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Impact of Using Graphing Calculator in Problem Solving

Mary Ann Serdina Parrot [1], Kwan Eu Leong [1*]

[1] University of Malaya, Kuala Lumpur, MALAYSIA

* CORRESPONDENCE: rkleong@um.edu.my

ABSTRACT

The purpose of this study is to investigate the impact of graphing calculator on students' problem solving success in solving linear equation problems and their attitude toward problem solving in mathematics. A quasi-experimental non-equivalent control and treatment group using the pre-test post-test design was employed in this study to test the hypotheses. The sample of the study involved two Form Four classes from one public secondary school in Sarawak, Malaysia. Students in the experimental group received problem solving based instruction using graphing calculator while the control group students underwent the traditional chalk and talk method without the graphing technology. Two instruments were used in this study, namely the Linear Equation Problem Solving Test and the Mathematical Problem Solving Questionnaire. Findings of this study show existence of a significant difference in the mean scores between the two groups; students who used graphing calculator performed better in problem solving tasks compared to students without access to graphing calculator. Furthermore, a questionnaire was used to obtain students' attitude toward problem solving in mathematics. Results from the survey revealed that students who use graphing calculator have a better attitude toward problem solving in mathematics. This study is pertinent as it investigates a different approach in teaching linear equation through problem solving while integrating the latest graphing calculator technology in the lessons.

Keywords: graphing calculator, linear equations, problem solving success, secondary students

INTRODUCTION

Almost everything in life is a problem and it has become the central part of human life as well as in the mathematics field. The beginning of mathematics has been influenced by mathematicians making an effort to work out challenging problems. For most mathematical scholars, mathematics is tantamount to solving problems in such a way when we are doing mathematics; looking for patterns, interpreting diagrams, word problem, proving theorem and so on. A remark made by Paul Halmos, "The mathematician's main reason for existence is to solve problems" (Halmos, 1980). The ability to solve problems cannot be learnt separately; it has to be taught along with other skills as an on-going process building up of experience in acquiring strategies to solve problems. Hence, the expression of "problem solving" has to be understood as a long-term goal to achieve and hopefully this skill will be used in everyday life.

With advances in information and communications technology, it is impossible to avoid the impact of technology on mathematical problem solving. Technology use also contributes to mathematical reflection, problem identification, and decision making. With guidance from effective mathematics teachers, students at different levels can use these tools to support and extend mathematical reasoning and sense making, gain access to mathematical content and problem-solving contexts, and enhance computational fluency. Recently, a steady increase in interest in using hand-held technologies in particular graphic calculators, has been seen among mathematics educators, curriculum developers, and teachers (Kissane, 2000). Use of graphing

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calculators in learning mathematics will allow students to explore and model mathematical problems and view multi representation of mathematical problems. Technology that supports multiple representations can increase students' use of visualization in problem solving and lead to gains in understanding (Center for Technology in Learning, 2007).

PROBLEM STATEMENT

In real life, students need to solve problems because this is a skill needed in the 21st century to succeed in life. Skills endow people to face with challenges of everyday life, related to making decisions, solving problems and dealing with unexpected events. To become a good problem solver in mathematics, one must develop a base of mathematics knowledge (Wilson, Fernandez, & Hadaway, 1993). According to Mayer, there are four types of knowledge pertaining to problem solving, namely: (1) linguistic and factual knowledge, (2) schema knowledge, (3) algorithmic knowledge, and (4) strategic knowledge (Mayer, 1982). Difficulty in problem solving might happen throughout the following phases of knowledge, that is, reading, comprehension, choosing strategy, executing strategies, transformation, process skill and solution (Newman, 1983).

Mathematics skills such as language, number fact, information and arithmetic are vital in problem-solving. Deficiency in any of these skills could cause difficulties among students who want to become good problem solvers (Tambychik, Meerah, & Aziz, 2010). Past research indicated that many students who are lacking in mathematical skills face difficulties in carrying out mathematical tasks involving problem solving (Tambychik, 2005; Tay, 2005). The ability to use cognitive abilities in learning is crucial for meaningful learning to take place. However, many students face hindrances in using these cognitive abilities. They were reported to face difficulties in making accurate perceptions and interpretations, memorizing and retrieving facts, concentrating and using their logical thinking (Andersson & Lyxell, 2007; Bryant, 2009; Tambychik, 2005). Students did not totally acquire mathematics skills needed especially in problem-solving; failure in problem-solving generally resulted from failing to organize the mathematical operations, to choose the most effective method, to analyze, to understand the point of the problem and to monitor and control operations carried out (Victor, 2004).

In Malaysia, studies had shown that students faced difficulty in mathematics especially in problem-solving because they had problems in understanding and retrieving concepts, formulas, facts and procedure; they lack the ability to visualize mathematics problems and concepts, are inefficient in logic-thinking and lack the strategic knowledge in problem-solving (Kadir et al., 2003; Tambychik, 2005; Tay, 2005). A study conducted on 242 Form Four students to evaluate the level of Malaysian students' problem solving ability showed that students have fairly good command of basic knowledge and skills but they did not show the use of problem solving strategies. The common strategy used by students was algorithms and procedures as well as counting; these students did not use more suitable and effective strategies. Generally, the mastery of problem solving skills among Malaysian students is still low (Zanzali & Lui, 1999). In the Programme for International Student Assessment (PISA) on problem solving, Malaysia ranked 39 out of 44 countries, with a mean score of 422 which is below the average (OECD, 2014). It was found that more than one in five Malaysian students could not even reach basic levels of problem solving.

LITERATURE REVIEW

The information processing theory is the theoretical framework underpinning this study. The basic characteristics of information processing theory that shape the problem solving efforts are reflected in the process of receiving, storing and locating new information. It also focuses on the mechanism of the problem solving process (Laurillard, 2002). In addition, understanding the procedures that students adopt helps integrate these into a more deterministic account of how students solve problems. Consequently, Polya (1965) promoted the idea that the application of general problem-solving strategies was important in developing problem-solving expertise and intellectual performance. The four steps in the problem solving process as suggested by Polya: understand the problem, devise the plan, carry out the plan and looking back.

Graphing Calculator

Graphic calculators are handheld, battery powered devices equipped with functions to plot graphs, give numerical solutions to equations and perform statistical calculations, operations on matrices and perform more advanced mathematical functions such as algebra, geometry and advanced statistics (Kor & Lim, 2003). In fact, Mitchelmore and Cavanagh noted that the first graphing calculators appeared in the mid-1980s and since then such calculators have become more affordable and powerful (Cavanagh & Mitchelmore, 2000). With this new technology, the graphing calculator brought many new and exciting changes in the mathematics curriculum (Choi-Koh, 2003).

Graphing calculators were first seen in 1985, when they were developed by Casio, and later were developed even further by Texas Instruments in 1995. With the invention of graphing calculators came a new way to deal with mathematics that provided access to mathematical problem solving that, before this time, could only be done on computers (Waits & Demana, 1998). Several varieties of graphing calculators exist, but all graphing calculators have certain functions and capabilities in addition to computation such as graphing, viewing tables, and running programs and applications. The most recent handheld graphing technology from Texas Instruments is the TI-Nspire CX. These graphing calculators have all of the capabilities of other graphing calculators in addition to the ability to view multiple representations on the same screen, to construct and animate geometric figures, and to receive documents that allow visualizations of solids of revolution.

In a study conducted to investigate the use of graphing calculator (TI-Nspire), there are five roles of graphing calculator in classroom mathematical practice based on the findings; namely: exploratory tool 1 role, graphing tool 2, confirmatory tool 3, problem-solving tool 4, and multi-dimensional tool 5 (Ng, 2011). The researcher concluded that graphing calculator (TI-Nspire) is an effective tool for developing mathematical concepts, promote learning and problem solving. Doerr and Zangor found that five patterns and modes of graphing calculator use emerged in the practice: computational tool, transformational tool, data collection and analysis tool, visualizing tool and checking tool (Doerr & Zangor, 2000).

Past Research

Researchers in different settings have investigated various studies regarding graphing calculator usage in teaching, learning, achievement and attitude in various domains of mathematics. Even more significantly, vast research has shown that using graphing calculator has a positive effect on students' performance in problem solving. Rich, in a study of two high school pre-calculus classes, found that students were more willing to tackle problem-solving activities when they had access to graphing calculators (Rich, 1991). The students were also able to solve non-routine problems that might have been too difficult for them without the availability of a graphing utility; this permitted the introduction of problem-solving situations that were of interest to the students.

Carter found that the graphing calculator seemingly led to improved problem-solving, as less time was consumed with algebraic manipulations (Carter, 1995). He also reported that the students used the calculators as a monitoring aid while solving word problems. Bitter and Hatfield also found that students using calculators showed improved problem-solving skills (Bitter & Hatfield, 1991). Szetela and Super found a better attitude toward problem-solving when the calculator was used. However, the scores were not significantly higher for those students using the calculators than for their counterparts who did not use them (Szetela & Super, 1987).

Allison conducted a case study to determine the impact of graphing calculator on four students' mathematical thinking while solving problems. The researcher adapted Schoenfeld's model of mathematical thinking and Berger's interpretive model of graphing calculator as the theoretical framework. Data were collected through task-based clinical interviews and the task includes contextual non routine problems, non-contextual non-routine problems and exploratory problems. The results indicate that graphing calculator is integrated and serves as impetus for a students' mathematical problem solving (Allison, 2000). Some of the researcher's findings were:

i. Graphing calculator amplified the speed and accuracy of problem solving strategies
ii. Graphing calculator encouraged participants to use graphical approaches to solve problems and influenced their ways of thinking
iii. Graphing calculator enhanced the participants' ability to focus on reasoning and to look back at their answer.

The participants agreed that the graphing calculator added speed and accuracy to their problems solving efforts.

In an experimental study involving graphing calculator in learning probability, the graphing calculator formed a "thinking tool" which enabled students to develop conceptual understanding and problem-solving abilities in mathematics. It provided the opportunity for exploring problem solving and increased the students' confidence in solving more challenging problems (Tan, Harji, & Lau, 2011).

Dibble performed an action research project to examine the impact of graphing calculators on students' problem solving abilities and attitudes toward mathematics. Students with similar capabilities were divided into two groups, the experimental group which used graphing calculator throughout the instruction and the control group without access to graphing calculator. Pre-survey and post-survey were administered to both groups to measure their attitudes towards mathematics. Pre-test and post-test were to measure students' problem solving abilities, assessed through short answer tests and quizzes. The findings of this study concluded that graphing calculators had no impact on problem solving abilities in the experimental group as compared to the control group (Dibble, 2013). However, graphing calculator use created higher enjoyment in mathematics compared to learning without graphing calculator.

Hunter investigated the impact of graphing calculator use on calculus students' reasoning skills through a mixed method study. Reasoning skills mentioned previously are related to problem solving according to Mayer and Wittrock (2006). The researcher adapted the idea of constructivism as the theoretical framework of the research. The study included a quantitative, quasi-experimental component and a qualitative component. Results of the quantitative and qualitative analysis indicate that (Hunter, 2011):

i. graphing calculators had a positive impact upon students' reasoning skills,
ii. graphing calculators were most effective in initiating a strategy and monitoring progress,
iii. students' reasoning skills were most improved when graphing calculators were used together with the analytic approach during both instruction and testing, and
iv. students who used the graphing calculator performed equally as well in all elements of reasoning as those who used pencil and paper to solve problems.

Hatem investigated the relationship between use of graphing calculators and student achievement which was determined by assessing students' problem solving skills in his experimental study. He found inconsistent results regarding the effect of graphing calculator use on student achievement (Hatem, 2010). However, significantly, his study found that integrating graphing calculators into the learning process improved students' perceived progress in their problem solving skills. Lastly, Texas Instrument Education listed out several effects of graphing calculators on learning outcomes:

i. Students using graphing technology have demonstrated better understanding of functions and variables, and performed better in solving algebra problems in applied contexts and interpreting graphs.
ii. Technology that supports multiple representations is shown to increase students' use of visualization in problem solving and gains in understanding.
iii. Appropriate use of graphing calculators is shown to provide all students at various levels greater access to complex mathematical concepts.

Results of past studies varied, with some showing no effect and some showing a positive effect associated with graphing calculator use. However, there is a need to look at the impact of graphing calculator on problem solving ability among Malaysian students.

Problem Solving using Graphing Calculator

Studies have been done on the positive effects of using graphing calculators such as using visualisation through graphical and numerical approaches in solving problems (Karadeniz, 2015) and positive association between the usage of graphing calculators and improved mathematics achievement (Wareham, 2016). Previous researches have established that the usage of graphing calculator in the teaching and learning of mathematics have benefited students in terms of mathematics achievement, visualization and cognitive understanding. (Chen & Lai, 2015; Karadeniz, 2015; Wareham, 2016).

Problem solving with a graphing calculator can be enhanced on many levels. It can be argued that the highest level integrates graphical analysis and lowest level involves simple arithmetic (Crippen, 1999). According to Kutzler, graphing calculators (the trivialization of arithmetic, graphics and algebra) in teaching mean that educators or teachers can tackle more complex and realistic problems. Kutzler proposed three steps of characteristics for problem solving by using graphing calculator (Kutzler, 2000). The first step is choosing the model and translating the real world problem into the language of the model, which requires us to grasp and understand the problem. The second step is applying the available algorithms to solve the model problem, yielding a model solution. Students use the graphing calculator in this phase to calculate and solve. The third or final step is to translate the model solution into a real world solution. However, we need to check the solution whereby graphing calculator can be used to check back the answer. If it is not correct, then the whole process needs to be repeated. In this study, the graphing calculator used was TI-NSspire CX.

Purpose and Research Questions

The purpose of this study is to investigate the impact of graphing calculator on students' sucsess in solving problem involving linear equations and their attitude towards problem solving in mathematics. The study was guided by the following research questions:

1. Is there a significant difference in students' success to solve problems on linear equation between experimental and control group?
2. Is there a significant difference in students' attitude towards problem solving in mathematics between experimental and control group?

METHODOLOGY

Whenever the true experimental design is not feasible, the most appropriate research design in investigating effectiveness of an intervention with the availability of intact groups is quasi experimental research (Creswell, 2011; Fraenkel, Wallen, & Hyun, 2011). Therefore, the researcher chose to employ the quasi-experimental non-equivalent control-group design for this study.

The population for the study included Form Four (Grade 10) students in the state of Sarawak in Malaysia. The study took place in one of the public secondary schools which has approximately 1500 students. The sample of this study consists of 60 Form Four students who are taking Mathematics as their core subject. The average age of the students ranged between 15 to 16 years old and they had successfully completed the major public assessment during Form Three. In the school, there were seven Form Four classes, but only two classes were randomly chosen for the study. One of the classes served as the experimental group and used the graphing calculator while the other class or control group learned using the traditional approach.

The type of data collected in this study consists of quantitative data. At the beginning of this study, all participants were required to complete the pre-test. Graphing calculators were provided to the experimental group and they were allowed to use them to complete the test. The score from pre-test will be used to check the similarity between both groups. Throughout this study, the control group received traditional instruction in learning the concept of linear equation and the experimental group received intervention involving the use of graphing calculators in a problem based learning environment. Approximately four weeks after administration of the pre-test and upon completion of the series of lessons, participants from both groups were required to complete the post-test. The researcher taught both groups.

Instrumentation

Two instruments (test and survey) were used to gather data in this study. The first instrument was the Linear Equation Problem Solving Test designed to assess the students' proficiency in each step of the linear equation problem solving process. This internal consistency of the instrument was measured using the Cronbach alpha and the value obtained was 0.72. In this study, pre-test and post-test were developed to measure the changes in participants' process in solving linear equations. The measurement of change provides a vehicle for assessing the impact of graphing calculator during participants' problem solving of linear equations. The tests comprised four problems that will take 1 hour 20 minutes to complete. Each problem was broken down into four fundamental questions to probe individual processes in solving the problem. With the questions, participants are able to write out what they were thinking during the problem solving process. In this way, the researcher will be able to assess students' effort in solving the problems. Each problem has a maximum score of 12 points; that is, maximum of three points to be given for each fundamental question. They were scored by a modified version of the Analytic Problem Solving Rubric developed by Charles, Lester, and O'Daffer (1987) and Krulik and Rudnick (1998) which has been widely used in other problem solving research (Quinones, 2005; Rosli, Goldsby, & Capraro, 2013; Wittcop, 2008; Yeo, 2011).

The second instrument was to measure students' attitude towards problem solving. The researcher adapted the student attitudes' instrument by Charles et al. (1987) and Conway (1996). The Cronbach alpha value of 0.75 indicates that the instrument has appropriate internal consistency. The Mathematical Problem Solving Questionnaire contained 20 items which utilized the 5-point Likert scale with the options of "Strongly

Table 1. Mean Score Differences between Group using Independent t-test

Group	Mean	SD	*t*-value	Sig (2 tailed)
Experimental (n = 30)	7.50	3.57	1.51	.14
Control (n = 30)	6.07	3.79		

Table 2. Independent t-Test for Post-test

Group	Mean	SD	*t*-value	Sig (2 tailed)
Experimental (n = 30)	24.27	6.51	7.80	.000
Control (n = 30)	13.03	4.46		

Table 3. Mean Score Differences between Group using Paired Samples

Group	Mean	SD	*t*-value	Sig (2 tailed)
Experimental (n = 30)	16.77	5.71	16.08	.000
Control (n = 30)	6.97	6.36	6.00	.000

Disagree", "Disagree", "Undecided", "Agree" and "Strongly Agree". In the questionnaire, the rating of 1 implies the option "Strongly Disagree" followed by the rating of 2 for "Disagree" and ending with 5 for "Strongly Agree". Both the instruments were checked by lecturers and experts in the problem solving area to improve the content validity.

RESULTS

Research Question 1

To answer the first research question regarding students' ability to solve problems involving linear equations, the researcher used the Linear Equation Problem Solving Test. It was intended to find out if students who used graphing calculators in class were better problem solvers than those who did not use them. The first research question was analyzed using independent *t*-test. The dependent variable is students' score in the test and the independent variable is the treatment type for both groups. Independent *t*-test has three assumptions which are the independency of scores, normality and homogeneity of variances. For the first assumption, scores were independent since data were collected from two different groups. For normality, results from Shapiro-Wilk's test were used. Levene's test of equality was used to determine the equality of variance assumption.

Table 1 shows that the experimental group scored higher with a mean score of 7.50 while the control group obtained a mean score of 6.07. However, the *p*-value was 0.14 ($p > .05$) indicating that the difference in the mean score of the two groups was not significant. This result illustrated that both groups have similar abilities before the intervention was administered.

Students' scores in the experimental and control groups were normally distributed, as assessed by Shapiro-Wilk's test ($p > .05$). There was homogeneity of variances for test score between the control and experimental groups, as assessed by Levene's test for equality of variances ($p = .092$). The experimental group score ($M = 24.27$, $SD = 6.51$) was higher than the control group score ($M = 13.03$, $SD = 4.46$), a statistically significant difference: $M = 11.23$, 95% CI [8.35, 14.11], $t(58) = 7.80$, $p = .000$. The effect size of this analysis ($d = 2.01$), was found to exceed Cohen's (1988) convention for a large effect ($d = .80$). This indicates that the average students in the experimental group would score higher than 98% of the control group.

Next, a paired-samples *t*-test was used to determine whether there was a statistically significant mean difference between the pre-test and post-test scores of both groups. Results for the test are shown in **Table 3**. The mean score difference between the post-test and pre-test of the experimental group was 16.77 as compared to the control group with 6.97. There was a significant difference between the pre and post-test score with the *t*-value was 16.08 and *p*-value less than .05 in the experimental group. Whereas in the control group, the result reveals that the *t*-value was 6.00 and *p*-value less than .05 suggests that there was a significant difference as well. This implies that the individual students' score on the post-test was significantly higher than on the pre-test.

Table 4. Overall Mean Differences between Group for Pre-Survey

Group	Mean	SD	*t*-value	Sig (2 tailed)
Experimental (n = 30)	3.48	.59	.45	.653
Control (n = 30)	3.42	.26		

Table 5. Overall Mean Differences between Group for Post-Survey

Group	Mean	SD	*t*-value	Sig (2 tailed)
Experimental (n = 30)	3.77	.39	7.24	.000
Control (n = 30)	3.08	.35		

Research Question 2

The second research question which used the Mathematical Problem Solving Questionnaire measured the students' attitude toward problem solving. The survey was conducted twice which is before and after the intervention. The results are presented in **Table 4** and **Table 5**.

The assumption of normality test for the pre-survey and post-survey for both groups were normally distributed, as provided by Shapiro-Wilk's test ($p > .05$). According to Levene's test, the homogeneity of variances assumption was satisfied ($p = .092$).

The overall mean of students' attitude towards problem solving in mathematics in the pre-survey of the experimental group was 3.48 ($SD = .59$) while the control group mean was 3.42 ($SD = .26$). An independent t-test showed the difference in means was not significant, $t = .45$, $p > .05$. Meanwhile, the overall mean of students' attitude toward learning mathematics in the post-survey of the experimental group was higher ($M = 3.77$, $SD = .39$) compared to the control group ($M = 3.08$, $SD = .35$). An independent t-test showed the difference in means was significant, $t = 7.24$, $p < .05$. The results indicated that there was significant difference in the overall mean of students' attitude towards problem solving in mathematics in the post-survey between the experimental and control groups. These findings indicate that both groups have different attitude toward problem solving in mathematics after the intervention. The experimental group had a better attitude toward problem solving in mathematics compared to the control groups. The value of the effect size in this analysis was, $d = 1.86$. According to Cohen's (1988) measure, this was considered as a large effect size. This indicates that the average students in the experimental group would score higher than 96% of the control group for an effect size of 1.86.

DISCUSSION AND CONCLUSION

Problem solving is viewed as an important part of understanding and learning in Mathematics, and emphasis increasingly is being placed upon improving problem solving abilities in mathematics. It is therefore important to investigate ways for improving problem solving skills; graphing calculator is one of the ways suggested to improve these skills. The purpose of the current study was to investigate the impact of graphing calculator on students' ability to solve problems involving linear equations.

Previous researches showed that students who have access to the graphing calculator significantly score higher in problem solving compare to their counterparts who did not use the graphing calculator (Allison, 2000; Bitter & Hatfield, 1991; Carter, 1995; Hatem, 2010; Rich, 1991; Tan et al., 2011). These findings are compatible with the results obtained in this study. An independent sample t-test was conducted in order to determine whether significance differences exist between those using the traditional approach and those using graphing calculator. Results obtained show that the experimental group which had access to graphing calculator during the lesson and test scored significantly higher than the control group. This indicates that the use of graphing calculator had a positive impact on students' ability to solve problems. This was supported by other researchers who reviewed that students are better problem solvers when graphing calculator was used in class and during assessment (Pilipczuk, 2006; Schrupp, 2007). However, the discrepancy in scores could be due to either the teaching approach used or the individual difference in problem solving skill. From visual inspection, students who used graphing calculator were exposed to different strategies in solving problems.

With respect to students' attitude toward problem solving, students who underwent the intervention had a better outlook and perception on the problem solving task compared to those who underwent the traditional approach without access to the graphing calculator. This result supports the findings obtained by Szetela and

Super (1987) and Dibble (2013) who reported that students had a better attitude toward problem solving when the graphing calculator was used. A number of reasons account for this result; one of the unique features in the graphing calculator technology is that it allows students to view more than one representation in the split-screen mode. This multiple representation of linear equation involved was in the form of graphical, tabular, and computation. Besides, the representation can be dynamically linked so that changes are made to each representation. Students have more time to think on the problem itself without worrying about long algebraic procedures. Graphing calculators are advantageous because the multiple representation of a concept enhances clarity and understanding. Thus, it is highly recommended that students be allowed to use graphing calculator for a longer period to enable familiarity with its varied functions.

Disclosure statement

No potential conflict of interest was reported by the authors.

Notes on contributors

Mary Ann Serdina Parrot – University of Malaya, Kuala Lumpur, Malaysia.

Kwan Eu Leong – University of Malaya, Kuala Lumpur, Malaysia.

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