Exploring the Use of Calculators in the Singapore's Primary Mathematics Curriculum

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Abstract: *The use of scientific calculators will be first allowed in Singapore Primary School Leaving Examination (PSLE) for all primary level mathematics subjects from the year 2009 onwards. All Primary 5 and 6 mathematics teachers will be expected to explore the use of calculators into their mathematics lessons from 2008 onwards. To meet the new assessment requirements, primary school mathematics teachers are required to be proficient in using the calculator and adept at facilitating pupils' usage of the calculator. Evidence from literature review and research has showed that calculator is an effective tool for enhancement of mathematical concepts, development of mental arithmetic skills, pattern recognition, mathematical investigation, solving real-life problems and improving problem-solving ability. The purpose of this paper is to review what research says about outcome of calculator use in the learning of primary mathematics. This paper also describes six appropriate calculator activities that can be incorporated in the teaching and learning of mathematics at the primary level.*

1. Introduction

With the launch of the electronic calculator for more than 40 years, there has been increased coverage on the use of handheld technology in enhancing teaching and learning of mathematics [14]. In Singapore the use of scientific calculators in national examinations was first allowed in early 1980s for all mathematical subjects offered at the secondary level. The use of calculators will be introduced in the Singapore primary mathematics curriculum in Primary 5 (Grade 5) from year 2008 onwards. With the introduction of calculators, Primary 6 pupils (12 years old) will be allowed to use calculator in the Primary School Leaving Examination (PSLE) for the first time in 2009 to solve mathematical problem in one of the examination papers [11]. The Primary School Leaving Examination (PSLE) is a national examination conducted in Singapore annually. The examination covers topics from whole numbers, fractions, decimals, measurement, data analysis, geometry, speed, ratio, percentage and algebra (for syllabus details, see the Singapore Ministry of Education web site, http://www.moe.gov.sg/cpdd/syllabuses.htm). The value of basic numeracy skills like mental calculation and estimation will continue to be emphasized, and pupils will be tested in one of the examination papers [9]. The impact of the decision to include the use of calculators in the primary revised mathematics curriculum has been significant. Schools need to restructure their curricular programmes and refine their modes of assessment so that they could incorporate the use of calculators. Teachers may need to acquire new skills in using the calculators as well as improving classroom pedagogy to include instructions on calculator use and to harness the power of calculators in teaching. Primary school pupils will need to acquire the skills in using a scientific calculator to solve mathematical problems. In fact, calculators, like any other technology, cannot substitute basic understanding and intuitions in mathematics. This idea was also reported in one of the Singapore's Ministry of Education press release statement on the introduction of calculators in Primary 5 - 6 Mathematics:

> The introduction of calculators at Primary 5 and Primary 6 aims to enhance the teaching and learning of mathematics at the primary level in two ways. First, calculators facilitate the use of more exploratory approaches in learning mathematical concepts, some of which may require repeated computations, or computations with large numbers or decimals. With a calculator, pupils can perform these tasks and better focus on discovering patterns and making generalisations without worrying about computational accuracy. Second, the use of calculators also enables teachers to use resources from everyday life, such as supermarket advertisements, to set real-life problems with real-life numbers that may be difficult for pupils to work with without a calculator. Pupils would hence be better able to see the connection between mathematics and the world around them [11].

Mathematical skills continue to be an important goal in the primary mathematics curriculum. Much work needs to be done with calculators to support these mathematics skills and improve the quality of pupil's responses. In my work with upper primary mathematics school teachers in Singapore, I frequently hear the concerns about incorporating calculators into the mathematics curriculum. In addition, upper primary mathematics school teachers may also face a number of difficulties when they introduce calculators in their classrooms. As this is the first time Singapore primary mathematics school teachers will be using calculators in their teaching, the purpose of this paper is to review what research says about outcome of calculator use in the learning of primary mathematics. This paper also describes six appropriate calculator activities that can be incorporated in the teaching and learning of mathematics at the primary level. The activities will assist the mathematics teacher to focus less on the calculator and more directly on the mathematics and concepts so that pupils will see that mathematics has value.

2. A Review of Literature on the Use of Calculators

Teachers and parents are concerned that the use of calculator at the primary school level might lead to a dependence on the calculator and a reduction of mental arithmetic and basic computation skills. Teachers and parents are also fretful that pupils will become so dependent upon the use of calculators to the point of not being able to do simple calculations in their daily lives without the aid of a calculator. Their concern was that the only mathematical skill that pupils will acquire upon completion of their mathematics education is button-pushing. Primary school teachers fear that the use of calculators may thwart pupils from learning the basic mathematics that they need later in life. Many teachers are more than concerned at the mere thought of implementing the use of calculators at all grade levels. The author challenges this one-dimensional view of the role of calculator. According to Groves and Stacey, they could not get any evidence that the third and fourth grade pupils became dependent on calculators at the expense of their mental computation ability [6]. In fact, they indicated that compared to the non-users, the calculator users in their study performed better overall and were able to make appropriate choices of calculating devices. Furthermore, they indicated that it was feasible to use calculators to assist young pupils to develop number sense and mental computation strategies even before they were taught the formal algorithm.

Smith conducted a meta-analysis that extended the results of Hembree and Dessart meta-analysis [17, 8]. Smith analyzed twenty-four research studies conducted from 1984 through 1995, asking questions about attitude and achievement as a result of student use of calculators. As in the Hembree and Dessart study, test results of pupils using calculators were compared to those of students not using calculators. Smith's study showed that the calculator had a positive effect on increasing conceptual knowledge. This effect was evident through all grades and statistically significant for pupils in third grade, seventh through tenth grades, and twelfth grade. Smith also found that calculator usage had a positive effect on pupils in both problem solving and computation. Smith concluded that the calculator improved mathematical computation and did not hinder the development of pencil-and-paper skills. This was supported by a long-term study of calculator use in Sweden [1] indicated that pupils in grade 4 to grade 6 using calculators did not lose skill in pencil-and-paper calculations as compared to pupils in the traditional classes. Similar results that calculator use did not create any adverse effect on basic computational ability of pupils in primary schools can also be found in U.K [16].

Another issue raised was related to pupils' mathematical problem-solving ability. Hembree and Dessart's [8] meta-analysis showed that using a calculator in problem solving created a computational advantage and more often resulted in selection of a proper approach to a solution. Moreover, calculator use produced a greater positive effect size for high- and low-ability students than average-ability students. Studies have shown that appropriate use of calculators enhances young children's ability to learn basic facts [20] and that those who use calculators frequently exhibit more advanced concept development and problem solving skills than those who do not use calculators [7]. When calculators are built-in into the learning process, achievement in problem solving increases, and more solution methods and strategies are used. Furthermore, Stiff [18] in his National Council of Teachers of Mathematics president's message also agreed that calculators are effective tools in mathematics teaching and learning and can be utilised effectively to encourage higher-order thinking and to assist pupils become flexible and resourceful problem solvers. Moreover, the calculator makes exploration of hypotheses feasible, and is useful in developing counting, computation, estimation and other mathematical skills [19]. In the same vein, Dick [3] stated that calculators could lead to improved problem solving as they free more time for classroom lessons, provide more tools for problem solving, and change students' perception of problem solving as they are freed from the burden of computation to concentrate on formulating and analysing the solution. It was supported by Campbell & Stewart [2] who has shown that appropriate use of calculators resulted in greater persistence in problem solving. This could be explained by the fact that since calculator use allow more time for them to explore, pupils could solve enough problems to discover and observe patterns which are not seen when computations are done by tedious paper and pencil methods. Furthermore, Waits and Demana [22] also recommended that "teaching problem solving should use paper-and-pencil and then support the results using the technology, or vice versa; and use manipulative and paper-and-pencil techniques during the initial concept development and use calculators in extension and generalizing phases" (p.59).

Teachers think that since calculators do all the work, pupils will be less motivated and challenged. This is not the case as Hembree and Dessart [8] found that students who use calculators exhibit greater self confidence and that calculator use generates more enthusiasm about mathematics. Many teachers believe that mathematics is and should be hard work, which normally are associated with manual computations and manipulations. Calculators eliminate much of that work, making them appear nothing but a "crutch" for students who are too "lazy" to perform the assigned mathematical tasks. The truth is calculators are simply tools to help pupils solve problems. They do not do the work for pupils. It is still up to the pupil to read the problem, understand what is asked, determine the solution, and decide whether the answer makes sense. The use of calculators simply allows teachers and pupils to spend more time on the non-computational parts of the problem-solving process [2].

Ellington [4] use the method of meta-analysis to combine the findings of 54 research studies carried out between January 1983 and March 2002 and determine the effects of calculators on pupils' achievement. Each of the studies compared the outcomes of experiments in which the treatment group used calculators while a control group received equivalent method of mathematical instruction with no access to calculator. Results revealed that pupils' operational skills and problem-solving skills improved when calculators were an integral part of testing and instruction. At the other end of the spectrum, Golden [5] found that teachers' practices of frequently using calculators for mathematics instruction reduced students' ability to do well on computational problems at the year end tests where calculators were not allowed. In a local study, Toh [21] conducted a use of calculator over two weeks. It was found that there was no difference in basic skills and problem solving skills between the calculator and non-calculator groups. In fact, the National Research Council's publication, Adding it Up [14], indicated that calculator use was more controversial in mathematics lessons in primary levels than the use of manipulative materials. They stated that "…persistent concerns have been expressed [by mathematics teachers] that an extensive use of calculators in mathematics instruction interferes with students' mastery of basic skills and the understanding they need for more advanced mathematics (p. 254)". From the Trends in Mathematics and Science Study (TIMSS) results, it is clear that mathematical competence at the grades K–6 level does not require calculators. Two of the highest-achieving countries at the fourth- and eighth-grade levels, Singapore and Japan, use calculators sparingly in primary schools.

As aforementioned, there are meta-analyses of research studies on calculator use [8, 4] and by and large the findings support the use of calculators in the mathematics lessons, especially in the upper primary levels. Although calculators have their value in the learning mathematics for the upper primary levels, we should not advocate using them merely because they are popular. Instead, teachers need to establish thoughtful rationales for deciding how and when to use calculators in their classrooms. Therefore schools should strongly encourage the use of calculators in all aspects of mathematical instruction including the development of mathematical concepts and the acquisition of computational skills. Moreover, from the review above it appears that calculator is an effective tool for enhancement of mathematical concepts, development of mental arithmetic skills, pattern recognition, mathematical investigation, solving real-life problems and improving problem-solving ability.

3. Sample Calculator Activities for Upper Primary School Pupils

In the Singapore Revised Mathematics Syllabus [12], the conceptualization of the mathematics curriculum is based on a framework where active learning via mathematical problem solving is the main focus of teaching and learning. One of the main emphases of the primary level mathematics curriculum has been the acquisition and application of mathematical concepts and skills. While the revised curriculum continues to emphasise this, there is now an even greater focus on the development of pupils' abilities to conjecture, discover, reason and communicate mathematics with the aid of calculator. Guidance for teachers must demonstrate how mental facility can be developed alongside calculator use. The appropriate use of calculators in the classroom is the key factor. Since calculator is an effective tool for enhancement of mathematical concepts, development of mental arithmetic skills, pattern recognition, mathematical investigation, solving real-life problems and improving problem-solving ability, it will be useful to provide six such appropriate calculator activities for primary mathematics teachers to incorporate in their mathematics lessons. The following section describes six such appropriate calculator activities that can be incorporated in the teaching and learning of mathematics at the primary level.

1. Enhancement of Mathematical Concepts

In Activity 1 below, the concept of average is reinforced. For pupils who are lacking in conceptual knowledge of average may make an attempt to add up all the even numbers from 2 to 2008 and then divide the total by 1004 terms. Such pupils may find this process of calculating average very tedious and cumbersome. Activity 1 requires the pupils to group the 1004 even numbers into 502 pairs such that each of the sums is equal to 2010. The average can then be computed as (502 x 2010) $\div$ 1004 using the calculator. This may enhance the pupils' understanding the concept of average. Compare this activity to the standard textbook problem of asking the pupils to find the average of a limited set of numbers. Activity 1 is a non-routine problem and it provides opportunities for the pupils to conjecture, discover and reason. Pupils need to apply the sharing techniques of finding average before they use a calculator to assist them in finding the average.

<u>Activity 1: Finding Average (Primary 5)</u>

Find the average of these numbers:
2, 4, 6, 8, 10, …, 2002, 2004, 2006, 2008

2. Development of Mental Arithmetic Skills

<u>Activity 2: Decimal points missing (Primary 5)</u>

John forgot to place the decimal point in the answer of each calculation. Describe how you can use estimation to place the decimal point correctly.

(a) 0.97 x 42 = 4074
(b) 35.4 x 17 = 6018
(c) 7651 x 0.0083 = 635 033
(d) 37.986 $\div$ 0.004 = 44 965
(e) 15.6192 $\div$ 69.33659 = 225266342

Sometimes teachers unduly pressurize the child to remember the rules of placing decimal point in multiplication and division computation sums. However, pupils may forget or confuse easily as they have no understanding of why these rules work and it is not meaningful to them to commit to memory. Pupils should be strongly encouraged to use their understanding of the quantities and of the operations to elucidate through the placement of the decimal point. Therefore, the aim of Activity 2 is to enhance the pupils' estimation skills where pupils need to place decimal points in the products and quotients. Pupils should be encouraged to interpret the first problem as "This is about 1 times of 40, so the answer is about 40." The last division problem is demanding to estimate. It requires 15.679 to be thought of as "about 156 tenths" and then this is to be shared among 70 children, so each child will receive at least two tenth.

3. Pattern Recognition

Number sense involves the flexibility in thinking about numbers that emerges with the ability to relate, compose and decompose numbers [13]. Pupils can use calculator as a tool to explore numbers in the ways that contribute to the development of this flexibility. In the Principle and Standards for School Mathematics [13], teachers may assume that pupils should know that "mathematics involves examining patterns and noting regularities' (p.262), that "statements need to be supported or rejected by evidence", and that "assertions should always have reasons" (p.56). In order for the pupils to examine patterns and note regularities in a set of numbers, the sum of the digits activity involves examining patterns in the sum of digits (see Activity 3). In Activity 3, it will not be possible to multiply the two sets of 2008 digits together using the calculator as most calculators could only take up to 10 digits. Pupils could use the calculator to solve part (a) to (d) to perform the multiplication. The final answer will be: 9 x 8 = 72 (Sum of digits = 9 x1), 99 x 88 = 8712 (Sum of digits = 9 x 2), 999 x 888 = 887112 (Sum of digits = 9 x 3) and 9999 x 8888 = 88871112 (Sum of digits = 9 x 4). From the answers in part (a) to (d), it could be observed that there is a pattern in the sum of the digits and the sum of digits is always multiple of 9. This creates an opportunity for pupils to explore and appreciate number patterns. Performing the computations for activity 3 would be tedious and complex and would render the activity inaccessible to the vast majority of primary 6 pupils; therefore, the use of calculator is necessary.

<u>Activity 3: Sum of the Digits (Primary 6)</u>

Use your calculator to find the sum of the digits in the value of the following:
(a) 9 x 8 (b) 99 x 88 (c) 999 x 888 (d) 9999 x 8888

There is a pattern in the sum of the digits? What is it?

Given that a = $\underbrace{999\ldots999}_{\text{2008 digits}}$, b = $\underbrace{888\ldots888}_{\text{2008 digits}}$

Find your hypothesis what would be the sum of the digits in the value of a x b.

4. Mathematical Investigation

With the use of calculators, teachers in investigative classrooms no longer spend a great deal of time transmitting information via talking or reading and waiting for pupils to complete their long calculations by paper and pencil. Instead, the investigative problems if given on a regular basis would instill in pupils that understanding and explanation are critical aspects of mathematics. In Activity 4, when pupils investigate Peter's trick, they will usually begin with some specific examples or special cases (specialisation) before they make an attempt to generalise. Along the way, the pupils may arrive at certain conjectures which may be false. For example, Peter's trick will not work for three-digit numbers which are repeated. After working through a number of different three-digit numbers, pupils may begin to notice certain features in their solutions. They may articulate these common features and make conjectures to try and explain for them. Therefore, it appears that mathematical investigation would engage the pupils in mathematical thinking: specialisation, generalizing, conjecturing and verifying [10]. Pupils may not succeed in conjecturing, verifying or generalisation but as long as they examine specific examples or specific cases (specialisation) using calculators with the intention of formulating and justifying conjectures so as to generalise, then pupils are doing mathematical investigation. This task also familiarises with the pupils the usage of operational keys in the calculators. In addition, pupils of wider range of abilities can work on the same task (see Activity 4) using calculators.

Activity 4: Three-Digit Numbers (Primary 5)

Peter has a trick he does with numbers.
Here it is. Choose a three-digit number.
For example, 987

Step 1:	Write down all the numbers that may be formed by changing the positions of the digits, 987, 879, 789, 978, 798, 897.
Step 2:	Add them: 987 + 879 + 789 + 978 + 798 + 897 = 5328
Step 3	Find the sum of the digits in the original number: 9 + 8 + 7 = 24
Step 4:	Divide the total by the sum of the original digits: $\frac{5328}{24} = 222$

Repeat steps 1, 2, 3 and 4 using other three-digit numbers.
Peter says that every time he does this trick the final answer is always 222. Do you agree with him?
Investigate Peter's trick. How do you think it works? Write down any observations and results

5. Solving Real-Life Problems

The use of calculators allows realistic data to be used as problem contexts, problems whose solutions are within the conceptual grasp of pupils but whose computational demands are not. The use of realistic data is motivational and helps pupils to see connections between school mathematics and the mathematics used in the world. Activity 5 is a mathematical task that includes real-life data taken from authentic situations. It also provides an opportunity for pupils to use realistic numbers and experience using large numbers and decimals in authentic situations. The rate of exchange, transaction and sale mentioned in the trip from US to Singapore are real-life situations. By and large, primary school teachers would not give such problems to their pupils as they are worried that the computations will involve products and quotients with too many decimal places. Using calculator in this Activity 5 will reduce the impacts of poor computation skills or anxiety about computations as well as avoid messy calculations. Pupils will experience the benefit of calculator as an everyday tool.

Activity 5: Rate and Percentage (Primary 6)

Let us assume you are living in USA, and would like to visit Singapore for one week during the "Great Singapore Sale".

(a) Before coming to Singapore, you bought some Singapore dollars. The rate of exchange between US dollars (US$) and Singapore dollars (S$) was US$1 = S$1.44. You also had to pay the bank 1.5% commission for the money. You bought S$3500 from your bank. Calculate the total amount, in US dollars, you paid to the bank.

(b) You planned to stay at a hotel in city area. On the internet, you found a hotel that offered a week's stay for $1300+++.
This meant that to a basic cost of $1300 you would have to add a service charge of 10% and CESS of 1% of the basic cost.
In addition, you would have to pay a Good and Services Tax (GST) of 7% on the total, that is the sum of the basic cost, service charge and CESS.
 (i) Calculate the amount you would have to pay for hotel accommodation.
 (ii) Express the increase in cost due to service charge, CESS and GST as a percentage of the basic cost of the hotel stay.

(c) While in Singapore, you bought a digital camera for $725.
This price included the 7% GST. Calculate, correct to the nearest ten cents, the GST paid for the camera.

6. Improving Problem-Solving Ability

In Singapore the primary purpose of teaching mathematics is to enable pupils to solve problems and it is therefore crucial that pupils learn to use calculator at each stage of the problem solving process in order to fully harness its capabilities. Having access to a calculator permits pupils to study various cases of a problem situation in a way that is both swift and precise. It also provides a means for pupils to identify patterns and relationships between variables, information from which they may generate possible solution methods and strategies to solve the problem. In Activity 6, the calculator enables pupils to check and correct any computation errors with considerable ease. Activity 6 also allows the pupils to use calculator to compute the total amount saved. Precious time that has been formerly spent on tedious paper-and-pencil calculations can now be passed on to the development of problem-solving strategies and thinking skills. The problem-solving strategies use in this problem could be "tabulation", "simplify the problem" and "look for patterns".

Activity 6: Square Numbers (Primary 5 and 6)

Mary uses a piggy coin box to save money. She deposits 1 cent on the first day, 3 cents on the third day, 5 cents on the fifth day, 7 cents on the seventh day, 9 cents on the ninth day and so on.

(a) How much money will Mary have saved at the end of the 89th day?

(b) How much money will Mary have saved at the end of the 365th day?

(c) How long does Mary need to save at least $400?

These six activities exemplify how calculators assist upper primary school pupils to explore various types of mathematical tasks. This is only possible when the mathematical tasks that teachers use in their classrooms go beyond computations and rote algorithms. The six activities are just first step towards making the use of calculators in the classroom a meaningful one where emphasis is on the process (reasoning and thinking) rather than the product (final answer). In addition, the ongoing use of calculators will provide opportunities and possibilities for pupils to enhance their mathematical learning. This was shared by Shuard and Groves and Stacey [16, 6] reported how primary school pupils' use of calculator led them to meet and become fascinated in topics that were not traditionally part of their mathematics curriculum, such as big numbers, negative numbers, decimals and square roots. The usage of calculators in the primary mathematics classroom enhances pupils' learning of mathematical concepts and skills, problem solving and attitudes [7].

4. Conclusions

The six activities have shown that calculators are used to generate a series of numbers rapidly so as to help develop pupils' number sense, which is vital to learning mathematics meaningfully. Number sense is a major area of the NCTM *Principle and Standards for School Mathematics* [13]. In this paper, the first three activities illustrate how calculator can play an important role in primary school pupils' number development. In an environment where calculators are available, the emphasis of mathematics teaching should be on meaningful concept development as reflected in Activity 1. Although pupils are able to apply the formula involving average in Activity 1, they will find it difficult and tedious to compute such a large set of even numbers. In Activity 1, the primary emphasis will be on the concept of average rather than its computation using calculators. Calculators, like any other technology, cannot substitute basic understanding and intuitions in mathematics. For instance, in Activity 2, pupils need to place the decimal point in each number sentence. Pupils have to use their understanding of the quantities and knowledge of the effect of operating on a pair of numbers. This activity could also be linked to real-world problems or problems posed by the pupils. Teachers may request the pupils to pose stories, real or imaginary, about situations in which they or someone else needs to multiply or divide with decimals. Such problem posing activity is an effective strategy of evaluating pupils' number and operation sense of decimals. In Activity 3, pupils may lose interest if they have to perform the four multiplication sentences without using calculators. However, with calculators, pupils of wider range of abilities can work on the problem task. They can make and test conjectures about the number relationships. In addition, it will also provide a platform for some pupils to wonder whether such products can be extended to decimals. As a result, a new mathematical problem may be created, leading to a meaningful mathematical activity.

The ideal calculator environment should be an environment that fosters the ideas of mathematical reasoning, connections and communication, as outlined in the *Principle and Standards for School Mathematics* [13]. For example, in Activity 4, pupils have to reason, make connections and communicate their results when they are working on the investigative task. Mathematical investigations which were challenging in the past are now explored more easily by pupils using the calculators. This enables the pupils to make more complex and insightful discoveries. Similarly, in Activity 5, a problem is posed for the pupils to understand scenario where they see connections between school mathematics and the mathematics used in the world. As mathematical problem solving is the central focus in Singapore's mathematics curriculum, Activity 6 is a non-routine problem which could be integrated into mathematics lessons. Integrating such non-routine problem into mathematics lesson could create an opportunity for the pupils to develop appropriate connections across topics, extend and apply their mathematical reasoning, reflect on their own experiences, communicate what they know and make mathematical knowledge on their own. Teachers could also request the pupils to work on these six activities outside the classroom or during their free time. This will give the pupils more time to explore and think.

Although calculators can reduce the time spent in performing tedious calculations and illustrating concepts, the use of calculators at the primary level should be restricted and controlled. There is a need to strike a balance between basic numeracy skills, conceptual understanding and problem solving. In addition, to assist pupils accustom themselves with the use of scientific calculators under examination conditions; assessment needs to be modified at the school level in order to focus on this new development. The changes that school leaders, curriculum specialists, teachers and pupils need to manage for successful integration of calculators into the primary mathematics curriculum clearly bring a number of challenges along with them. Ultimately, the decision to use calculators in the mathematics lessons is up to the teacher. It is hoped that teachers will bear in mind the appropriate use of calculators by relating it to their pedagogical goals and their pupils' abilities.

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