Scientific calculators in mathematics classroom: A hindrance or a scaffold?

Pientha Glenys Amanti[1,*], Lisa Natasya[1], Ng Kok Min[2]

[1]Casio for Education, Jakarta, Indonesia
[2]Casio for Education, Singapore, Singapore
* Correspondence: pientha.glenys@casio.com.sg

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Abstract

Due to their nature as a calculation tool, it cannot be neglected that calculators are often seen as a hindrance in learning mathematics. Many teachers believed that calculators would make students lazy and even unable to do calculations and, therefore, their basic calculation skills will not develop. Based on this fact, the present study was aimed to seek evidence whether calculators hinder students' mathematics skills. For this purpose, a quasi-experimental research approach was used. A pretest-posttest control-group design was used that involved 940 students from 21 senior high schools in nine provinces in Indonesia joined this study. A calculator-supported inquiry learning was implemented in the experimental groups, whereas a regular classroom instruction with paper-and-pencil activities was implemented in the control groups. Scientific calculators in the experimental groups were used to explore and discover mathematics concepts. The results of this study show the students in the experimental group significantly outperformed the students in the control group in terms of their critical thinking skills. This finding can be seen as evidence of how scientific calculators do not hinder students' learning of mathematics. Instead, the use of calculators as an exploration tool could develop students' critical thinking skills.

Keywords: critical thinking skills, experiment, inquiry learning, scientific calculators

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INTRODUCTION

The development of information and communication technology (ICT) has been considered as a positive support in mathematics instructional activities. The National Council for Teachers of Mathematics (2000) highlighted that technology holds a crucial role in the learning of mathematics and could support students' learning. When they are engaged in ICT-based mathematical activities, students could work more effectively and do check, try, and refine their strategies or ideas during the learning process (Ruthven, Deaney, & Hennessy, 2009). Among various types of ICT, calculators are frequently neglected as important tools for educational purposes (Kissane & Kemp, Conceptual development and the modern scientific calculator: using a forgotten technology, 2013). Most people consider calculators mainly as tools to do mathematical calculations. Consequently, mathematics teachers avoid to use calculators in their instructional activities. In addition, many teachers also neglect to calculators in their mathematics classes because they are worried that calculators do not only hinder students' learning process, but also interfere teachers' role in the classrooms (see e.g. Lee & McDougall, 2010).

Despite some negative perspective about calculators for learning mathematics, many studies have been conducted to investigate the use of calculators. Nevertheless, these studies shown various results regarding the benefits of using calculators to improve students' mathematics achievement. Some studies found significant effect of calculators on students' mathematics achievement, but some other studies found no significant differences (Close, 2003). Hembree and Dessart (1986) found that scientific calculators did not have a bad influence on students' paper-based basic calculation skills.

When calculators were used in a long period, Close et al (2003) found that calculators did neither advance nor hinder students' mathematics performance. A larger study was conducted by Lapointe, Mead, and Askew (1992) who investigate the effects of scientific calculators on students' mathematics achievement in Taiwan, Canada, England, Hungary, France, and Scotland. This study revealed that students who learned mathematics by using calculators had a significant gain of performance in comparison to their counterparts who did not use calculators. However, another study which was conducted in Ireland (Martin, Hickey, & Murchan, 1992) found that no effect of calculators on students' mathematics achievement. The Trends in Mathematics and Science Studies (TIMSS) in 1995 shown that the top performing countries like Japan and Singapore used calculators differently in their mathematics classroom. The use of calculators in mathematics classrooms in Japan was much lower than in Singapore, even until now. A different use of calculators but lead to similar mathematics performance also found in France and Ireland (Beaton et al., 1996). Regarding another international assessment, i.e. the Programme for International Student Assessment (PISA), students who did the test using calculator scored higher even for the items which were designed to be calculator neutral (Shiel, Cosgrove, Sofroniou, & Kelly, 2001). These aforementioned (inconsistent) results regarding the use of calculators in mathematics classroom certainly urge for further studies in this particular field.

Although calculators are mainly designed as a calculation tool, Kissane and Kemp (2012) developed a model regarding various modes in using calculator. According to Kissane and Kemp, there are four categories of using calculators for learning mathematics, i.e. representation, computation, exploration, and affirmation. The first function – representation – is about the use of calculator to change mathematical object across forms; for example, changing a decimal from and to percent or fraction. The second type of using scientific calculators is as computation tool which is often seen as the main function of calculators. Using calculators as a computation tool helps students give more attention to the mathematics concepts or ideas because the basic calculation is performed by calculators. The exploration purpose of calculators means the use of calculator to do exploration in which the data generated by calculators can be observed for its pattern and then generalized to discover mathematics concepts or ideas. Lastly, when calculators are used as an affirmation tool students can check the correctness of their work. Kissane and Kemp's four purposes of calculators are similar to four functions of calculators suggested by Kutzler (2000). Kutzler proposed four functions of calculators in mathematics classrooms, i.e. trivialization, visualization, experimentation, and for concentration. The function of trivialization refers to the use of calculators to simplify mathematics problems. The second function of calculators is a visualization tool, namely the use of scientific calculators to depict mathematical forms or facts or objects. The forms of visualization can be numbers, equations, or graphics. Experimentation purpose refers to the use of calculators for discovering mathematics concepts. This experimentation purpose comprises four main steps, i.e. (1) applying known algorithms to get data or examples, (2) observing the characteristics and properties of the data or examples to make mathematical conjectures, (3) proving the mathematical conjectures to get a theorem, and (4) implementing the new theorem to get a new algorithm. The last function of calculators mentioned by Kutzler is that calculators can be used for concentration which means calculators can help students focus on the mathematics concepts because the calculators already handle the mathematical calculation.

Among the four functions of calculator, the experimentation (Kutzler) or exploration (Kissane and Kemp) is potential to develop critical thinking because these functions involve the process of generating conjectures, observing and exploring data, and making generalization of data or findings. Critical thinking is an important skill required to cope with the demands of the 21st century era (Ananiadou & Claro, 2009; Binkley et al., 2012; Partnership for 21st Century Skills, 2002). Critical thinking is also taken into consideration in international assessment, such as PISA and TIMSS. Critical thinking corresponds to a logical and reflective thinking which relate to a decision making or a particular action (Ennis, 1985). Critical thinking covers a range of skills, namely selecting and identifying data, analyzing data, seeking for patterns in the data, and making conclusions (Linn, 2000). Ennis (1985) proposed five indicators of critical thinking, namely elementary clarification, drawing inference, basis for the decision, advanced clarification, and integration. The indicator of elementary clarification corresponds to the process of identifying problems, analyzing reasons or arguments, and asking challenging and clarifying questions. Drawing inference includes making and judging a conclusion, generating and assessing an induction, and making reasonable decision. Basis for the decision means checking whether the data is credible or not. Advanced clarification is related to the process of identifying and assessing assumption and definition. The last indicator is supposition and integration which are about judging premises, assumption, and arguments.

Considering the positive advantages of calculators for the learning of mathematics and the need for critical thinking skills to deal with demand of the 21st century society, this study is aimed to investigate the effect of scientific calculators on critical thinking skills. As mentioned earlier, there is an inconsistent result regarding the effect of calculators on students' mathematics achievement. Therefore, it is expected that this study could contribute to provide further explanation and evidence regarding the effect of calculators in mathematics instruction. Furthermore, in Indonesia using calculator in assessment is not allowed although some schools permit their students to use calculators in mathematics classroom activities. Based on those facts, it is essential to explore the effect of scientific calculators on students' mathematics achievement which in this study is seen from the perspective of critical thinking skills.

METHODS

To achieve the objective of this study, a quasi-experimental research involving experimental and control groups and using pretest and posttest design was employed. The students of the experimental group learned mathematics in the setting of calculator-supported inquiry learning. The students of the control group learned mathematics in regular classroom activities without using scientific calculators. Examples of worksheet content which were used in the experimental group are shown in Figure 1 and Figure 2. The participants of this study were 940 students from 21 senior high schools and senior vocational schools in nine provinces in Indonesia.

Observe the value of x and $f(x)$ in the table below and identify the general rule or formula to determine the value of $f(x)$.

(1)

	x	$f(x)$
1	1	9
2	2	16
3	3	25
4	4	36

(2)

	x	$f(x)$
1	1	-9
2	2	-25
3	3	-49
4	4	-81

Formula for Table (1):

Formula for Table (2):

Use the feature 'Table' on *Classwiz* scientific calculator to check whether your formulas are correct. Input your predicted formula to the calculator and observe whether the generated output is the same as the values in Table (1) and Table (2).

Figure 1. An example of worksheet to generalize a formula based on given data

Activate the Table mode of your Classwiz scientific calculator. Input functions $f(x) = 2x$ and $g(x) = 2x + 5$. Use the interval $-10 \leq x \leq 10$ and step = 1.
Observe the tables of $f(x)$ and $g(x)$. For the same value of x, observe and compare the values of $f(x)$ and $g(x)$. What can you about the relation between the two functions?

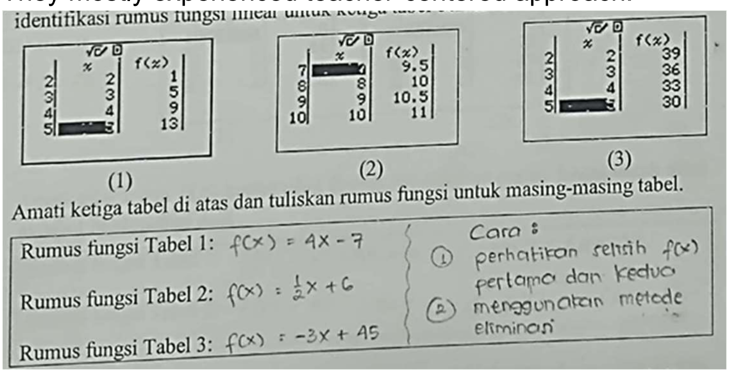
Figure 1. Student worksheet to investigate transformation of function

Before the research intervention, students in both the control and the experimental groups had to do a pretest. Post-test was administered in the two groups after the intervention. For the purpose of the study, the pre- and post-tests comprised items addressing critical thinking skills. The test was addressed in the form of a paper-and-pencil test. This test was aimed to measure critical thinking skills that focused on elementary clarification, drawing conclusion or inference, recognizing patterns, advanced clarification, and generating conjectures. With regard to the mathematics topic, the test was about linear and quadratic functions and their graph. The test instrument was validated by two experts in the field of mathematics education. Furthermore, a reliability test was also applied to the test instrument. The reliability test shown that the instrument was reliable (reliability coefficient 0.658).

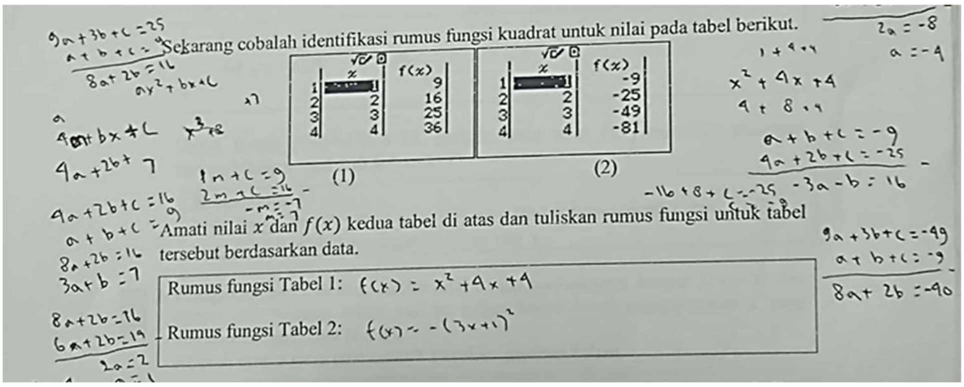
A quantitative approach comprising descriptive and inferential statistics was used to analyze the data. The quantitative analysis was aimed to get a broad picture of the test results including minimum and maximum scores, mean score, and standard deviation. Inferential statistics was aimed to test the hypotheses with respect to the effect of scientific calculators on critical thinking skills. For this purpose, ANOVA was employed to see how scientific calculators affect students' critical thinking skills.

RESULTS AND DISCUSSION

The students in the experimental group learnt mathematics by using scientific calculators, whereas the students in the control group learnt the same topic through a regular teaching approach without using scientific calculators. The students in the experimental group learned about linear and quadratic functions by utilizing scientific calculators and related worksheets. Five sets of student worksheets (WS) were developed and implemented in this study. The activity in WS was about exploring and generalizing function, WS 2 was aimed to investigate the characteristics of the graphs of linear functions, WS 3 and WS 4 focused on quadratic function including quadratic graphs and their characteristics, and WS 5 dealt with the application of linear and quadratic functions in real life. With regard to the purpose of scientific calculators, in general they were used an exploration tool and confirmation tool during the classroom activities. For example, the feature 'Table' on the scientific calculator was aimed to facilitate students in producing data and observing the characteristics of the data in order to make conclusion about linear function and the characteristics of graphs. Every worksheet provided students with mathematical exploration activities. In WS 1, outputs of calculator's Table menu containing pairs of x and f(x) values were provided to students for exploration activity. Students were asked to investigate these outputs and to predict or generalize the relevant functions that could provide such data. In this respect, the scientific calculators were used as an exploration tool, i.e. to provide data to make predictions. In addition to exploration tool, the scientific calculators were used as affirmation tool. This was done by asking students to check the formulas they predicted in the previous activity. In this activity, students were asked to input their prediction onto the calculator and then observed whether the generated tables showed the same values as the values on the worksheet. In such activity, scientific calculators were utilized for affirmation purpose. Figure 3.a and Figure 3.b show examples of students' works in predicting the general formula which best represented the data in the table. It was observed that many students struggled in generalizing formula based on a given set of data. A possible reason for this difficulty was that the students were not yet familiar with such an inductive approach. They mostly experienced teacher-centered approach.



(a)



(b)

Figure 3. Examples of students' prediction

Another important activity addressed in WS 1 was about recognizing pattern and completing tables. In this activity tables showing pairs of x and f(x) values representing several functions were provided to students. Students were asked to recognize the pattern of the data and to add pairs of x and f(x) values. After recognizing the pattern, students were asked to check the correctness of their prediction by utilizing scientific calculators (see Figure 4). This predicting and checking activities were used as the basis to explore mathematics idea about domain and range of a function.

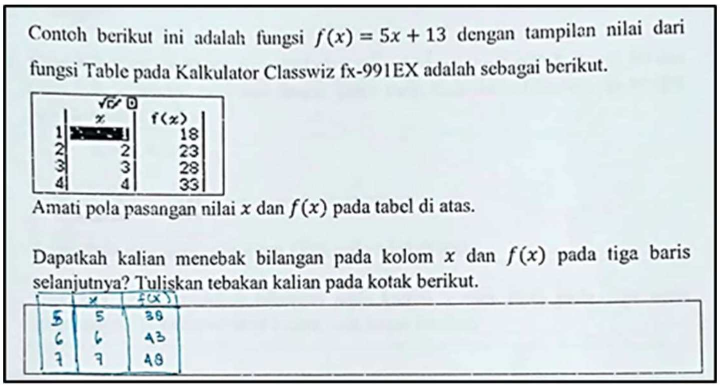


Figure 4. Students' prediction

WS 3 mainly dealt with an exploration of the characteristics of quadratic functions and graphs. One of the activities in this worksheet is exploring the relation between general formula of quadratic function and the shapes of the graph. For example, how the characteristics of graph of a quadratic function corresponded to the values of a, b, and c on the function formula f(x)=ax^2+bx+c. In this activity, the function of scientific calculators was to produce pairs of x and f(x). These pairs were used to generate graphs. WS 3 facilitated students in constructing the graphs in two ways, i.e. drawing the graphs manually by using paper and pencil and constructing the graphs by using the scientific calculators. Constructing the graphs by using scientific calculators was employed where students had sufficient facilities – i.e. smartphone or computer that is connected to internet – for which the students were asked to use the scientific calculators to generate QR code to construct the graphs (see Figure 5).

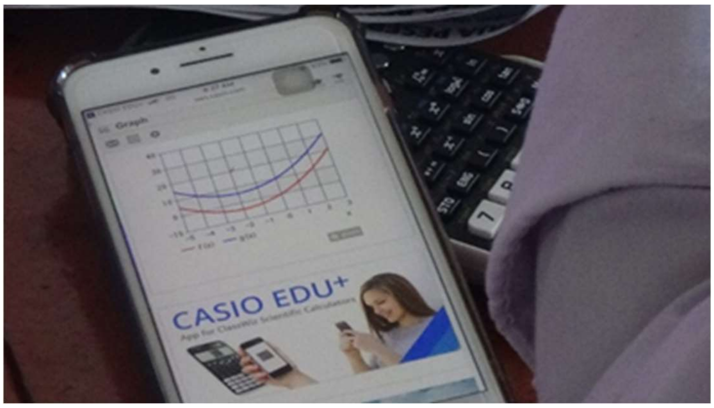


Figure 5. Exploring the characteristics of graph by using scientific calculators and app Casio EDU+

After constructing the graphs, the students were asked to observe the two graphs to find their differences and/or similarities. The observation was aimed to investigate and make conclusion regarding the characteristics of graphs, in particular regarding the relation between the graphs and the values of a, b, or c. Similar to the other worksheet activities, this activity was observed to be difficult for some students. Some students could not draw accurate conclusion based on the comparison of two graphs (see Figure 6). These students could not conclude that the values of a and b determine the position of the graph's line symmetry.

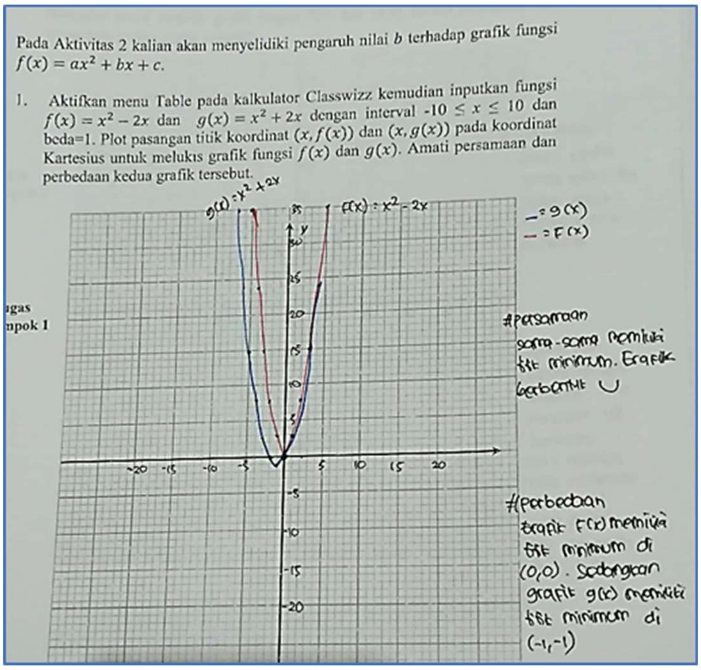


Figure 6. Students' difficulty in making conclusion based on data observation

In the experimental and control group, pre-test was administered before the mathematics lessons and post-test was done after all lessons were completed. The descriptive statistics analysis show the results of pre- and post-test (see Table 1).

Table 1. Students' scores in pre-test and post-test

Statistics	Experimental Group		Control Group	
	Pre	Post	Pre	Post
Mean	7.48	17.40	8.42	12.97
N	940.00	940.00	671.00	671.00
Std. Deviation	12.68	21.13	15.52	20.20
Minimum	0.00	0.00	0.00	0.00
Maximum	93.33	93.33	93.33	93.33

As shown in Table 1, the score from pre- to post-test increased by 9.92 points (or 132%) for students in the experimental group. A smaller gain score was found in the control group, i.e. by 4.55 points or 54%. This descriptive statistics indicates a positive effect of the use of calculators in the experimental group on the improvement of critical thinking skills. Inferential statistics was performed to get a generalizable result about the effects of scientific calculator on students' critical thinking skills. The effectiveness of scientific calculator was investigated by comparing the test scores of the students from both groups. The analysis showed a significant difference between the groups for their critical thinking skills in which the students in the experimental group (M =17.40, SD=21.13) outperformed the students in the control group (M = 12.97, SD = 20.00); p = .000 (see Table 2).

Table 1. The effect of scientific calculators on critical thinking skills

Dependent Variable	(I) Treatment	(J) Treatment	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
						Lower Bound	Upper Bound
Critical thinking (Post)	Exp.	Exp.	4.439*	1.049	.000	2.381	6.496
	Cont.	Cont.	-4.439*	1.049	.000	-6.496	-2.381

CONCLUSION

The result of this study shows a significant effect of scientific calculator-supported inquiry learning on students' critical thinking skills. It means that the students who learn mathematics by using scientific calculator for learning mathematics get a better improvement in their mathematics performance and critical thinking than the students who learned mathematics without using scientific calculators. A possible explanation for this finding is the concentration purpose of scientific calculator as mentioned by Kutzler (2000). In this regards, students could focus on the mathematics concept because the calculation is done by scientific calculators. This argument is in line the studies of Kastberg and Leatham (2005) and Ochanda and Indoshi (2011) which revealed that the use of scientific calculators in the learning of mathematics could minimize the time to do calculation and to solve problems. An example of the concentration purpose of calculator was observed when students were constructing graphs of functions. Students who constructed the graphs manually by using paper and pencil did not have enough time to observe the characteristics of the graphs. A different situation was observed for students who used scientific calculators to construct the graphs. By using scientific calculators it is not necessary for students to do a lot of calculation to get pairs of x and f(x) to be plotted on to Cartesian coordinate.

As a consequence, students can focus on observing and concluding the characteristics of the functions and graphs. Moreover, after students acquired the basic principles of drawing graphs, they could utilize QR code on the scientific calculators to get the graphs. Therefore, the students have more opportunity to observe and analyze the graphs. The experimentation or exploration purpose of calculator (Kissane & Kemp, 2013; Kutzler, 2000) was also found to be an important factor that contributed in improving the critical thinking skills of students. Important aspects of experimentation or exploration activities are recognizing and generalizing pattern. In this study, students were given pairs of x and f(x) which were obtained by scientific calculators. These students determined the correct formula that could provide the given data. The students need to generalize the formula and make decision by finding the pattern of the given data. This activity could positively influence students' critical thinking because as highlighted by Ennis (1985), making decision is an essential aspect of drawing inference which, therefore, is also a part of critical thinking skills. Similar principles of exploration also happen when students investigate the characteristics and shapes of graphs. In this respect, the graphical and numerical visualization provided by scientific calculators support students' exploration. The third function of calculator that seems to support the development of students' critical thinking skills is affirmation (Kissane & Kemp, 2013). After investigating patterns and making generalization, students were guided to evaluate the correctness of their generalization by using scientific calculators. This activity can serve as 'basis for the decision', which according to Ennis (1985) is an essential indicator of critical thinking skills.

As a conclusion, the finding of this study provides a scientific evidence that positive effect of using scientific calculators on improving students' critical thinking skills. This finding is in agreement with Ochanda and Indoshi (2011) who shown that calculators support students' in discovering and understanding concept and in generating conjecture. According to Ochanda and Indoshi, calculators help students when they are exploring numbers and generalizing concepts.

The results of this study lead to several recommendations for teachers and stakeholders. The first recommendation is related to developing learning materials such as textbooks for which integration of scientific calculators the students' activities can be considered. Such learning materials will be important for teachers because such limited material is still limited. Lastly, the results of this study recommends teachers to use scientific calculators to do mathematical exploration in their classrooms..

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