# Scientific Calculators to Improve Students' Critical Thinking Skills: An evidence from mathematical exploration in mathematics classroom

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**Abstracts.** *In Indonesia, most teachers hold negative perspectives toward the use of scientific calculators for learning mathematics. Many teachers are worried if calculators will weaken students' fluency in performing calculation and hinder students' understanding of mathematics concepts. Considering this situation, the present study is aimed at exploring scientific evidences that calculators are beneficial for developing students' conceptual understanding and critical thinking skills. The present study used a quasi-experimental research with a pretest-posttest control-group design. A total of 940 tenth graders from 21 schools in nine provinces in Indonesia participated in the study. The experimental groups learnt the topic of linear and quadratic functions by using scientific calculator Casio Classwiz, whereas the control groups learnt the same topic in regular activities utilizing paper-and-pencil approach. The use of Casio Classwiz in the experimental groups was not as a calculation tool, but as a tool to explore and investigate mathematics concept. The data analysis shows a significant difference for students' critical thinking in which the experimental group (M =17.40, SD=21.13) outperformed the control group (M = 12.97, SD = 20.00); p = .000. This finding serves as a scientific evidence that using scientific calculators in exploratory mathematics activities could improve students' critical thinking.*

## Introduction

Research has shown the benefits of information and communication technology (ICT) in teaching and learning of mathematics. According to the National Council for Teachers of Mathematics [1], technology is essential for learning mathematics and could also enhance students' learning. Engaging with ICT, students had the opportunity to work more effectively and could check-trial-refine their ideas or strategies [2]. Among various kinds of technology, calculators are often considered as forgotten tools in the massive development of ICT for education [3]. People mainly see calculators as tools for calculations and mathematics teachers often disapproved of using it. Many teachers have resisted using technology – more specifically calculators – in their instructional activities because they think technology will interfere their role as teachers [4]. Furthermore, many teachers are worried if the use calculators will hinder students' conceptual understanding.

The research studies on the advantage of using calculators on students' achievement give various results. Some research showed significant effect on students' achievement and the other proved no significant different, see [5]. Hembree and Dessart [6] found that the use of calculator did not deteriorate students' competencies on paper-based calculation. In long term use of calculator, it had neither advanced nor hindered students' achievement [5]. A study of international survey by Lapointe, Mead, and Askew [7] investigated the use of calculators for mathematics learning in England, Scotland, France, Canada, Hungary and Taiwan. They found a significant gain of students who used calculators compared who did not. However, in Ireland, it is found that no effect of the use of calculator in Ireland [8]. Cautious interpretation should be taken care from which there was no data about Irish students' characteristics. From TIMSS studies in 1995, the top performing countries like Japan and Singapore have different ways of using calculators. Japanese students did not use calculators as much as Singaporean student, even until now. Students in France and Ireland have no

different in mean of mathematics achievement though the use of calculators in respective countries is different [9]. In regard to another international assessment, PISA, where items are designed to be calculator neutral, showed that students who did the test using calculator scored higher [10].

With respect to the use of calculators for learning mathematics, Kissane and Kemp [3] have developed a strategic model of using calculator. According to Kissane and Kemp, the use of calculators for learning mathematics can be categorized into four categories, i.e. representation, computation, exploration, and affirmation. Representation refers to the purpose of calculator to convert mathematics forms across different types of representation; for example, converting a fraction from and to decimal or percent. The second function of calculator is for computation purpose which is often considered as the main function of a calculator. Computation purpose is important because calculator helps students to do calculation so that they can focus on the mathematics concepts. The exploration purpose refers to the use of calculator to do mathematical exploration for which pattern and generalization play a crucial role. Lastly, a calculator can also be used as an affirmation tool to check students' work. These four purposes of calculator are in line with the functions of calculator that are proposed by Kutzler [11]. Kutzler recommended four purposes of calculators for learning mathematics, i.e. trivialization, experimentation, visualization, and concentration. Trivialization means that calculators can be used to simplify mathematics problems, in particular with regard to the form of the problems. Experimentation corresponds to the use of calculators to discover mathematical knowledge by students. Kutzler specified this experimentation in four main steps. First, applying known algorithms to produce examples. The second step is observing the properties of the examples in order to make conjectures. In the third step the calculators are used to prove the conjectures to obtain a theorem. The fourth step is implementing the theorem algorithmically to obtain new algorithm. The next purpose of calculators is for visualization which refers to the use of calculators to illustrate mathematical objects, facts, or processes. Visualization can be in the form of numbers, equations, or graphical representation. With respect to the use of calculators for concentration, Kutzler explained that calculators can be used to help students to focus or concentrate on the mathematics concepts because the procedural calculation is done by the calculators.

Among the four purposes calculator, Kutzler's experimentation or Kissane and Kemp's exploration is interesting to see because it is related to critical thinking as indicated by the process of making conjectures, exploring data, and generalizing findings. Critical thinking is considered as one of the main skills required in the 21$^{st}$ century skills [12]–[14]. From the perspective of international assessment, critical thinking is also taken into account in PISA and TIMSS. All these facts indicate the importance of critical thinking. critical thinking refers to a logical and reflective thought that deals with a decision about a particular action [15]. Critical thinking involves a range of skills such as identifying relevant information, analyzing the credibility of the information, grasping patterns, and drawing conclusions [16]. Ennis [15] specified critical thinking into five indicators, i.e. (1) elementary clarification, (2) basis for the decision, (3) drawing inference, (4) advanced clarification, and (5) supposition and integration. Elementary clarification includes identifying questions, analyzing arguments, and posing clarifying and challenging questions. Basis for the decision deals with checking the credibility of information and doing observation. Drawing inference covers three aspect including formulizing and evaluating a deduction, formulizing and evaluating an induction, and making decision. Advanced clarification corresponds to identifying and evaluating definition and assumption. Lastly, supposition and integration are related to evaluating logical premises, arguments, and assumption.

Considering the potential benefits of using calculators for learning mathematics and the importance of critical thinking to cope with the demands of modern society, the present study is aimed to explore the effect of the integration of calculators into mathematics learning on students' critical

thinking skills. The present study is triggered by a growing concern about the use of calculator for learning mathematics. In her meta-analysis study, Ellington [17] revealed mixed empirical research findings regarding the effect of calculators on students' performance. Ellington reported positive benefits of calculators as indicated by the improvement of students' operational skills and problem solving skills when calculators were integrated in instruction and assessment. Nevertheless, inconsistent result was found when calculators were only utilized in instructional activities and were not used in assessment. Indonesia calculator is strictly prohibited in assessment although some schools allow the use of calculators during mathematics instruction. Therefore, it is important to investigate the effect of calculators on Indonesian students' performance which in the present study. The main concerns of the present study are students' critical thinking skills.

## Method

This study employed a quasi-experimental research with a pretest-posttest control-group design. In the experimental group, the students learnt mathematics through the integration of Classwiz scientific calculator, whereas the students in the control group joined regular classroom activities that did not use Classwiz scientific calculator. See Figure 1 and Figure 2 for examples of student worksheet for the experimental group. A total of 940 tenth graders from 21 general high schools (SMA) and vocational high schools (SMK) participated in the study. The 21 schools were located in nine provinces in Indonesia.

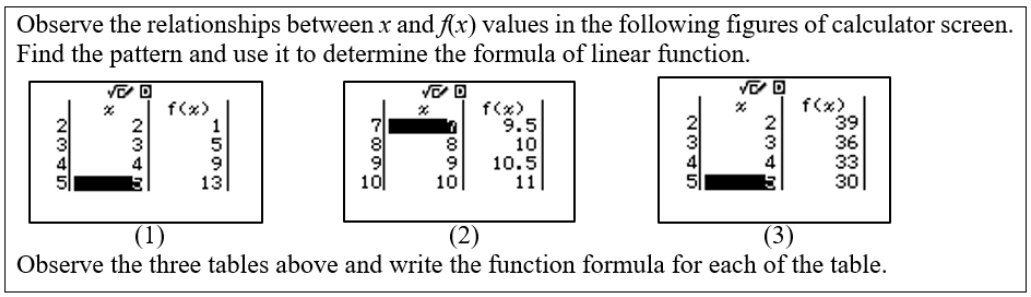



**Figure 1.** Student worksheet for investigating function formula (note: experimental group)

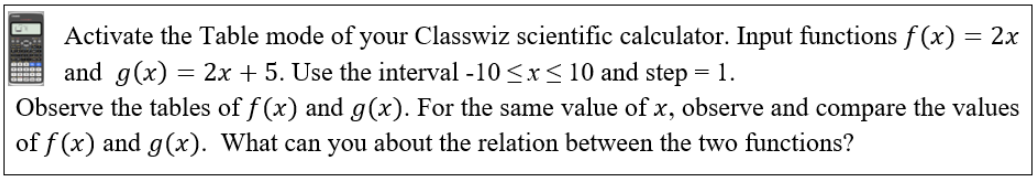



**Figure 2.** Student worksheet for investigating transformation of function (note: experimental group)

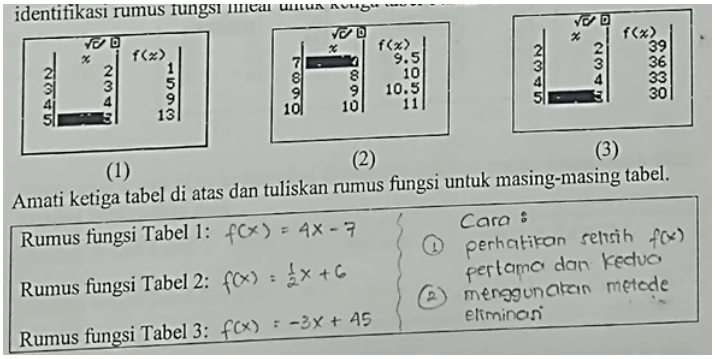
Data were collected before and after the treatment in the form of pre-test and post–test. Prior to the treatment, the pretest was administered to both the control and the experimental groups. After the treatment, the students in both groups got the posttest. For the purpose of pre-test and post-test, this proposed study used a critical thinking skills test. The test was a paper-and-pencil test in the form of extended-response questions. Extended-response test was selected because this type of question could give students more room to express their mathematical ideas. The critical thinking skills test concerned elementary clarification, recognizing patterns, drawing conclusion or inference, advanced clarification, and making conjectures. Regarding the mathematical content, the test covered the ability to predict the intersection between the graph of functions and coordinate axes; determine three different strategies or formulas to find the area of composite shapes, distinguish linear functions and

non-linear functions, analyzing and evaluating incorrect answer, and identifying relevant information. After the test items were developed, they were validated by two experts in mathematics education. The test items were tried out in two non-experimental schools in order to measure their reliability. The critical thinking skills test was reliable; i.e. 0.658 for the reliability coefficient.

The data were analyzed quantitatively. The first step of the quantitative analysis was performing descriptive statistics to get a general overview of the test results, such as maximum and minimum scores, mean score, and standard deviation. The next step was performing inferential statistics to obtain more convincing conclusion about the effect of the Classwiz scientific calculator on students' critical thinking skills. For the inferential statistics, ANOVA was used to see the effect of calculators on students' critical thinking skills.

## Results and Discussion

In the present research the students in the experimental group learnt the topic of linear and quadratic function by using Casio scientific calculator Classwiz, whereas their counterpart in the control group learnt mathematics in a regular approach with paper-and-pencil activities. The students in the experimental group learnt this topic with the help of Classwiz scientific calculator and the supporting worksheets. Five sheets of worksheets (LKPD) were developed and implemented in this research. LKPD 1 dealt with exploring function LKPD 2 focused on investigating the characteristics of graphs of linear functions, LKPD 3 to LKPD 4 covered quadratic function that included the graph and its characteristics, and LKPD 5 application of linear and quadratic functions. Regarding the purpose of Classwiz scientific calculator, in general it was utilized as an exploration tool during classroom activities. By using the function or feature 'Table' on Classwiz scientific calculator, students were encouraged to produce data and to observe the characteristics of data in order to make conclusion about function and the characteristics of graphs. Every worksheet started with various activities that encourage students to do exploration. In LKPD 1, students were provided with several outputs of Classwiz's Table menu that consisted of a set of $x$ and $f(x)$ values. By investigating these outputs, students were asked to predict the relevant functions. In this situation, the scientific calculator was used as an exploration tool, i.e. to provide data for generating prediction. After students made prediction, they were motivated to check their prediction by inputting their prediction onto the calculator and then observing whether the generated tables were like the tables on the worksheet. In this activity, the scientific calculator was used for affirmation purpose. Figure 3.a and Figure 3.b are examples of students' works in making prediction. During the exploration activity, many students struggled in making prediction. A possible reason for this difficulty was students' unfamiliarity with inductive approach.


identifikasi rumus fungsi linear untuk ketiga

| x | f(x) |
|---|---|
| 2 | 1 |
| 3 | 5 |
| 4 | 9 |
| 5 | 13 |

(1)

| x | f(x) |
|---|---|
| 7 | 9,5 |
| 8 | 10 |
| 9 | 10,5 |
| 10 | 11 |

(2)

| x | f(x) |
|---|---|
| 2 | 39 |
| 3 | 36 |
| 4 | 33 |
| 5 | 30 |

(3)

Amati ketiga tabel di atas dan tuliskan rumus fungsi untuk masing-masing tabel.

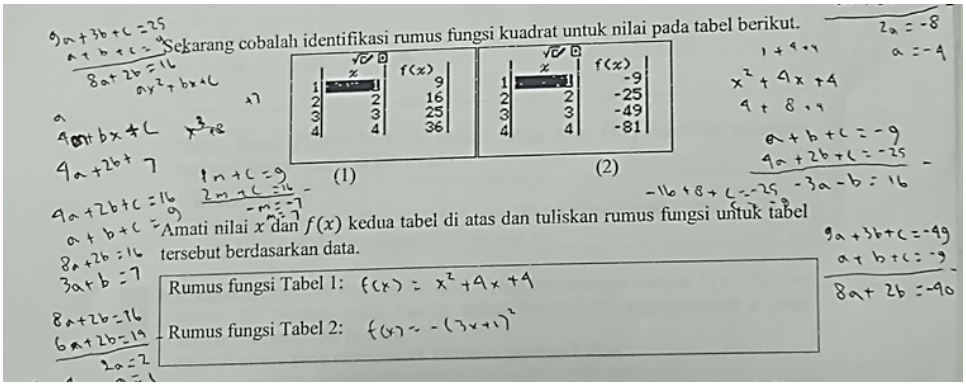
Rumus fungsi Tabel 1: $f(x) = 4x - 7$

Rumus fungsi Tabel 2: $f(x) = \frac{1}{2}x + 6$

Rumus fungsi Tabel 3: $f(x) = -3x + 45$

Cara :
1. perhatikan selisih $f(x)$ pertama dan kedua
2. menggunakan metode eliminasi

**(a)**




**(b)**

**Figure 3.** Examples of students' prediction

Another essential activity in LKPD 1 was looking for pattern and completing tables. In this activity students were provided tables showing the outputs of several functions. Students were asked to predict the pattern and to add pairs of $x$ and $f(x)$ values. Again, the next activity was using Classwiz scientific calculator to check whether students' prediction was correct or not (see Figure 4). This activity served as the basis for exploring the idea of domain, codomain, and range of a function.

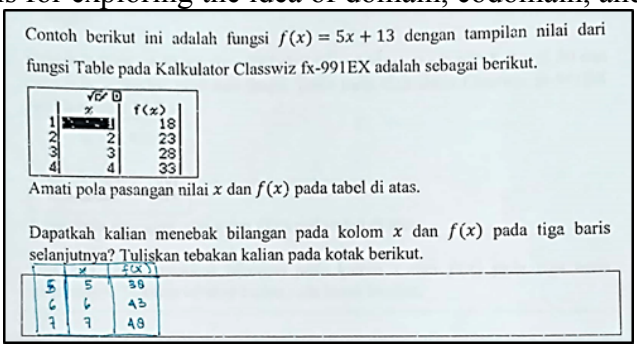



**Figure 4.** Students' prediction

LKPD 3 mainly focused on exploring the characteristics of functions and their graphs, such as exploring the relation between the graph of a quadratic function and the values of a, b, and c on the generic formula $f(x) = ax^2 + bx + c$. The function of Classwiz scientific calculator was to produce pairs of $x$ and $f(x)$ to be used to construct graphs. LKPD demanded students to manually construct the graph with paper and pencil. However, students with sufficient facilities – i.e. smartphone and internet connection – were introduced to QR code to construct the graphs. In a short time, students could fluently use the QR code and Casio EDU+ (see Figure 5).

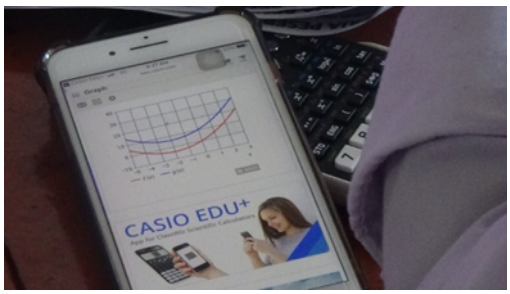



**Figure 5.** Graphical exploration with Classwiz scientific calculator and Casio EDU+

After students construct the graphs, they observed the similarities and/or differences between the graphs. This observation was used to conclude about the characteristics of graphs in relation to the values of *a*, *b*, or *c*. Like the other activities, this activity seemed to be difficult for some students. Figure 6 shows an example of student's work with inaccurate conclusion. This student did not completely conclude that *a* and *b* values determine the line symmetry of the graph.

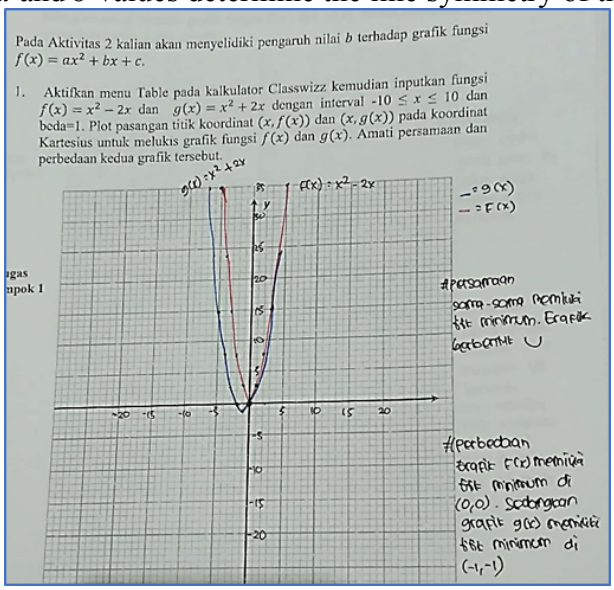



**Figure 6.** An example of students' difficulty in deriving conclusion

Pre-test was administered for both groups of students prior to the series of the mathematics lessons and post-test was administered after all lessons were done. Table 1 shows the descriptive statistics for the results of pre-test and post-test.

**Table 1.** Descriptive statistics

| 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 |

Table 1 shows that the gain score from pre-test to post-test was 9.92 points for the experimental group and 4.55 points for the control group. In terms of percentages, the score of the experimental group increased by 132%, whereas the increase in the control group was 54%. Based on this descriptive statistics, we get an early impression that the use of calculators in the experimental group contributed to the improvement of students' critical thinking. In order to get a more convincing result regarding the effects of Classwiz scientific calculator, inferential statistics was used. The effectiveness of Classwiz Scientific Calculator was investigated by comparing the achievement of the students from the experimental and control groups. The analysis revealed a significant for the critical thinking in which the experimental group (M =17.40, SD=21.13) outperformed the control group (M = 12.97, SD = 20.00); p = .000 (see complete results in Table 2).

**Table 2.** The effect of Classwiz scientific calculator 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 data analysis revealed a significant effect of calculator on students' critical thinking skills. Students who used Classwiz scientific calculator for learning mathematics gained better scores on mathematics achievement and critical thinking than their counterparts in regular classes. A possible reason for this finding is what Kutzler [11] called as a *concentration* purpose of calculator. In this respect, calculator handled the calculation and, therefore, students could focus on the mathematics concept. This argument is in agreement with Kastberg and Leatham [18] and Ochanda and Indoshi [19] who found that the use of calculator for learning mathematics could reduce the time to do calculation and to solve problems. A clear example of the *concentration* purpose of calculator is when constructing graphs of functions. In this activity students did not have to do a lot of calculation to obtain pairs of $x$ and $f(x)$ values to be plotted on the Cartesian coordinate because the pairs were generated by calculator. With this strategy, students could give more attention to observe the characteristics of the graphs. Furthermore, once students already master the basic principle of constructing graphs, the students could utilize QR code feature, so they could have even more opportunity to observe the graphs. In addition to the *concentration* purpose of calculator, it seems that the *experimentation* or *exploration* purpose of calculator also contributes to the improvement of students' critical thinking skills. Some important aspects in an experimentation or exploration are pattern recognition and generalization. In the present study, students were provided with pairs of $x$ and $f(x)$ values that were generated by Casio scientific calculator. The students were asked to determine the equation formula that fitted the given data. In this situation, students need to formulate an induction and make decision based on the given data. According to Ennis [15], formulating induction and decision are aspects of drawing inference and, therefore, parts of critical thinking. Similar principles of exploration also occurred when students investigated the characteristics of graphs of functions. The use of calculators could support students' exploration through graphical and numerical visualization. The third purpose of calculator that might contribute to students' achievement is what Kissane and Kemp called as *affirmation*. After investigating pattern and making generalization or prediction, students were asked to check their prediction by using Classwiz scientific calculator. Such activity can be categorized as 'basis for the decision'; i.e. an indicator of critical thinking [15].

To conclude, the finding of the present study suggests that the use calculators in the learning of mathematics could improve students' critical thinking skills. This finding is in line with Ochanda and Indoshi [19] who argued that calculators can support students' concept formation and conjecture generation. According to Ochanda and Indoshi, calculators help students in exploring numbers and generalizing concepts.

The results of the present study provide several recommendations for teachers and/or stakeholders. The first recommendation deals with developing learning materials such as textbooks that integrate the use of calculators. Such learning materials are important for teachers because such

limited material is still limited. In relation to the first recommendation, we can recommend teachers to use calculators for exploration activities.

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