Calculator Use in Mathematics Classrooms

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Introduction

For several decades, handheld calculators have been present in mathematics classrooms, and students have been using them for a variety of purposes. Counting tools have been available as early as 500 B.C. when the Egyptians invented a version of the abacus. The slide rule, used for more complex operations, was developed in the late 17th century, and it was seen in American schools approximately two centuries later. (Collins, Ayers, & Lasater, n.d.). More recently, Texas Instruments created the first handheld calculator in 1967; it was bulkier than the models seen today, and it was only used to compute the four basic arithmetic operations (Shackner, 2009). Scientific calculators, which can instantly compute various function values, were soon developed, as well as the first graphing calculator in 1986. Since then, advanced models have been created with computer-like memories and algebraic functions (Waits, B.K. & Demana, F., 2000). From the time of its initial introduction to today's models, teachers have needed to regulate when students are allowed to have calculators during class. Students can become so reliant on the technology that they do not develop a conceptual understanding of the procedures they are performing on the device. This common issue is the reason I have chosen calculators as the topic for this paper; I have already seen it prevalent in several of the schools I have been working. In this paper, I focus on the two types of calculators most commonly seen in mathematics classrooms today: scientific and graphing. I first examine strategies that suggest instances for appropriate calculator use with students. Potential negative consequences will also be discussed, such as a dependency on the tools. Finally, I present research studies that have measured the impact of student learning when each type of calculator is used.

Appropriate Uses

When designing lessons, teachers must decide if calculators are necessary for the learning targets. Thompson and Sproule (2000) propose a framework with two dimensions that can be used to make this choice. The first aspect is student-oriented; a calculator is either essential or nonessential based upon his or her mathematical abilities. When a calculator is classified as essential, it "can give some students the opportunity to explore worthwhile areas of mathematics that would otherwise be inaccessible to them" (Thompson & Sproule, 2000). On the other hand, even if a calculator is considered nonessential, it can still be beneficial to students; the technology can prevent them from performing arduous calculations that consume valuable time. The framework's second dimension classifies the lesson's goals as either process oriented or product oriented. In the former type of lesson, "the calculator is used to facilitate understanding of mathematical problem-solving processes" (Thompson & Sproule, 2000). A product oriented lesson is focused on reaching an end result by computation. This framework is only one of several strategies for teachers to use while planning with technology. Although there are potential limitations to it in some cases, the authors argue the framework is useful when teachers must determine if technology is appropriate for each lesson.

Handheld calculators, when used correctly, can "enhance problem-solving strategies, encourage discourse, [and] allow students to become familiar with multiple ways of using a calculator" (Moss & Grover, 2006). These benefits can occur if teachers employ a multi-step process suggested by the authors. Students must first estimate the solution to an application problem in ink; this material prevents students from altering their initial answer. They are then given time to compare their estimates in pairs, followed

by a whole-class discussion. This opportunity will allow students to view multiple solution strategies and encourage them to critique the reasoning of others. After the discourse, the class should be given calculators to test their estimates. Each student is required to record their keystrokes so they can compare their methods with their peers. Many students will obtain different answers, depending on their familiarity with the device; therefore, teachers should conduct another discussion regarding the different approaches. An incorrect answer could have been displayed if there was an input error, such as using the number 25 for 25%. Many students mistakenly believe calculators will always provide the right answer, but the output is dependent on the user's input. Students can then learn about a calculator's limitations and the correct way to use it. The authors cite several instances of this advantage occurring when students achieve varying results. Finally, students must be able to interpret the displayed answer in the given context. For example, in a percentage question about the number of students who walk to school, students should explain what a result of 10.5 would mean in this scenario. This procedure is only a recommendation for teachers; they can choose the steps in it that are appropriate to each lesson. There are other lessons that may only briefly involve calculators and alleviate the need for this strategy. Students who follow the steps suggested by Moss and Grover, however, will be learning new content as well as meeting several process standards.

Even without a graphing utility, scientific calculators can be used to develop a better conceptual understanding of several mathematical topics. Students can use technology at the introduction of the order of operations to see the necessity for the rules. After initially making a prediction of the result on their own, students can use calculators to find the value of a string of operations. The displayed result will likely be different than the

prediction for students unfamiliar with the order of operations. A discussion of this discrepancy would help motivate the new topic. Calculators can also be used to explore the properties of various numerical subsets when students are learning how to extend the number system. For example, students could be asked to explore why some rational numbers terminate and others repeat. Teachers can provide one of each number and have students discuss the implications of the calculator displays for each of them. When scientific calculators were first used in the classroom, they allowed students to immediately find values, such as trigonometric ratios, that were previously only available in a table. The technology allows easy access to many other areas of trigonometry, such as verifying identifies and degree reductions (Maor, 1976). He suggests scientific calculators can be used to prevent the common misconception that $2\sin(x) = \sin(2x)$; after a few brief experiments students should believe the equation is incorrect. There are many more possible concepts that can be learned through the use of scientific calculators, but these examples are some of the most common.

The introduction of the graphing calculator provided mathematics teachers with many opportunities for further exploration of concepts that were previously impossible. Rather than painstakingly creating graphs of advanced functions by hand during valuable class time, students can now quickly view them to begin analyzing their characteristics. Similar to the arithmetic functions on the more basic calculators, students should not use the graphing capabilities until they are able to make the representations on their own. I recently used graphing calculators to assist Coordinate Algebra students investigate the various transformations of exponential functions. They had already spent several days graphing parent functions, so the technology was used to efficiently create several

transformations. Graphing calculators also allow teachers to explore new areas of mathematics that would otherwise be inaccessible. Waits et al. (2000) explain that, "the parametric graphing utility…make mathematical modeling and simulation possible to illustrate and solve problems that are impossible with paper and pencil alone." As more functions are added to calculators with each new model, teachers are able to design new lessons that can effectively explore mathematical ideas through the technology.

Potential Negative Consequences

Although there are many appropriate uses for using calculators in mathematics classrooms, they can also have negative consequences. The most common one is "that if you allow students to use a calculator arithmetic problems that can be done by hand, then the students will be unable to do arithmetic when the calculator is absent" (Usiskin, 1978). Usiskin refers to this idea as the *crutch premise*. He suggests that calculators should not be given to students who have not yet learned basic arithmetic skills, regardless of whether they are in elementary school or high school. These foundational abilities include knowing the standard multiplication facts and algorithms for small numbers. Once they have been established, students can use calculators to avoid more time-consuming operations. This issue has been observed throughout my limited teaching experience; I have primarily taught high school students, yet many of them are unable to perform simple procedures. For example, I was once working with a 10th grader who had simplified an algebraic equation to 6 = 3x. When the student told me he needed to divide both sides of the equation by three, I asked him, "Ok great. And what is six divided by three equal to?" He immediately reached for his calculator without first attempting to answer the question mentally. This anecdote is one of many instances I have seen of older students relying more on technology

than their own arithmetic abilities. They immediately choose the former because it is often quicker and typically correct.

Although these gaps in prerequisite knowledge may be frustrating for teachers to witness, they could cause those students to fall behind in a mathematics course. Usisikin (1978) argues that, "for such people the calculator is not a crutch; it is the only way to get a right answer." For example, I once witnessed a student in a Math III class attempting to find the determinant of a matrix yet struggling with basic arithmetic. She knew how to correctly apply the standard algorithm, but she asked me for a calculator because she did not know the value of one times zero. Thus, some students will reach a point in their mathematical career where the calculator crutch is the only way they can be successful. In these cases, the ability to correctly use a calculator and interpret its results is more relevant than knowing basic arithmetic facts.

After teaching high school and middle school students in the same school system, I noticed a trend opposite of the crutch premise. The freshmen I taught were extremely reluctant to use their calculators for certain problems, such as solving multiplication problems with extremely large factors. Many of them would spend valuable time on an assessment computing these products even after I suggested using a calculator. I discussed this observation with another mathematics teacher at the school, and she explained that when the students are in middle school, they are never allowed to use calculators. I can understand why calculators may be used sparingly in middle schools: students are still learning number operations, the primary use of handheld calculators. In high school, these operations are expected prerequisite knowledge so students can use them to explore advanced concepts. This counter to the crutch premise can also be seen in the upper grades

when students are taking assessments. Most of the tests in these classes involve mathematical concepts beyond standard computations in which a calculator could be used appropriately. Many students may be hesitant to use them, however, due to the limits on the technology in middle school. Even though calculators could be used to save time and focus on the current concepts, the students could feel as if they are cheating on the test

Although I have only witnessed these calculator restrictions in a few schools, they occur often on a global scale; approximately 54% of international students in the 4th grade are banned from using calculators (Vasagar & Shepherd, 2011). Beginning in 2014, 11 year olds in England can no longer use calculators on any mathematics test. Education and Childcare Minister Elizabeth Truss explains, "children were not getting the rigorous grounding in in mental and written arithmetic they needed to progress" ("Calculators banned in tests for 11-year-olds", 2012). Completely barring calculators in middle schools, however, can have negative impacts on children's mathematical skills. They will neither know how to operate the device or how to recognize an appropriate situation for its use. Robert Siegler, a professor at Carnegie Mellon University, suggests "a better use for calculators is on problems that can't be solved merely by the calculation itself, ones in which the real challenge is knowing what steps on the calculator to take" (Shackner, 2009). In such a problem, students would first determine a solution strategy and how a calculator would be beneficial, rather than immediately using the technology. Thus, teachers must design lessons that find a balance of dependence and avoidance of calculators.

Effects on Achievement and Attitude

Many formal studies have been conducted that measure the computational, conceptual, and attitudinal abilities of students who use calculators. Hembree and Dessart

(1986) conducted a meta-analysis of 79 of these reports that revealed many findings. Each of the studies involved one group of students doing mathematics with some type of calculator and another that was not provided the technology. One of the most important results from the paper was the calculator impact when students are separated by ability level. The authors found there was no significant change in the operational skills for low and high ability students when using a calculator, yet average ability students showed a large improvement in this area when compared to a control group. The only exception for this trend was with students in the 4th grade. When examining problem-solving abilities with a calculator, the authors noticed a pattern opposite the one for operational abilities. Regarding attitudes, "significant positive effects were found for attitude toward mathematics and self-concept,… [but] a nonsignificant effect was found for anxiety toward mathematics" (Hembree & Dessart, 1986). The authors suggest, based on the collected research, calculators can greatly improve students' mathematical skills during both instruction and assessment.

Ellington (2003) wrote an updated meta-analysis under the direction of Donald Dessart, and it includes new results absent from the earlier one. In most of the studies she used, curriculum materials were not specifically designed to involve calculators, but students were still actively using them in the learning process. The author examined two types of studies, the first of which was calculators only used during instruction. In these cases, there were only gains in students' operational skills and their ability to select the appropriate problem-solving strategy. In studies where "calculators were part of both testing and instruction, the operational skills, computational skills, skills necessary to understand mathematical concepts, and problem-solving skills improved for participating

students" (Ellington, 2003). As in the previous meta-analysis, students who used calculators while learning mathematics showed more positive attitudes toward the subject. She also investigated the types of situations when a calculator is being used during instruction. The technology was most beneficial "when calculators had a pedagogical role in the classroom and were not just available for drill and practice or checking work" (Ellington, 2003). Finally, calculators were found to have a greater impact when used for more than nine weeks. This result has an important implication for classroom use; teachers who consistently use calculators for an entire course give students a better opportunity to learn mathematics through the technology.

When the graphing calculator was introduced in 1986, the research emphasis shifted to studying its effects on student achievement; thus, there has been relatively little research on scientific calculator use in the last two decades. Tajuddin et al. (2009) investigated the effects on students' achievement and attitudes when graphing calculators were used by comparing those measures to a class without technology. Post-test results showed that the students using the devices performed significantly better in all variable categories, including conceptual knowledge and performance on transfer problems. These participants exhibited higher meta-cognitive awareness during their work than the other students. The authors concluded that "learning by integrating the use of graphing calculators was instructionally more efficient than learning using conventional strategy" (Tajuddin et al., 2009). Additionally, Ellington (2003) reported on the benefits of using graphing calculators in her meta-analysis. They were the "central reason for student improvement in three areas: understanding of graphical concepts, the ability to make meaningful connections between functions and their graphs, and enhanced spatial

visualization skills" (Ellington, 2003). Graphing calculators allow students to explore many new topics in mathematics, and there is ample research that supports their use in the classroom.

Conclusion

In only a few decades, calculators have advanced from only having four functions to being able to analyze the characteristics of virtually any function. As the technology progresses, mathematics teacher must create new lessons that allow students to explore new ideas with all types of devices. My research and personal experiences have uncovered a variety of advantages and disadvantages to using these calculators in the classroom. They can be used to facilitate mathematically rich discussions and introduce different solution strategies through well-designed lessons; as mentioned earlier, using a scientific calculator to validate various trigonometric identities would be one example. Students can also learn new capabilities of the technology, as well as its restrictions. Certain concepts can be discovered or explored further through the devices. Unfortunately, an abundance or lack of time using calculators can have negative effects on student learning. They may become too dependent on the tools for arithmetic operations, or they could be inexperienced with them when they are necessary in upper mathematics. There is still a need for research on scientific calculators in the current generation of mathematics classroom. Many recent studies exist solely about graphing calculators, but very few are related to the effects of the simpler calculator models when used with the new curriculum.

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