. These extraneous activities will only contribute to the unnecessary extraneous cognitive load in which it can be detrimental to learning. Thus, for better learning and transfer performance is achieved, the main idea of the theory is to reduce such form of load in order to make more working memory capacity for the actual learning environment. In other words, the main premise of CLT is that instructional design should take into account the limitations of working memory.

Until five years ago, studies on CLT have found several effects that affect the effectiveness of teaching practices such as goal free effect, worked examples effect, problem completion effect, split-attention effect, redundancy effect, and modality effect. CLT was primarily used to study instructional methods intended to decrease extraneous cognitive load for novice learners. However, over the last five years, more and more CLT related studies have investigated the effects of instructional manipulations on intrinsic and germane cognitive load, and related those effects to the level of expertise of the learners (van Merrienboer & Sweller, 2005).

Recently, more and more applications of CLT have begun to appear in the field of technology learning environment (e.g., van Merrienboer and Ayres, 2005; Mayer and Moreno, 2003, Pass et al., 2003). 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; Pumadevi, 2004; 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.

The main objective of the study is to investigate the effects of using graphics calculator on form four secondary school students' mathematics performance in the learning area of relation and function, specifically in the topic of Straight Lines. In this study, performance was measured by the number of problems solved during the test phase, the total score of the conceptual knowledge for the test phase, the total score of the procedural knowledge for the test phase, the total score of the test phase, the number of similar problems solved during the test phase, the total scores of similar problems for the test phase, the number of transfer problems solved during the test phase, and the total scores of transfer problems for the test phase. Further, students' views about their experiences using graphic calculators in the learning of mathematics, the benefits of using graphic calculators in the learning of mathematics and the difficulties caused by using graphics calculators in practice were also sought.

Method

The research study employed the quasi-experimental non-equivalent control group design. The sample of the study consisted of two intact classes of form four students from a secondary school in Selangor, Malaysia. According to the principal and mathematics teachers, both groups had comparable socio-economic and ethnic background, and each class was assigned with mixed ability - high, average and low. In order to control the differences in the dependent variables, the monthly test was used as a proxy pretest (Cook & Campbell, 1979). For this study, one class was assigned to be the experimental group (21 students) and the other class was assigned to be the control group (19 students). The experimental group was guided by the instructional formats that incorporate the use of TI-83 Plus graphic calculators. The control group students were guided by the same instructional formats with one exception. It is a conventional whole-class instruction and they were not allowed to use the TI-83 Plus graphic calculator.

The instruments in this study consisted of a Straight Lines Achievement Test (SLAT) and a Graphic Calculator Usage Survey (GCUS). The SLAT was designed by the researcher to measure students' understanding of the Straight Lines topic. It comprised of seven questions based on the subtopic of straight lines covered in the experiment. The time allocated to do the test is 40 minutes. The overall scores for the SLAT are 40. The GCUS was prepared by the researcher to determine students' of GCS group views about the graphic calculator usage in teaching and learning of mathematics. There are three open questions in the survey: (i) Explain your experience using graphic calculators in learning of Straight Lines topic, (ii) What do you think are the benefits of using graphic calculators in learning of Straight Lines topic, and (iii) What are the difficulties caused by using graphic calculators in practice.

The experiment lasted for 2 weeks with the researcher handling the two intact classes scheduled consecutively on the same day, three times a week, 40 minutes per meeting. Both groups have identical conditions in terms of the lessons structure, mathematical tasks and contact hours. 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. At the end of the study, the SLAT was administered to both the experimental and control groups. In addition, the experimental group was given the GCUS which requested information on students' views of the graphic calculator usage.

Results

Students' mathematics performance

Table 1 gives the means and standard deviations of the monthly test score for both graphic calculator (GC) and conventional groups. The total monthly test score is 100. The mean score for the experimental group and the control group are 59.00 and 59.26 respectively. For all statistical analyses, the 5% level of significant is used throughout the paper. The result of the t-test indicates that there is a statistically no significant difference between the mean of monthly test score for the GC group and conventional group ($t\ (38) = -0.051$, $p > 0.05$, SE difference $=5.183$). This suggested that the students' mathematics performance for both groups in our sample does not differ significantly. Therefore, an independent samples t-test is used to compare the means of the dependent variables for both two independent groups, GC group and conventional group.

Table 1: Means and Standard Deviations for Experimental (graphic calculator) and Control (conventional) Groups on Monthly Test

Test		Group	
		Graphic Calculator	Conventional
Monthly Test	N	21	19
	Mean	59.00	59.26
	Standard Deviation	10.252	21.189

Table 2: Means and Standard Deviations for Graphic Calculator and Conventional Groups on Aspects of Performance

Aspects of Performance		Group	
		Graphic Calculator	Conventional
No. of problems solved	Mean	2.19	1.53
	SD	1.12	0.84
Total score of the conceptual knowledge	Mean	9.10	7.26
	SD	3.40	3.46
Total score of the procedural knowledge	Mean	7.71	5.26
	SD	2.43	2.56
Total score of the test	Mean	16.81	12.53
	SD	4.76	4.99
No. of similar problems solved	Mean	1.48	1.26
	SD	0.75	0.65
Total scores of similar problems	Mean	9.67	8.21
	SD	2.00	1.96
No. of transfer problems solved	Mean	0.71	0.26
	SD	0.85	0.56
Total scores of transfer problems	Mean	7.14	4.32
	SD	5.00	4.22

The means and standard deviations of the variables under analysis are provided in Table 2. The posttest data were analyzed with independent samples t-test. As can be seen from Table 2, the GC group (M= 2.19) has a higher mean for the number of test problems solved than the conventional group (M= 1.53). However, the t-test showed that the differences in the means were not significant, t(38) = 2.098, SE difference = 0.317. This implies that both groups performed more or less equally on the test problems.

Similar results were obtained for the other variables such as the total score of the procedural knowledge (t(38) = 1.686, SE difference = 1.087, $P > 0.05$), the number of similar problems solved (t(38) = 0.953, SE difference = 0.223, $P > 0.05$), the number of transfer problems solved (t(38) = 1.965, SE difference = 0.230, $P > 0.05$), and the total score of transfer problems (t(38) = 1.921, SE difference = 1.471, $P > 0.05$). This indicates that the GC and the conventional groups were scoring more or less the same for the procedural knowledge and the transfer problems, and also both groups were successfully solved more or less the same number of similar and transfer problems during the test phase.

For the total score of the procedural knowledge (t(38) = 3.107, SE difference = 0.789, $P < 0.05$), the total score of the test phase (t(38) = 2.777, SE difference = 1.543, $P < 0.05$), and the total scores of similar problems (t(38) = 2.316, SE difference = 0.629, $P < 0.05$), the data analyses indicated a significant difference between the GC and conventional groups. The GC group has higher means for all the three variables (M=7.71, 16.81, and 9.67 respectively) than the conventional group (M= 5.26, 12.53, and 8.21 respectively). This indicates that the GC group was scoring better for the conceptual knowledge, test questions phase, and similar problems than the conventional group.

Overall, the results of the t-test analyses indicate that both groups were quite similar in performing the test problems, scoring the procedural knowledge and the transfer problems, and solving the number of similar and transfer problem during the test phase. However, the GC group has performed better than the conventional group on all the total scores such as the conceptual knowledge, the test questions, and similar problems accept the score for the transfer problems. This result might due to the short-term use of the GC was insufficient in demonstrating the transfer problems skills in the test without the aid of GC. Dick (1992) asserts that the time available for students to concentrate on analyzing problems and solution is doubled.

> With powerful numeric, graphical, and symbolic computational tools in hand, the students can see the 'carry out the plan' stage of problem solving as the least daunting step. Students appreciate more the relative importance of heuristics processes, mathematical modeling, and the interpretation of results. [15, p. 152]

It is also important to note that the use of GC does assist in increasing conceptual knowledge score without adversely affecting procedural knowledge score which is in line with Barton's report (Connors & Snook, 2001). The findings of this study also supported the previous syntheses of the literature and meta-analyses on the effects of using GC in teaching and learning of mathematics indicated that overall, handheld graphing technology can be an important factor in helping students develop better understanding of mathematical concept, score higher on performance measures, and achieve a higher level of mathematical problem solving skills (e.g. (Burill et al., 2002; Connors & Snook, 2001, Dunham, 2000; Dunham, 1994; Kastberg & Leatheam 2005).

Students' GCUS Summary

(i) Students' views about their experiences using graphic calculators in learning of straight Lines topic

Overall, students' experience using graphic calculator can be divided into two categories: positive experience and negative experience. Most of the students (26 students - 92.9%) expressed their experience using graphic calculator in learning of Straight Lines topic with positive affection. The commonly used words to describe their feelings are "interesting", "exciting", "good", and "impressive". Only two students (7.1%) feel that they have negative experience. There 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 the learning of Straight Lines topic

The overall remark made by the respondents was positive and encouraging. There were four categories found. Firstly, 12 students (42. 9%) suggest that the GC usage helps them to understand the straight lines concept better. They claimed that GC usage enhances students' performance, helps in determining the value of gradient easier, draws graph easier, helps in solving problems, and provides information and various graphing capabilities. Secondly, 12 students (42.9%) agree that the GC usage helps them to get the answer faster and accurate. In addition, they can save time and papers when doing problem solving. Thirdly, 3 students (10.7%) feel that the GC usage stimulates their interest in learning the Straight Lines topic. Finally, one student (3.6%) notes that the GC usage provides opportunity in using new technology.

(iii) Students' views on the difficulties caused by using graphic calculators in practice.

Out of 28 students that respond 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 GC in practice can be summarized due to the first time that GC were introduced and were used in learning mathematics. Therefore, they do not have enough time to learn the different function keys of the GC. The majority of the students also claimed that the keys on GC are difficult to remember, many steps to follow in the instructions of using GC, and they have to be very cautious in using the cursor to trace the coordinates on the straight line.

Overall, even though a few students are having difficulties due to the first time that GC were introduced and were used in learning mathematics, we are very encouraged with the survey findings. The majority of the students responded positively and favorably towards using GC in teaching and learning of Straight Lines topic. This result coincides with many other studies such as Hennesey et al. (2001), Kor Liew Kee & Lim Chap Sam (2003), and Quesada (2003), Smith and Shortberger (1997). For example, from the cognitive domain Smith and Shortberger (1997) 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 GCs facilitated graphing using visual representation, by making the process less time-consuming, and encouraging translation. An interesting result from the study by Kor Liew Kee & Lim Chap Sam (2003) is that students "looked upon themselves as technological-able and valued themselves as more marketable in the society" (p. 23). However, a few studies also demonstrate that there are some difficulties associated with the use of GC such as using an incorrect syntax for formula entry leading to incorrect answer (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 results from the experiment provided some evidence that the use of GC can be helpful in improving students' performance in mathematics. Specifically, this study showed that the treatment group outperformed the control group in students' conceptual knowledge score, test phase score and similar problems score of a Straight Lines topic. A number of students also had difficulties in using GCs due to the first time the GC were introduced and were used in learning mathematics.

It is also important to note that simply having access to technology does not insure it will be used to enhance learning of mathematics (Connors & Snook, 2000). Moreover, Dunham and Dick (1994) also noted that the mere presence of graphing technology may not account for the positive results that have been found in studies. Several studies also suggested that the impact of the technology in the secondary classroom might depend as much on the ways in which the technology is used to mediate mathematics in the classroom [e.g. Burrill et al., 2002; Hennessey, 2000). In general, more research is uncovering the specific areas of mathematics that are helped by graphic calculator use and those areas that are hindered by the technology. It is not really clear what causes the improvement in scores when the GC is used. Several factors may be considered. Thus, the findings of the study will be used to help the researcher to emphasize the need to highlight certain considerations when designing future experiments.

When designing future experiments, the researcher would like to emphasize on the cognitive load theory which focuses on the role of working memory in the development of instructional methods. Since little consideration is given to the concept of CLT, many conventional instructional designs are less than effective (Pass et al., 2003). Thus, for better learning and transfer performance is achieved, the main idea of the theory is to reduce such form of load in order to make more working memory capacity for the actual learning environment. Some researchers have suggested that the use of calculators and/or GCs can reduce cognitive load when students learn to solve mathematics problems (Jones, 1996, Kaput, 1992; Pumadevi, 2004; Wheatley, 1980). This possibility will be further tested in future experiments.

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