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Assessing U.S. High School Mathematics Students' Dependency on Calculators for Basic Arithmetic Operations Involving Integers from Single-Digit Fact Families

John Jeremy Sneed
University of Texas at El Paso, jsneed10@gmail.com

ASSESSING U.S. HIGH SCHOOL MATHEMATICS STUDENTS' DEPENDENCY ON CALCULATORS FOR BASIC ARITHMETIC OPERATIONS INVOLVING INTEGERS FROM SINGLE-DIGIT FACT FAMILIES

JOHN JEREMY SNEED

Department of Mathematical Sciences

APPROVED:

Lawrence M. Lesser, Ph.D., Chair

Olga M. Kosheleva, Ph.D.

Helmut Knaust, Ph.D.

Bess Sirmon-Taylor, Ph.D.
Interim Dean of the Graduate School

Dedication

For my parents, who simply wanted me to do what I was capable of doing;
for my wife, who simply wanted me to be happy;
and for my Father, who simply loved me enough to use me for His glory.

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by

JOHN JEREMY SNEED, B.S.

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Abstract

This study was designed to investigate the extent to which high school students use calculators to perform basic operations, and how well they actually perform those same operations without using calculators. The investigation involved the testing of math classes of students—male and female, mixed ethnicities—in grades nine through twelve. Students were asked to perform all four basic math operations (add, subtract, multiply, divide) involving integers based on single-digit addition and multiplication fact families with and without calculators. The testing was in two environments—timed and untimed, with students recording their completion times—in order to investigate discrepancies in students' calculator use in regards to the restriction of their available time. Students were also asked to record their completion time and anxiety levels in completing the tests. Binary logistic regressions and least-squares regressions were used to analyze responses based on question characteristics (operation, double-sign, correctness of student response) and test conditions (calculator availability, time limit, student completion time, student anxiety level). While influence of independent variables was mixed, the overall result is that availability of calculators is primary factor in student use of the calculators, along with the existence of a double-sign in the problem, and correctness of the answer. When students don't have a calculator available, they often think they don't need them, but when one is available they use it heavily.

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Chapter 1: Introduction

I recall in my high school years (the early-to-mid 1990s) being introduced to the "graphing calculator," heralded as an essential progression in mainstream math education that would further enhance the help one could receive from a calculator in demonstrating and performing more complex mathematical concepts. I remember learning how to use the calculator and being very impressed with its abilities—you could type in an equation and it would not only graph it for you but would make a table of values so you could see where the graph would be at any position along its path; you could type in an entire sequence of mathematical operations at once and it would provide you with the correct answer sorting through all the order of operations for you. I also remember not needing it to do most of the mathematical work I was asked to do. In fact, I was often required to do that work without the use of the calculator on tests and quizzes. I always viewed a calculator as a convenience—available for computational checking, complex operations (such as working with logarithms), or occasionally speeding up the process of tedious calculations.

Fast-forward to the last decade. As a secondary math educator, the first thing I was assigned each year during teacher in-service week was my class set of graphing calculators. I have watched students use calculators for every operation presented to them, including 5×3 and $-4 + 7$. As I tried to hold these students accountable for math computations such as factoring polynomials, evaluating trigonometric functions, and solving exponential equations, I couldn't help but notice the time spent on the simplest of calculations, basic operations with single-digit integers. The number of students who picked up a calculator to find the answer to multiplication facts that they should have memorized in elementary or middle school is a noticeable and distracting observation that I made on almost a daily basis. Once in an Algebra II class, I told the students that a unit was coming up in which they would not be allowed to use their calculators to perform some of the computations; a student responded—right then, in front of the entire class—that I wasn't allowed to not let them use calculators, and that her parent would be contacting the

administration of the school about this requirement. It was as if I were refusing her a Constitutional right to a calculator. I found myself in conflict with what I was capable of doing when I was the students' age, and what they were seemingly incapable of doing in today's math classes, where the expectations—and consequences—are constantly being raised. As I decided to take time to further my own education in order to better serve this new generation of math learners, I found myself in a position to evaluate my own observations and assumptions that I made while "in the trenches" of education. I had been so afraid of and focused on the long-term consequences of students being so calculator dependent, I never got the opportunity to really investigate just how dependent these students were on their calculators for performing even the most basic of operations, and if they truly needed the aids as badly as they claimed.

Chapter 2: Literature Review

2.1 Background

Anyone who has taught a secondary math class in the last 20 years is very familiar with the progression of calculator use in the classroom. Most everyone involved with math education is aware of the research indicating positive results in regards to calculator use. In the 1970s and 1980s, Suydam (as cited in Barton, 2000) compiled a collection of studies primarily at the elementary school level: of the 95 comparisons made between calculator-using students and non-calculator users, about half (47) of the comparisons showed no significant difference in achievement between the groups; of the remaining 48 comparisons, forty-three showed higher scores by the calculator groups. As calculators became more accessible, similar studies were conducted in the 1970s and 80s with similar results: seventy studies conducted amongst kindergarten through twelfth-graders showed a significant positive effect on overall achievement at almost all grade levels (not fourth grade), even when the calculators were not used on the test in some studies (Hembree & Dessart, 1986). In fact, the researchers found "[t]he use of calculators in testing produces much higher achievement scores than paper-and-pencil efforts, both in basic operations and in problem solving. This statement applies across all grades and ability levels" (p. 96). Improved attitudes towards math were also observed at all levels in their study. Following Hembree and Dessart's lead, Smith conducted a similar analysis in the decade following; his findings—both with regards to overall achievement and improved attitudes—were consistent with his predecessors' (Smith, 1996). As graphing calculators became more accessible and affordable, they were introduced full-steam into math education. And why not? With the rave reviews that simple handheld calculators had been receiving, it seemed only natural that incorporating additional technology with more diverse capabilities should be even more beneficial to secondary math students. So much positive research for calculator use has been produced that in recent years, these devices have become widely accepted for their abundance of

enhancing qualities, and regarded as the standard for future educational technology development (Roschelle & Singleton, 2008).

However, despite all of the positive press on calculator use, there has certainly been a negative side to the discussion. Even as early as the 1970s, parents and educators have hesitated to open the calculator floodgates, while administrators and national organizations like the National Council for Teachers of Mathematics have pushed for increased usage (Banks, 2011). While the NCTM has included regular use of technology in all grade levels as part of its national standards, the language regarding such use has been vague—instructing teachers to “incorporate appropriate instructional technology” (NCTM, 2003, p.1). So teachers have done it, but are still unsure of both the most appropriate ways to do so and the long-term ramifications of that use (Walcott & Stickles, 2012). Closer examination of the improved achievement heralded throughout the years reveals some of the reasons for this reluctance. In my experience, and having discussed the issue with “more experienced” colleagues in their teaching careers, one of the primary reasons calculators have been so widely accepted in math classes was the notion that if students had trouble with a particular skill early in their math careers (say, fractions in the fifth grade), then that deficit shouldn’t prevent them from demonstrating higher levels of mathematical processing (solving a system of equations) later in their math education. Calculators have been thoroughly ingrained into math education curricula and have grown more sophisticated in their capabilities; almost all high school math classrooms today are provided a class set of graphing calculators, available to students whether they have their own or not. Despite such indoctrination, standardized testing in general has had reason to decrease the amount of questions considered to be “mechanical”—the types of questions that would be very easily answered by a scientific or graphing calculator—but has made no major changes in either the number of questions at that level of operation or how those questions are written (Brown, 2010). Thus, if students are using a calculator for basic computations they were once responsible for doing with no assistance, increased achievement would be expected; a lack of increase or any sign of decrease should certainly be viewed as a major disappointment. And being able to use a

calculator on a problem doesn't necessarily mean that the calculator provides all the answers to that problem. High school sophomores and juniors who used calculators as an aid with linear and parabolic graphs still had problems with verifying the correctness of the graph they were given, as well as with interpreting or extracting information from the graph they saw (Mitchelmore & Cavanagh, 2000). The major negative I personally noticed in my tenure was a drastically high percentage of secondary students using their calculators for almost all basic computations—particularly the addition, subtraction, multiplication, and division of single-digit integers. A professor once gave me this analogy: if you asked high school students to write an in-class essay for English, you wouldn't expect them to look up every word they used in the dictionary, would you?

Thus, I was persuaded to research this particular type of calculator use—that is, relying on calculators to perform simple arithmetic operations like 4×3 or $8 + 5$. Unfortunately, my search—which included the ERIC, GoogleScholar, MathEducDatabase, and SpringerLink databases with the following search criteria: calculator use, calculator use and education, calculator dependency, calculator dependence, calculator depend* (the asterisk being a "wild card" entry for the search), calculator use and dependency and secondary and basic, calculator noncalculator, calculator need, calculator need basic operation, calculator basic operation—yielded only a limited number of references regarding if or how much secondary students depended on their calculators for basic operations; none of these results seemed to be applicable to my particular study. This encouraged me to blaze the trail myself.

2.2 Research Questions

Having spent ten years in high school math education, I understand the value of having calculators available to students. Multiple representations of equations and/or their solutions presented by a graphing calculator can reach a very diverse population of learning styles, as well as connecting those representations to give each student the chance to realize multiple methods of problem-solving. Even a "10-digit" calculator can expedite complicated calculations, like

multiple-digit multiplication or taking square roots. Yet in my experience students seem to have increased their calculator usage for even the most basic of operations; i.e., problems so simple they are often referred to as “math facts”—because they should require virtually no “computation” at all, just simple recall from memory. Because these operations are often intermingled with higher math operations (such as working with formulas or solving for and graphing equations) it had been difficult for me to focus more specifically on how often and for what the students were using the calculators.

Thus I have designed this study to ascertain what factors might influence the students’ want or use of a calculator for these basic operations—like -4 + 7 or 5 × 8—and to what extent those factors might have an impact on that want or use. Specifically, the research questions for this study include:

1. (a) To what extent does the level of operation in the problem (add/subtract versus multiply/divide) predict students’ perceived need of a calculator?

   (b) To what extent does the level of operation in the problem (add/subtract versus multiply/divide) predict students’ calculator use?
2. (a) To what extent does the existence of a “double-sign” (i.e., the second addend or subtrahend is negative) in the problem predict students’ perceived need of a calculator?

   (b) To what extent does the existence of a “double-sign” (i.e., the second addend or subtrahend is negative) in the problem predict students’ calculator use?
3. (a) To what extent does whether or not the student got the problem right predict students’ perceived need of a calculator?

   (b) To what extent does whether or not the student got the problem right predict students’ calculator use?
4. To what extent does the availability of a calculator predict students’ perceived need or use of a calculator?
5. (a) To what extent does the existence of a time limit for an activity predict students’ perceived need of a calculator?

(b) To what extent does the existence of a time limit for an activity predict students' calculator use?

6. (a) To what extent does the amount of time the student takes to complete the assessment predict students' perceived need of a calculator?

   (b) To what extent does the amount of time the student takes to complete the assessment predict students' calculator use?

7. (a) To what extent does the students' level of anxiety predict students' perceived need of a calculator?

   (b) To what extent does the students' level of anxiety predict students' calculator use?

Chapter 3: Methodology

3.1 Sample

Students were selected from a high school in a suburban school district from a major metropolitan area in the state of Texas. The campus's student population was comprised of approximately 80% Hispanic, 10% White, and 10% other/multi-racial students; 70% Economically Disadvantaged; and 60% At-Risk, all according to the Texas Education Agency (2013). The school's math department selected classrooms from Math Models and Applications, Algebra II, Algebra III, and Precalculus classes. Tests were given to all students in each classroom, as the activity falls within the scope of expected classroom ability; having all students participate in the activity also helped eliminate the "singling out" of students whose data would be included in the study from those whose would not. Due to the school district's policies on research conducted in their schools, the only data allowed into the study was from students who returned signed parental consent forms (see Appendix A). Of the 125 students who returned their consent forms and were present for at least one test, only 70 completed all four tests in such a way that their data was usable (see section 5.1).

3.2 Instrument Development

As I began to explore the different types of problems to use on the test, many factors came into play. Initially I had to think about if I wanted to use double-digit integers in my work, and how. Two ideas contributed to this decision. First, I looked at the single-digit fact families stemming from positive single-digit integers in addition and multiplication—many of these facts result in double-digit answers (e.g., $5 + 6 = 11$ and $-3 \times 8 = -24$), and thus incorporate double-digit integers into those fact families. Additionally, one of the main influences for me to conduct this study was my experience with higher-level high-school-math students (namely Algebra II) using their calculators for quizzes on factoring simple quadratic trinomials of the form $x^2 + bx + c$. To work such problems, one must be able to factor c into the possible integer combinations, then add those integer factors to get b; in an attempt to help students focus more on the process

of factoring, we (the teachers who wrote & gave the quizzes) made sure the factors used were primarily single-digit factors of *c*—and a noticeable portion (what seemed to me to be a majority) of students were still using their calculators. Both the fact families and my personal experience led me to believe that basic operations involving double-digit integers which resulted in a single-digit answer (such as 11 – 6 and -24 ÷ 3) were appropriately within the scope of my study.

Finally, an extension of the integer-operations problem is that not all operations involving integers result in integer answers. For example, the problem 5 ÷ 8; here the solution is not an integer, and it can be represented either in decimal form (.625) or ratio form (⅝). This began a slippery slope of potential problems to consider: are students expected to recognize or expect ratio answers when they see a problem; what about reducible and irreducible fractions—should they have to know how to simplify, and would an unreduced answer be correct; should they round non-terminating decimals, or know that the answer will be a non-terminating decimal and write the ratio form; does it matter if the numerator is the "larger" number or the "smaller" number (-15 ÷ 6 versus 6 ÷ -15)? In considering how to represent all of these potential issues, as well as the fact that my study's focus is on integer work with fact families, I decided not to include problems resulting in non-integer answers.

Once these decisions were made, the collection of problems representing one of each combination of operation (+, -, ×, ÷), positive/negative numbers and their order (++, +-, -+, --, positive answer/negative answer), and single- and double-digit numbers in the problem (two digits in the problem, two digits in the answer) consisted of 41 problems. A pilot study revealed an average completion time of nearly seven minutes (approximately 6:46), ranging from a little over 3 minutes to almost 15; including teacher instruction and test distribution/collection time, it took over 20 minutes to complete the activity in one class period. Not only was this time much longer than expected, it would be a very class-intrusive amount of time, which would make potential schools and math departments reluctant to participate. The target time for each test's administration (passing out papers, going over instructions, students taking the test, and

collecting them when finished) was 5-10 minutes. A stepwise multiple regression of the pilot results was used to determine which (if any) types of questions might be removed from the tests in order to shorten the time to take each one: The factors that differentiate the types of questions on the test were the type of operation (add/subtract versus multiply/divide), the existence of a double-sign (e.g., 4 – -5 or 3 + -2), whether or not the problem involved a double-digit number (either in the problem or the answer), and whether or not the problem had a negative number (either in the problem or in the answer). A stepwise regression in Minitab (Alpha-to-Enter and –Remove: 0.5) showed that the existence of double-digit numbers somewhere in the problem was the most significant predictor of students' calculator use ($p < 0.001$ regardless of other variables' inclusion). As 21 of the 41 problems had only single-digit numbers both in the problem and in the answer, the test was reduced to the 20 problems that included double-digits either in the problem or in the answer.

3.3 Protocol

A sequence of tests was given, involving the basic math operations—addition, subtraction, multiplication, and division—with single-digit integers (see Appendix B). Each test had the same types of problems, but with different numbers and in a different order—both of which were determined with the assistance of a random-number generator. Tests were administered one test per week for four weeks; because of scheduling conflicts, there was an extra week between the third and fourth tests due to the school's Spring Break. They were administered in the following sequence: first, no time limit and no calculators allowed (NT-NC); second, a time limit of five minutes and still no calculators (T-NC); third, no time limit but calculators were available for use (NT-C); and last, with both the five-minute time limit and calculators available (T-C). The tests without a time limit were still expected to take not much longer than five minutes to complete.

In order to answer questions about students' perceived need for and actual usage of calculators, a pair of check-boxes was displayed on each question. On Tests 1 and 2, students

were asked to check either the “calc” box if they thought they would have used a calculator in any way to arrive at their final answer, or the “no calc” box if they did not think they would have used a calculator at all for their final answer. On Tests 3 and 4, students were asked to check similar boxes to indicate if they used a calculator in any way or not at all, respectively.

For each of the tests, teachers were asked to display a clearly-visible stopwatch (such as the one available at http://www.online-stopwatch.com/large-stopwatch/) during the test; as students finished they were prompted to record the time displayed on the clock (to the second)—the amount of time it took them to complete the test.

Finally, at the end of each test, a simple “scale of 1 to 5” question was asked about the students’ perceived anxiety level in regards to the activity they just completed.

3.4 Analysis

The following table displays and describes the characteristics of the variables involved:

Table 3.1: Independent and dependent variables used for analysis.

		Variable Name	Variable Title	Type	Description/Explanation
Independent Variables	Per-question	Operator	Operator	Binary (“1” or “0”)	Each problem was categorized as either an “addition” fact family operation (+ or -), or it was “multiplication” (× or ÷)
		Double-sign	Double-sign	Binary	The problem had a “double-sign” (negative subtrahend/ second-addend), or it didn’t
		Correct	Correct	Binary	The problem was either correctly answered, or it wasn’t
	Per-test	Allowed Calculator	AllowedCalc	Binary	Either a calculator was available for the test, or it wasn’t
		Time Limit	Timed	Binary	Either the test had a time limit of 5 minutes, or it didn’t
		Completion Time (in seconds)	TimeSec	Ratio	Student-recorded completion time, converted from mm:ss format to total number of seconds
		Anxiety Level	Anxiety	Ordinal	Student-indicated anxiety level, on a 1-to-5 scale
Dependent Variables	Per-question	Want/Use Calculator Indicated	WUCalcInd	Binary	For each question, a student either indicated they wanted/used a calculator, or indicated they didn’t want/use a calculator (no response → blank no data entered)
	Per-test	Want/Use Calculator Percentage-Total	WUCalcPct-T	Ordinal	For each test, the percentage of “yes” indications out of the 20 items on the test
		Want/Use Calculator Percentage-Responses	WUCalcPct-Rsp	Continuous	For each test, the percentage of “yes” indications out of the total number of responses made by the student

The dependent variables represent the students' perceived need ("want") of a calculator in the tests when one wasn't available, and their actual use of a calculator when one was available. For all research questions involving perceived need ("part a" of each), regressions were run on the two tests with no calculator available (NT-NC and T-NC); the questions about use ("b") were analyzed under the calculator-allowed test condition (NT-C and T-C). Since the "Allowed Calculator" variable would have no variation in responses within each of those calculator testing conditions—NC and C—its regressions were run on all four testing conditions together in one set, and on the only other available condition split, NT v. T.

For the first three research questions' independent variables—Operator, Double-Sign, and Correct—all were answered on a "per-question" basis: each of these independent variables, along with the corresponding variable indicating students' use of a calculator, was recorded for each individual test item. As the dependent variable "Want/Use Calculator Indicated" was a binary value, a binary logistic regression was run on those variables together.

The other four questions' independent variables were all recorded on a "per-test" basis—i.e., once for each test. In order to run any sort of analysis on those numbers in terms of want or use of a calculator, the dependent "Want/Use Calculator Indicated" variable's individual responses were converted into percent-usage statistics, so that the responses could be represented once per test. While I was making this conversion, I discovered a conflict in the calculation—not every student indicated calculator use on every question; some students either chose not to indicate or forgot to indicate their calculator use on one or more individual items on each test. Thus, two percentages were created: "Want/Use Calculator Percentage–Total", using the number of problems on which the student indicated "yes" to calculator want/use out of the twenty questions on the test; and "Want/Use Calculator Percentage–Responses" used the percentage of "yes" indications out of the number of indications given on the test. (Example: if a student marked "yes" on ten questions, "no" on five, and left five with no indication at all, his "indicated percentages" were $10/20 = 50\%$ and $10/15 \approx 67\%$, respectively.) In the analyses, I compared the

two variables' results, as the "real answer" would be somewhere in between. Now that these dependent variables were converted from binary to continuous data, a least-squares regression was the more appropriate method for analysis.

Chapter 4: Results

The results for each regression, performed in Minitab, were as follows:

4.1 Regressions for Research Questions 1, 2, and 3

The Operator, Double-sign, and Correct independent variables were all analyzed together against the Want/Use Calculator Indicated dependent variable, since each variable's responses were recorded on a "per-question" basis. Binary Logistic Regression was used here since all four variables were also binary (either a "1" or "0" value was recorded for every response). Since part "a" of each question refers to indicated *need* of a calculator and part "b" the *use* of the calculator, the regressions were run on the No Calculator-versus-Calculator (NC v. C) condition splits. For each test condition (NC, C): 20 questions per test, two tests per student, 70 students included yielded 2800 potential responses.

Table 4.1.1: Binary Logistic Regression for Research Questions 1, 2, 3 under "No Calculator" test condition (in Minitab).

Link Function: Logit							
Response Information 2602 cases were used, 198 cases contained missing values							
Logistic Regression Table							
					Odds	95% CI	
Predictor	Coef	SE Coef	Z	P	Ratio	Lower	Upper
Constant	-1.37016	0.144302	-9.50	0.000			
Operator	-0.664449	0.196192	-3.39	0.001	0.51	0.35	0.76
Double-sign	0.801847	0.198556	4.04	0.000	2.23	1.51	3.29
Correct	-1.20222	0.143727	-8.36	0.000	0.30	0.23	0.40

Table 4.1.2: Binary Logistic Regression for Research Questions 1, 2, 3 under “Calculator” test condition (in Minitab).

Link Function: Logit							
Response Information 2633 cases were used, 167 cases contained missing values							
Logistic Regression Table							
Predictor	Coef	SE Coef	Z	P	Odds Ratio	95% CI Lower	Lower
Constant	-2.58341	0.225535	-11.45	0.000			
Operator	-0.175531	0.130844	-1.34	0.180	0.84	0.65	1.08
Double-sign	0.584178	0.132270	4.42	0.000	1.79	1.38	2.32
Correct	1.08369	0.219711	4.93	0.000	2.96	1.92	4.55

4.2 Regressions for Research Question 4

The Allowed Calculator, Time Limit, Completion Time, and Anxiety Level independent variables were all analyzed together against both the Want/Use Calculator Percentage-Total and Want/Use Calculator Percentage-Responses dependent variables, in order to see how the missing responses may have affected the influence of the independent variables. For Question 4, the analyses couldn’t be run on the NC v. C test condition, as that variable is constant in each condition. Thus, the analyses for this variable were run on all tests together, as well as on the only other available condition split, Not Timed-versus-Timed (NT v. T); for the same reason given above, the Time Limit variable was excluded from these analyses. Since the dependent variables were continuous and the independent variables were both categorical (either ordinal—showing rank/order—or binary, as above) and continuous, the standard Least-Squares Regression was used. For the four-test analyses (“All” test conditions): 1 response per test, four tests per student, 70 students included yielded 280 potential responses; for the split conditions (NT, T): one response per test, two tests per student, 70 students included yielded 140 potential responses.

Table 4.2.1: Regression for Research Question 4 under “All” test conditions, for Want/Use Calculator Percentage-Total dependent variable (in Minitab).

The regression equation is WUCalcPct-T = - 11.9 + 12.6 AllowedCalc - 1.83 Timed + 0.0786 TimeSec + 2.51 Anxiety				
Response Information 268 cases used, 5332 cases contain missing values				
Logistic Regression Table				
Predictor	Coef	SE Coef	T	P
Constant	-11.854	3.954	-3.00	0.003
AllowedCalc	12.618	2.046	6.17	0.000
Timed	-1.833	2.034	-0.90	0.369
TimeSec	0.07864	0.01506	5.22	0.000
Anxiety	2.5128	0.8643	2.91	0.004
S = 15.9817 R-Sq = 20.8% R-Sq(adj) = 19.6%				

Table 4.2.2: Regression for Research Question 4 under “All” test conditions, for Want/Use Calculator Percentage-Responses dependent variable (in Minitab).

The regression equation is WUCalcPct-Rsp = - 11.6 + 13.7 AllowedCalc - 2.25 Timed + 0.0869 TimeSec + 2.13 Anxiety				
Response Information 264 cases used, 5336 cases contain missing values				
Logistic Regression Table				
Predictor	Coef	SE Coef	T	P
Constant	-11.611	4.286	-2.71	0.007
AllowedCalc	13.706	2.219	6.18	0.000
Timed	-2.247	2.215	-1.01	0.311
TimeSec	0.08693	0.01662	5.23	0.000
Anxiety	2.1311	0.9446	2.26	0.025
S = 17.2740 R-Sq = 20.6% R-Sq(adj) = 19.3%				

Table 4.2.3: Regression for Research Question 4 under "Not Timed" test condition, for Want/Use Calculator Percentage-Total dependent variable (in Minitab).

The regression equation is WUCalcPct-T = - 12.3 + 18.5 AllowedCalc + 0.0674 TimeSec + 2.40 Anxiety				
Response Information 134 cases used, 2666 cases contain missing values				
Logistic Regression Table				
Predictor	Coef	SE Coef	T	P
Constant	-12.310	5.818	-2.12	0.036
AllowedCalc	18.464	3.319	5.56	0.000
TimeSec	0.06742	0.02059	3.27	0.001
Anxiety	2.397	1.371	1.75	0.083
S = 17.8318 R-Sq = 22.1% R-Sq(adj) = 20.3%				

Table 4.2.4: Regression for Research Question 4 under "Not Timed" test condition, for Want/Use Calculator Percentage-Responses dependent variable (in Minitab).

The regression equation is WUCalcPct-Rsp = - 11.9 + 20.6 AllowedCalc + 0.0769 TimeSec + 1.66 Anxiety				
Response Information 133 cases used, 2667 cases contain missing values				
Logistic Regression Table				
Predictor	Coef	SE Coef	T	P
Constant	-11.853	6.423	-1.85	0.067
AllowedCalc	20.553	3.664	5.61	0.000
TimeSec	0.07688	0.02318	3.32	0.001
Anxiety	1.660	1.532	1.08	0.281
S = 19.6858 R-Sq = 21.5% R-Sq(adj) = 19.7%				

Table 4.2.5: Regression for Research Question 4 under "Timed" test condition, for Want/Use Calculator Percentage-Total dependent variable (in Minitab).

The regression equation is WUCalcPct-T = - 16.7 + 7.05 AllowedCalc + 0.128 TimeSec + 1.98 Anxiety				
Response Information 134 cases used, 2666 cases contain missing values				
Logistic Regression Table				
Predictor	Coef	SE Coef	T	P
Constant	-16.701	4.185	-3.99	0.000
AllowedCalc	7.050	2.301	3.06	0.003
TimeSec	0.12760	0.02206	5.78	0.000
Anxiety	1.983	1.003	1.98	0.050
S = 13.0240 R-Sq = 26.9% R-Sq(adj) = 25.3%				

Table 4.2.6: Regression for Research Question 4 under "Timed" test condition, for Want/Use Calculator Percentage-Responses dependent variable (in Minitab).

The regression equation is WUCalcPct-Rsp = - 17.6 + 7.08 AllowedCalc + 0.138 TimeSec + 1.97 Anxiety				
Response Information 131 cases used, 2669 cases contain missing values				
Logistic Regression Table				
Predictor	Coef	SE Coef	T	P
Constant	-17.604	4.317	-4.08	0.000
AllowedCalc	7.082	2.371	2.99	0.003
TimeSec	0.13794	0.02306	5.98	0.000
Anxiety	1.965	1.034	1.90	0.060
S = 13.3230 R-Sq = 28.3% R-Sq(adj) = 26.6%				

4.3 Regressions for Research Questions 5, 6, and 7

As discussed in the previous section, the independent variables for Questions 5, 6, and 7 were run together because their data types match. These regressions were also run on the NC v. C conditions, per section 4.1. As in section 4.2, there were 140 potential responses possible for each test condition.

Table 4.3.1: Regression for Research Questions 5, 6, 7 under "No Calculator" test condition, for Want/Use Calculator Percentage-Total dependent variable (in Minitab).

The regression equation is WUCalcPct-T = - 11.0 + 4.08 Timed + 0.0701 TimeSec + 1.69 Anxiety				
Response Information 137 cases used, 2663 cases contain missing values				
Logistic Regression Table				
Predictor	Coef	SE Coef	T	P
Constant	-10.974	3.800	-2.89	0.005
Timed	4.076	2.320	1.76	0.081
TimeSec	0.07006	0.01426	4.91	0.000
Anxiety	1.6921	0.9725	1.74	0.084
S = 12.7013 R-Sq = 20.2% R-Sq(adj) = 18.4%				

Table 4.3.2: Regression for Research Questions 5, 6, 7 under "No Calculator" test condition, for Want/Use Calculator Percentage-Responses dependent variable (in Minitab).

The regression equation is WUCalcPct-Rsp = - 11.7 + 4.64 Timed + 0.0788 TimeSec + 1.47 Anxiety				
Response Information 135 cases used, 2665 cases contain missing values				
Logistic Regression Table				
Predictor	Coef	SE Coef	T	P
Constant	-11.722	3.895	-3.01	0.003
Timed	4.638	2.386	1.94	0.054
TimeSec	0.07876	0.01501	5.25	0.000
Anxiety	1.466	1.009	1.45	0.148
S = 12.9613 R-Sq = 21.9% R-Sq(adj) = 20.2%				

Table 4.3.3: Regression for Research Questions 5, 6, 7 under "Calculator" test condition, for Want/Use Calculator Percentage-Total dependent variable (in Minitab).

The regression equation is WUCalcPct-T = - 7.98 - 7.17 Timed + 0.143 TimeSec + 3.33 Anxiety				
Response Information 131 cases used, 2669 cases contain missing values				
Logistic Regression Table				
Predictor	Coef	SE Coef	T	P
Constant	-7.981	6.764	-1.18	0.240
Timed	-7.166	3.223	-2.22	0.028
TimeSec	0.14340	0.03406	4.21	0.000
Anxiety	3.330	1.395	2.39	0.018
S = 18.0432 R-Sq = 21.3% R-Sq(adj) = 19.4%				

Table 4.3.4: Regression for Research Questions 5, 6, 7 under "Calculator" test condition, for Want/Use Calculator Percentage-Responses dependent variable (in Minitab).

The regression equation is WUCalcPct-Rsp = - 6.02 - 8.66 Timed + 0.153 TimeSec + 2.82 Anxiety				
Response Information 129 cases used, 2671 cases contain missing values				
Logistic Regression Table				
Predictor	Coef	SE Coef	T	P
Constant	-6.023	7.537	-0.80	0.426
Timed	-8.662	3.596	-2.41	0.017
TimeSec	0.15276	0.03787	4.03	0.000
Anxiety	2.822	1.559	1.81	0.073
S = 20.0166 R-Sq = 19.8% R-Sq(adj) = 17.8%				

Chapter 5: Discussions

5.1 Limitations

When working with high-school-age subjects, there are a number of impediments to data collection. First and foremost are the legal ramifications of working with minors in a school setting. Yes, parents are often concerned with what is being asked of their students at school, which can reduce participation; even more cumbersome is the school district's and campus's concerns about being protected from parents as a result of the students' involvement in data collections conducted on campuses. Thus, while the data collected was not considered "sensitive" or "private" by the University of Texas at El Paso Institutional Review Board, the school district required that signed consent forms be collected from any student whose data was to be included in the study. Asking high school students to take a form home, have their parents sign it, and return it to their teacher is a daunting task; doing so for a study that has no direct impact on their class grade is even more so. The original design of the study included data from mathematics class populations of two schools in different areas within Texas, potentially involving close to 4000 students' responses. However, one school was reluctant to participate at the requested time; while school district and campus approvals were being processed for the participating school, curricular conflicts arose and eliminated the Algebra I and Geometry populations from availability. Both of these factors not only reduced sample size, but also limited the representation of the campus—while a varying range of grade levels and subject levels were represented (see section 3.1), the excluded populations accounted for nearly one-half (45%) of the school's mathematics population.

Also limiting was the manner in which data was recorded. Paper-and-pencil data collection in the classroom relied heavily on participants' understanding and accuracy. While samples from 125 students were collected for analysis in the study (see section 3.1), a number of factors removed them from inclusion in the study: most eliminated students were, for unknown reasons, not present for all four tests; a few students left the tests completely or almost

completely blank, to the extent that what little (if any) data was available couldn't be used/compared to other data; some data recorded was incorrectly or unclearly marked (such as a time recorded with a number larger than "59" in the seconds' blank); as noted in the Chapter 4 tables of regression results, even students whose data was usable was not always complete, and some were often omitted by Minitab because there was not a response to include from them in one or more response categories. A more ideal situation might have used a computer for data collection: a survey-type site where students can't advance unless all questions are answered in an appropriate manner, and the completion time can be recorded automatically instead of entered by the student.

5.2 Interpretation of Findings

In the each regression, we are able to compare each independent variable's p-value to the standard $\alpha = 0.05$, where any $p < \alpha$ indicates that the variable examined has a significant impact in predicting whether or not a student would want (if it wasn't available) or use (if it was available) a calculator.

The regressions in Section 4.1 addresses Research Questions 1, 2, and 3. In considering the Operator and Double-sign variables, one must realize that they are inherently overlapping: if Operator is a "0" value, Double-sign must also be "0"—since the definition used here for "double-sign" is based on addition and subtraction. In fact, in looking at the correlations of the two variables, one finds a Pearson *r* value of 0.535 ($p < 0.001$). Think of it this way: Double-sign represents the significance of addition and subtraction problems with a double-sign; then Operator represents the other types of problems (add/subtract without double-sign, multiplication, and division). The p-values for each variable in the first regression are well below the $\alpha = 0.05$, which shows that all three variables are significant predictors regarding a student's perceived need for a calculator (RQs 1a, 2a, and 3a). In other words, the operator in the problem, the existence of a double-sign, and whether or not they got the problem right are all strong predictors in whether or not a student thinks they need or would want a calculator for the

problem. In considering the collinearity of the Operator and Double-sign variables, looking at them individually under the Pearson *r* (See Appendix C) shows that the operator in the problem is not correlated with calculator need ($p > 0.05$). The second regression shows that, while the double-sign and correctness again influence a student's use of a calculator (RQs 2b and 3b), the operation in the problem does not (RQ 1b); this is also supported by the Pearson *r* values. In short, when students don't have a calculator, the operation, double-sign, and correctness of the problem all contribute to them *wanting* a calculator; when one is available, their *use* is predicted by correctness and the existence of a double-signed problem, but not by the other types of operations.

Section 4.2 refers to Question 4, the availability of a calculator. Again, since this variable is constant under the NC and C conditions, it was analyzed with the other "test-based" variables using all test conditions as one collective group, and on the NT and T conditions. Two regressions were run for this variable because of the "percentage" calculation differences. The results from all regressions show that the availability of a calculator significantly predicts the want or use of a calculator. This is well-supported when looking at the data in another way (as displayed in Appendix D): each test's problems were listed along with how many "yes" indications for wanting or needing a calculator for that problem. The mean and median number of "yes" indications per questions stayed the same under the two no-calculator tests (approximately 6 students marked "want" per question); those numbers increased by roughly 150% (15 students "used" per question) once the calculator was made available, and though it decreased to the last test, it was still 50% higher than when the calculator wasn't present (9 students per question). When a calculator is not available, students don't seem to want it all that much; but once it is available, they will use it as much as possible.

The final set of regressions pertains to the final three Research Questions. As with the previous data set, two regressions were run for each test condition based on the two percentages for Want/Use Calculator Indicated, but the results from the two don't differ all that much in terms of significance. In both regressions for the no-calculator condition, knowing that the

activity had a time limit and the students' anxiety levels (RQs 5a and 7a) were not significant indicators of a student wanting a calculator (both p-values > 0.05, for Timed and Anxiety), while their completion time was significantly associated (RQ 6a; both TimeSec p-values < 0.05). When calculators were present, the existence of a time limit and how quickly they worked were significant factors in students' calculator use in both regressions (RQs 5b and 6b); the last results (RQ 7b) were mixed: with the "total percentage" Anxiety was significant, but with the "responses percentage" it was not.

In summary: when a calculator isn't available, the operation, double-sign, correctness, the availability of the calculator, and student completion time are all significant predictors of a student's perceived need for a calculator. When a calculator is available, double-signs, correctness, the calculator's presence, the existence of a time limit, and the completion time significantly influence students' use of a calculator.

5.3 Future Directions

The data collected here was meant to be a "jumping-off" point of sorts for future studies. I am sure that I have only begun to scratch the surface in looking at this type of data, both for myself and for other future researchers. It is possible to dig further into the data as collected by this study. Had time permitted, I would have been interested to see what patterns might exist amongst the students' individual performances across the different testing conditions, how students in different classes or grades performed. Perhaps one teacher's students in one class did better or worse than a similar subject with the same teacher, or different teachers of the same subject-level had similar results. Also, while grading and recording the data, I began noticing how the students missed the problems—sign error on answer, adding instead of subtracting, etc. The collected data could be analyzed for the types of errors made by students, and used as a foundation for investigations into changes in teaching methods of these "trouble areas".

The most compelling follow-up study to me is an expansion of this study's scope. I originally envisioned this study as using entire populations from two different schools in two

different districts. Previously-noted struggles limited my sample size for this particular endeavor. If time and planning allowed, this study could be increased not just within the scope of the campus used, but to multiple campuses, multiple districts, and so on. Related to such an expansion could also be the manner in which the data could be collected. As noted in section 5.1, the instrument could be modified for a computer-based data collection; this could significantly increase the accuracy of the data collected.

As noted in section 3.2, there was a great deal of debate in choosing the types of problems to include in this particular study. Certainly problems with rational numbers would be worth further investigation. Throughout my educational career—even before I was a professional—one of the most popular reasons I heard from students for using a calculator has been “I’m not good at fractions”. Additionally, the National Mathematics Advisory Panel (2007) reported that teachers rated “rational numbers and operations involving fractions and decimals” as the second-poorest area of incoming Algebra I students’ preparedness (p.10). There is such an adverse reaction to rational number reasoning that I have adjusted my methods for teaching numerous math topics in such a way as to avoid using/working with fractions until absolutely necessary to have them. Yet regardless of “fraction-phobia”, perhaps there are particular types of rational numbers that are less intimidating to students than others: rational numbers with small numerators and denominators, or a fraction that easily simplifies using small numbers (*e.g.*, 3/9 or 10/15), just to name a couple.

In performing the regression equations, I also took notice of the R^2 values recorded for each regression. The highest R^2 value attained in any regression was 28.3%, meaning at best a little over 71% of the explanation of why students want or need a calculator for the types of problems studied here is still unaccounted for by the variables in this study. Certainly there are many more ways to classify the problems used here than just by the studied variables. For example, the size of the numbers involved in the different operations could be a factor: a student may not need a calculator for 2×6, but he might for 8×6, or even 4×6.

Even in considering the variables included here, a number of additional research questions were "inspired". For this study, students simply indicated *that* they used a calculator when one was available; a good follow-up to that could be *how/why* they used a calculator—maybe they had no idea what the answer might be, maybe they were just double-checking an answer—or why they thought they needed one when it wasn't available. In light of "correctness" being a predictor of want/use of a calculator, how much did the students already know before they used the calculator? Were they finding out they needed to change their original answer, or did it confirm a correct answer they already had? Or consider all the possibilities involved with anxiety level: the level of apprehension at the start of the activity; did their anxiety grow as the activity progressed; were there certain problems they were more/less anxious about knowing/answering; etc.

The order in which the tests were administered for this study was arbitrarily decided. A future design might have different groups of students taking the tests in different orders. Also, while the manner in which the problems' characteristics were chosen for this study helped make each test close to the same level of difficulty, the problems themselves were randomly-generated; so it is possible that the questions might have been "grouped by difficulty" on each test; i.e., maybe Test 1's problems are "harder" than the ones on Test 2, or Test 3 is the "hardest" of all of them. Successive studies might involve having the same problems on all four tests—randomly re-ordering them on each test—then giving the tests with more time in between each one, to eliminate practice effect. Or similarly, use the same problems (reordered) for Tests 1 and 3 (Not Timed) and then another for Tests 2 and 4 (Timed)—or another shuffling of problems and test order.

5.4 Implications for Teachers

"So, what does this study mean for us?" This entire study was conceived from my twelve years of experience as a professional educator at the high school and college levels. So there's got to be something that all of us as professional educators—at any level, not just high school—

can take away from this study. First and foremost, we can see that there is a great need for calculators felt amongst today's high school students. The existence of a double-sign in the problem, completion time, and correctness are all shown to be significant factors for a student's calculator want or use—regardless of the availability of the calculator. This isn't too surprising: all three of these factors can be traced back to a lack of skill mastery. I personally was pleased to see that my suspicions about students' want-vs.-use were confirmed by Question 4. It was once put to me this way (by the same professor with the English essay analogy in section 2.1): if you're in a room and someone asks, "On a scale of 1-10, would you like a sandwich", how much would your answer change if you could see a sandwich on a table in the room with you? If it's right there in front of them all the time, the students are going to want to use it—and use it—all the time, and not worry about trying to not need it.

The results from this study also show that even the simplest of calculations might be beyond a number of our students' capacities, driving them to use a calculator as often as possible (the aforementioned lack of skill mastery). The attitude in education—particularly in secondary education—has become such that "they'll eventually be able to use a calculator whenever they want, so why not give them one now and not worry about their previous struggles or deficiencies?" Or a more recent and more popular adage is, "This generation of students is so much more technologically advanced, we need to give them more technology and let them explore in order to learn." I'm certainly in support of instructional advancement, learning from "exploration" and experiences, and using technology to provide clearer and more versatile demonstrations or depictions; but using those as the crux for justifying "free use" of a calculator throughout a student's mathematical career is equivalent to giving today's average 2-year-old an iPad and expecting him to eventually figure out trigonometry on his own, without any "formal education" in mathematics.

No one will deny that in order for the brain to perform its duties it must be used regularly. Studies long before this one have shown that organisms with the most minimal of intellectual capabilities can be trained to do button-pushing-level tasks on command by the repetition of the

command/situation; a widely known example is training rats to get food pellets (Koh & Teitelbaum, 1961). But there are important factors at play here. First, those trained animals experience constant and long-term repetition. It's not enough for the rat to get the pellet twice and then assume it's "trained"; the rat is prompted numerous times in a row for days or weeks to ensure it knows how to get the pellet every time (or at least a significantly-high percentage of the time). The rats also suffer consequences for not performing the task correctly. The longer it takes for the rat to figure out getting the pellet, the hungrier it gets; or sometimes choices are accompanied by additional stimuli—electroshock, for example. In order for students to master the basic skills they must be relentlessly repeated, not just for that student's first year of leaning the skill, but repeatedly throughout the students' first few years of learning and mastering the skill. For as far back as I can remember, my mother had me adding up scores in family domino games—always my own, often everyone else's too; had I been handed a calculator to do it, would I still know how to do that simple addition in my head?

The retention of a low-level skill isn't the only issue at stake here. Consider learning a new language. "Meat now sunny he" makes no sense to anyone in the English-speaking world, because they know things like each of those words' definitions; the idea of a "verb"; that there's not a "verb" in that word collection; and that even if there had been a verb, certain types of words have to be in certain places around it in order for that collection of words to form a sentence, to have meaning or purpose. Isn't the same true for the "language" of mathematics? As a high school educator I have repeatedly put a graphing calculator into the hands of a student and asked them to tell me the maximum area of a sheet of plywood when given the width, and repeatedly had them stare right back at me as if I asked them to build the calculator they were holding. And even after hours of instruction on which buttons to push and which order to push them in to get to the point where they might be able to collect an answer to the question, they aren't sure how to read or use the answer they got, or if it's *reasonable*, or even *possible*. Then I get frustrated that they'll use that same powerful tool of exploration and explanation for a pedestrian -8 + 15. How can I as an educator expect them to remember how to answer a word

problem after one week of instruction if they can't even remember basic information that they've been exposed to for years before they ever got to me, especially if they haven't been asked to use that information regularly or been held fully accountable for knowing that information until that time?

Students at all levels of math must be required to demonstrate mastery of each skill set they are taught repeatedly and consistently from the day they are first exposed to it and told that they will need it in the future. And if they don't show the mastery of that skill set, they must be allowed to experience the consequences of not developing and mastering that skill set. We educators must not think the solution to their problems—or ours—is to hand students a calculator and teach them to push buttons. We must be responsible enough for their long-term betterment to require them to do basic skills in an efficient and accurate manner, so that they can use that basic skill development as they move forward in their math careers, where the tasks become more complex and more difficult. When students don't learn how to develop and master the basic skill sets, they are far less capable of developing and mastering more advanced skill sets. Then we—no, then *they* will never know just how much they might have been able to achieve.

References

Banks, S. A. (2011). A Historical Analysis of Attitudes toward the Use of Calculators in Junior High and High School Math Classrooms in the United States since 1975 [Abstract]. Retrieved from ERIC database: http://www.eric.ed.gov/contentdelivery/servlet/ERICServlet?accno=ED525547 .

Barton, S. (2000). What does the research say about achievement of students who use calculator technologies and those who do not? In P. Bogacki, E. Fife, & L. Husch (Eds.), *Electronic Proceedings of the Thirteenth Annual International Conference on Technology in Collegiate Mathematics, Atlanta, GA*. Retrieved from: http://archives.math.utk.edu/ICTCM/EP-13.html

Brown, R. G. (2010). Does the introduction of the graphics calculator into system-wide examinations lead to change in the types of mathematical skills tested? Educational Studies in Mathematics, 73(2), 181-203. doi:10.1007/s10649-009-9220-2

Hembree, R. & Dessart, D. (1986). Effects of hand-held calculators in precollege mathematics education: A meta-analysis. Journal for Research in Mathematics Education, 17(2), 83-99.

Hoffer, T.B., Venkataraman, L., Hedberg, E.C., & Shagle, S. (2007, September 27). *Final report on the national survey of algebra teachers for the National Math Panel.* Retrieved from http://www2.ed.gov/about/bdscomm/list/mathpanel/final-report-algebra-teachers.pdf

Koh, S., & Teitelbaum, P. (1961). Absolute behavioral taste thresholds in the rat. *Journal Of Comparative And Physiological Psychology*, *54*(3), 223-229. doi:10.1037/h0048474

Mitchelmore, M. & Cavanagh, M. (2000). Students' difficulties in operating a graphics calculator. Mathematics Education Research Journal, 12(3), 254-268. doi:10.1007/BF03217088

National Council of Teachers of Mathematics (NCTM) (2003). The use of technology in the learning and teaching of mathematics. Retrieved from http://www.nctm.org/about/position_statements/position_statement_13.htm

Roschelle, J. & Singleton, C. (2008). Graphing calculators: enhancing math learning for all students. International Handbook of Information Technology in Primary and Secondary Education. Springer International Handbooks of Education, 20(9), 951-959. doi:10.1007/978-0-387-73315-9_60

Smith, B. A. (1996). *A meta-analysis of outcomes from the use of calculators in mathematics education.* Retrieved from ProQuest Dissertations & Theses Full Text. (ProQuest ID 304315685)

Texas Education Agency (2013, Dec. 5). *Texas Academic Performance Report*. Retrieved from http://ritter.tea.state.tx.us/perfreport/tapr/2013/index.html

Walcott, C. & Stickles, P.R. (2012). Calculator use on NAEP: A look at fourth- and eighth-grade mathematics achievement. School Science and Mathematics, 112(4), 241-254.

Appendix A

University of Texas at El Paso (UTEP) Institutional Review Board
Informed Consent Form for Research Involving Human Subjects

Protocol Title: Assessing U.S. High School Mathematics Students' Dependency on Calculators for Basic Arithmetic Operations Involving Integers from Single-Digit Fact Families
Lead Investigator: J. Jeremy Sneed
UTEP Mathematical Sciences Department

In this information sheet, "you" always means the study subject—the student. If you are a parent or guardian, please remember: "you" refers to the student.

1. Introduction

You are being asked to take part voluntarily in the research project described below. Please take your time making a decision and feel free to discuss it with your family. Before agreeing to take part in this research study, it is important that you read the consent form that describes the study. Please ask your teacher to explain any words or information that you do not clearly understand.

2. Why is this study being done?

You have been asked to take part in a research study of secondary students' use of calculators. Approximately 600 students from math classes in your school are being asked to participate in this study. You are being asked to be in the study because you are a student in a secondary math class in your U.S. school district. Your involvement will last about 4 weeks, for an estimated 5-10 minutes a week, in your math classroom. You do not have to use any of your outside-of-class time, or come to school outside of your usual school time.

3. What is involved in the study?

To reduce identifying participants from non-participants, and because the activities involved are within the scope of the class, all students will participate in the activities in class. If you agree to take part in this study, your data will be sent to the lead investigator for analysis; if you choose not to take part, your data will be removed and destroyed without being analyzed.

4. What are the risks and discomforts of the study?

There are no known risks associated with this research.

5. What will happen if I am injured in this study?

While there are no foreseen possibilities for you to be injured in this study, The University of Texas at El Paso and its affiliates do not offer to pay for or cover the cost of medical treatment in the event of research-related illness or injury. No funds have been set aside to pay or reimburse you for such injury or illness. You should report any such injury to J. Jeremy Sneed at jjsneed@miners.utep.edu and to the UTEP Institutional Review Board (IRB) at (915-747-8841) or irb.orsp@utep.edu.

(OVER ☞)

6. Are there benefits to taking part in this study?

There will be no direct benefits to you for taking part in this study. This research may help educators to understand how high school students use calculators, and how to improve their use of calculators both at early and later stages of mathematics.

7. What other options are there?

You have the option to not include your data in this study. Since the activities fall within the scope of regular classroom curriculum, you will be participating in the activities in your class; however, there will be no penalties involved if you choose not to include your data in this study.

8. Who is paying for this study?

Funding for this study is provided by the lead investigator.

9. What are my costs?

There are no direct costs to you. Your participation will be part of your normal classroom activities.

10. Will I be paid to participate in this study?

You will not be paid for taking part in this research study.

11. What if I want to withdraw, or am asked to withdraw from this study?

Inclusion in this study is voluntary. You have the right to choose not to be included in this study. If you choose not to be included in the study, there will be no penalty.

If you choose to be included, you have the right to stop at any time. However, we encourage you to talk to your teacher so that they know why you are leaving the study. If there are any new findings during the study that may affect whether you want to continue to take part, you will be told about them. Your withdrawal should be a signed document from your parent/legal guardian stating you/they no longer wish for you to participate; that document should be turned in to your teacher.

The research team may decide to stop your participation without your permission, if members think that being in the study may cause you harm.

12. Who do I call if I have questions or problems?

You may ask any questions you have now and, if you have questions later, you may ask your teacher, call your campus principal, or contact J. Jeremy Sneed at jjsneed@miners.utep.edu.

If you have questions or concerns about your participation as a research subject, please contact the UTEP Institutional Review Board (IRB) at (915-747-8841) or irb.orsp@utep.edu.

13. What about confidentiality?

Your part in this study is completely confidential. None of the data will identify you by name to the lead investigator, and your teachers will not receive any information regarding your individual responses. All records will be kept secure, and any identifying information that might be collected during the study will be removed before results of analysis are published. No one will be able to individually identify your responses as belonging to you.

- - - - - - - - - - ✂ - - - - - - - - - - SIGN AND RETURN PORTION BELOW; KEEP INFO SHEET FOR YOUR REFERENCE - - - - - - - - - - ✂ - - - - - - - - - -

I have read the Study Information Sheet from Mr. Sneed; my student may participate in the study.

Participant Name (print):____________________________________

Parent/Legal Guardian Signature:____________________________________ Date:_______________

Appendix B

Teacher's Instructions for Test 1: No calculator, no time limit

~ Pass out papers, problem-side facing down.

~ Have students put ID Number (***not*** *name*), teacher, course, and grade level. Display stopwatch on projector:
http://www.online-stopwatch.com/large-stopwatch/

~ Remind students to complete instructions in order: answer math questions in the table, *then* record time (to the second), *then* respond to last item.

~ Answer any questions students might have.

~ All students begin at same time; start clock.

~ Collect papers when everyone's done.

Thanks!

- back of Test 1 Teacher, intentionally blank -

#1

Student ID ____________________

Teacher ______________________

Course **(circle one):** **Alg1 Geom MMA Alg 2 Alg 3 Precal Calc Stats**

Student's Grade **(circle one):** **9 10 11 12**

~ When your teacher tells you to, turn the paper over.

[1] Answer each math question in the table, and indicate if you would have used a calculator for that question if one had been available.

[2] As soon as you finish the math questions in the table, look up at the displayed stopwatch and write down the time you see (in minutes and seconds).

[3] Finally, after you have completed the table & recorded your time, respond to the last item.

~ If you have any questions, please ask your teacher at this time.

Thank you for your participation.
J Sneed

#1

Answer each question; check “calc” if you would have used a calculator, or “no calc” if not.

1 -6 × -4 = _____ ☐ Calc ☐ No calc	2 12 – 7 = _____ ☐ Calc ☐ No calc	3 -18 + 9 = _____ ☐ Calc ☐ No calc	4 7 + 7 = _____ ☐ Calc ☐ No calc
5 -7 × 8 = _____ ☐ Calc ☐ No calc	6 7 – 13 = _____ ☐ Calc ☐ No calc	7 -6 – -14 = _____ ☐ Calc ☐ No calc	8 -64 ÷ -8 = _____ ☐ Calc ☐ No calc
9 -5 + -6 = _____ ☐ Calc ☐ No calc	10 48 ÷ 6 = _____ ☐ Calc ☐ No calc	11 5 × -9 = _____ ☐ Calc ☐ No calc	12 3 – -9 = _____ ☐ Calc ☐ No calc
13 -11 – -7 = _____ ☐ Calc ☐ No calc	14 -36 ÷ 6 = _____ ☐ Calc ☐ No calc	15 8 + -12 = _____ ☐ Calc ☐ No calc	16 15 ÷ -5 = _____ ☐ Calc ☐ No calc
17 -5 + 13 = _____ ☐ Calc ☐ No calc	18 -7 – 8 = _____ ☐ Calc ☐ No calc	19 17 + -8 = _____ ☐ Calc ☐ No calc	20 8 × 8 = _____ ☐ Calc ☐ No calc

Record completion time now: ____:____
min sec

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How would you rate your anxiety level during this activity? 1 2 3 4 5
(circle a number) Very Low Very High

Again, your teacher and I want to thank you very much for participating in this activity; your responses are very important to us and your school. Please remember your responses are completely confidential—you haven’t given me your name, and no one will know that your responses or results came from you individually.

J. Sneed

Teacher's Instructions for Test 2: No calculator, 5 minutes

~ Pass out papers, problem-side facing down.

~ Have students put ID Number (***not*** *name*), teacher, course, and grade level. Display stopwatch on projector:
http://www.online-stopwatch.com/large-stopwatch/

~ Remind students to complete instructions in order: answer math questions in the table, *then* record time (to the second), *then* respond to last item.
Students have 5 minutes to complete the activity. If they do not finish before time is called, they will stop working problems, record a time of "5:00", and answer the last item.

~ Answer any questions students might have.

~ All students begin at same time; start clock.
When time is called, remind students who aren't finished to stop working problems, write "5:00" for their time, and answer the last item (as quickly as possible).

~ Collect papers when everyone's done.

Thanks!

- back of Test 2 Teacher, intentionally blank -

#2

Student ID ___________________

Teacher _____________________

Course **(circle one):** **Alg1 Geom MMA Alg 2 Alg 3 Precal Calc Stats**

Student's Grade **(circle one):** **9 10 11 12**

~ When your teacher tells you to, turn the paper over.

~ You will have 5 minutes to complete this activity:

[1] Answer each math question in the table, and indicate if you would have used a calculator for that question if one had been available.

[2] As soon as you finish the math questions in the table, look up at the displayed stopwatch and write down the time you see (in minutes and seconds).

[3] Finally, after you have completed the table & recorded your time (or if time is called before you complete it), respond to the item at the end.

~ If you have any questions, please ask your teacher at this time.

Thank you for your participation.
J Sneed

#2

Answer each question; check “calc” if you would have used a calculator, or “no calc” if not.

1 -10 + 1 = _____ ☐ Calc ☐ No calc	2 5 – -9 = _____ ☐ Calc ☐ No calc	3 -16 ÷ 4 = _____ ☐ Calc ☐ No calc	4 13 + -4 = _____ ☐ Calc ☐ No calc
5 -12 ÷ -6 = _____ ☐ Calc ☐ No calc	6 7 + -14 = _____ ☐ Calc ☐ No calc	7 -17 – -9 = _____ ☐ Calc ☐ No calc	8 45 ÷ 9 = _____ ☐ Calc ☐ No calc
9 -7 × 5 = _____ ☐ Calc ☐ No calc	10 8 + 4 = _____ ☐ Calc ☐ No calc	11 16 – 7 = _____ ☐ Calc ☐ No calc	12 -2 + -8 = _____ ☐ Calc ☐ No calc
13 -8 – -11 = _____ ☐ Calc ☐ No calc	14 -6 + 15 = _____ ☐ Calc ☐ No calc	15 6 × -4 = _____ ☐ Calc ☐ No calc	16 -8 – 4 = _____ ☐ Calc ☐ No calc
17 21 ÷ -3 = _____ ☐ Calc ☐ No calc	18 -9 × -7 = _____ ☐ Calc ☐ No calc	19 9 – 18 = _____ ☐ Calc ☐ No calc	20 4 × 8 = _____ ☐ Calc ☐ No calc

Record completion time now: ____:____
min sec

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How would you rate your anxiety level during this activity? 1 2 3 4 5
(circle a number) Very Low Very High

Again, your teacher and I want to thank you very much for participating in this activity; your responses are very important to us and your school. Please remember your responses are completely confidential—you haven’t given me your name, and no one will know that your responses or results came from you individually.

J. Sneed

Teacher's Instructions for Test 3: Calculator, no time limit

~ Make sure all students have same calculator (from class set or identical).

~ Pass out papers, problem-side facing down.

~ Have students put ID Number (***not*** *name*), teacher, course, and grade level. Display stopwatch on projector:
http://www.online-stopwatch.com/large-stopwatch/

~ Remind students to complete instructions in order: answer math questions in the table, *then* record time (to the second), *then* respond to last item.

~ Answer any questions students might have.

~ All students begin at same time; start clock.

~ Collect papers when everyone's done.

Thanks!

- back of Test 3 Teacher, intentionally blank -

#3

Student ID ____________________

Teacher ______________________

Course **(circle one)**: **Alg1** **Geom** **MMA** **Alg 2** **Alg 3** **Precal** **Calc** **Stats**

Student's Grade **(circle one)**: **9** **10** **11** **12**

~ When your teacher tells you to, turn the paper over.

[1] Answer each math question in the table, and indicate if you used a calculator for that question.

[2] As soon as you finish the math questions in the table, look up at the displayed stopwatch and write down the time you see (in minutes and seconds).

[3] Finally, after you have completed the table & recorded your time, respond to the item at the end.

~ If you have any questions, please ask your teacher at this time.

Thank you for your participation.
J Sneed

Answer each question; check "calc" if you used a calculator, or "no calc" if you did not.

1 10 ÷ 5 = _____ ☐ Calc ☐ No calc	2 -4 × -9 = _____ ☐ Calc ☐ No calc	3 -15 + 6 = _____ ☐ Calc ☐ No calc	4 -8 × 3 = _____ ☐ Calc ☐ No calc
5 7 + 9 = _____ ☐ Calc ☐ No calc	6 13 – 6 = _____ ☐ Calc ☐ No calc	7 -9 – 9 = _____ ☐ Calc ☐ No calc	8 -4 + 12 = _____ ☐ Calc ☐ No calc
9 -10 – -3 = _____ ☐ Calc ☐ No calc	10 8 – 14 = _____ ☐ Calc ☐ No calc	11 -42 ÷ 6 = _____ ☐ Calc ☐ No calc	12 7 × -5 = _____ ☐ Calc ☐ No calc
13 40 ÷ -8 = _____ ☐ Calc ☐ No calc	14 11 + -5 = _____ ☐ Calc ☐ No calc	15 6 – -8 = _____ ☐ Calc ☐ No calc	16 9 × 8 = _____ ☐ Calc ☐ No calc
17 -7 – -16 = _____ ☐ Calc ☐ No calc	18 9 + -18 = _____ ☐ Calc ☐ No calc	19 -54 ÷ -6 = _____ ☐ Calc ☐ No calc	20 -8 + -7 = _____ ☐ Calc ☐ No calc

Record completion time now: ____:____
min sec

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How would you rate your anxiety level during this activity? 1 2 3 4 5
(circle a number) Very Low Very High

Again, your teacher and I want to thank you very much for participating in this activity; your responses are very important to us and your school. Please remember your responses are completely confidential—you haven't given me your name, and no one will know that your responses or results came from you individually.

J. Sneed

Teacher's Instructions for Test 4: Calculator, 5 minutes

~ Make sure all students have same calculator (from class set or identical).

~ Pass out papers, problem-side facing down.

~ Have students put ID Number (***not*** *name*), teacher, course, and grade level. Display stopwatch on projector:
http://www.online-stopwatch.com/large-stopwatch/

~ Remind students to complete instructions in order: answer math questions in the table, *then* record time (to the second), *then* respond to last item.
Students have 5 minutes to complete the activity. If they do not finish before time is called, they will stop working problems, record a time of "5:00", and answer the last item.

~ Answer any questions students might have.

~ All students begin at same time; start clock.
When time is called, remind students who aren't finished to stop working problems, write "5:00" for their time, and answer the last item (as quickly as possible).

~ Collect papers when everyone's done.

Thanks!

- back of Test 4 Teacher, intentionally blank -

#4

Student ID ____________________

Teacher ______________________

Course **(circle one)**: **Alg1 Geom MMA Alg 2 Alg 3 Precal Calc Stats**

Student's Grade **(circle one)**: **9 10 11 12**

~ When your teacher tells you to, turn the paper over.

~ You will have 5 minutes to complete this activity:

[1] Answer each math question in the table, and indicate if you used a calculator for that question.

[2] As soon as you finish the math questions in the table, look up at the displayed stopwatch and write down the time you see (in minutes and seconds).

[3] Finally, after you have completed the table & recorded your time (or if time is called before you complete it), respond to the item at the end.

~ If you have any questions, please ask your teacher at this time.

Thank you for your participation.
J Sneed

Answer each question; check “calc” if you used a calculator, or “no calc” if you did not.

1 -9 – -13 = _____ ☐ Calc ☐ No calc	2 8 + -14 = _____ ☐ Calc ☐ No calc	3 8 × 6 = _____ ☐ Calc ☐ No calc	4 -18 ÷ 2 = _____ ☐ Calc ☐ No calc
5 -16 – -8 = _____ ☐ Calc ☐ No calc	6 7 + 6 = _____ ☐ Calc ☐ No calc	7 -7 × -5 = _____ ☐ Calc ☐ No calc	8 12 + -4 = _____ ☐ Calc ☐ No calc
9 6 – 15 = _____ ☐ Calc ☐ No calc	10 -9 + -3 = _____ ☐ Calc ☐ No calc	11 63 ÷ 9 = _____ ☐ Calc ☐ No calc	12 -5 × 9 = _____ ☐ Calc ☐ No calc
13 5 × -8 = _____ ☐ Calc ☐ No calc	14 2 – -9 = _____ ☐ Calc ☐ No calc	15 -11 + 7 = _____ ☐ Calc ☐ No calc	16 -9 – 1 = _____ ☐ Calc ☐ No calc
17 -49 ÷ -7 = _____ ☐ Calc ☐ No calc	18 10 – 1 = _____ ☐ Calc ☐ No calc	19 16 ÷ -8 = _____ ☐ Calc ☐ No calc	20 -8 + 17 = _____ ☐ Calc ☐ No calc

Record completion time now: ____:____
min sec

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How would you rate your anxiety level during this activity? 1 2 3 4 5
(circle a number) Very Low Very High

Again, your teacher and I want to thank you very much for participating in this activity; your responses are very important to us and your school. Please remember your responses are completely confidential—you haven’t given me your name, and no one will know that your responses or results came from you individually.

J. Sneed

Appendix C

Table C.1: Pearson correlation (*r*) and p-value for each research question variable, by test conditions (from Minitab).

Condition / Variables	NT-NC	T-NC	NT-C	T-C	NC	C	NT	T	All Tests
Operator v WUCalcInd	r = -0.018 p = 0.530	r = 0.004 p = 0.890	r = 0.008 p = 0.772	r = 0.039 p = 0.163	r = -0.007 p = 0.729	r = 0.021 p = 0.272	r = -0.001 p = 0.973	r = 0.023 p = 0.242	r = 0.010 p = 0.462
Double-sign v WUCalcInd	r = 0.070 p = 0.012	r = 0.091 p = 0.001^	r = 0.093 p = 0.001^	r = 0.076 p = 0.006^	r = 0.080 p = 0.000*	r = 0.084 p = 0.000*	r = 0.082 p = 0.000*	r = 0.082 p = 0.000*	r = 0.082 p = 0.000*
Correct v WUCalcInd	r = -0.169 p = 0.000^	r = -0.197 p = 0.000^	r = 0.113 p = 0.000^	r = 0.087 p = 0.002^	r = -0.183 p = 0.000*	r = 0.098 p = 0.000*	r = 0.010 p = 0.625	r = -0.050 p = 0.010*	r = -0.019 p = 0.178
AllowedCalc v WUCalcPct-T	#	#	#	#	#	#	r = 0.340 p = 0.000*	r = 0.135 p = 0.113	r = 0.247 p = 0.000*
AllowedCalc v WUCalcPct-Rsp	#	#	#	#	#	#	r = 0.352 p = 0.000*	r = 0.162 p = 0.059	r = 0.267 p = 0.000*
Timed v WUCalcPct-T	#	#	#	#	r = -0.000 p = 1.000	r = -0.238 p = 0.005*	#	#	r = -0.133 p = 0.026*
Timed v WUCalcPct-Rsp	#	#	#	#	r = 0.002 p = 0.984	r = -0.219 p = 0.010*	#	#	r = -0.129 p = 0.032*
TimeSec v WUCalcPct-T	r = 0.375 p = 0.001^	r = 0.548 p = 0.000^	r = 0.302 p = 0.011	r = 0.432 p = 0.000^	r = 0.403 p = 0.000*	r = 0.380 p = 0.000*	r = 0.123 p = 0.148	r = 0.449 p = 0.000*	r = 0.257 p = 0.000*
TimeSec v WUCalcPct-Rsp	r = 0.402 p = 0.001^	r = 0.578 p = 0.000^	r = 0.264 p = 0.027	r = 0.339 p = 0.005^	r = 0.427 p = 0.000*	r = 0.321 p = 0.000*	r = 0.106 p = 0.217	r = 0.405 p = 0.000*	r = 0.230 p = 0.000*
Anxiety v WUCalcPct-T	r = 0.120 p = 0.326	r = 0.353 p = 0.005^	r = 0.224 p = 0.073	r = 0.166 p = 0.184	r = 0.239 p = 0.005*	r = 0.206 p = 0.018*	r = 0.158 p = 0.068	r = 0.242 p = 0.005*	r = 0.194 p = 0.001*
Anxiety v WUCalcPct-Rsp	r = 0.109 p = 0.374	r = 0.351 p = 0.004^	r = 0.153 p = 0.224	r = 0.160 p = 0.205	r = 0.236 p = 0.006*	r = 0.161 p = 0.068	r = 0.110 p = 0.206	r = 0.242 p = 0.005*	r = 0.165 p = 0.007*
	Bonferroni α= .05/6 = .0083				α = .05		α = .05		α = .05

^ p < .0083 * p < .05 # no variance in I.V. under test conditions

Appendix D

Table D.1: Basic Statistics for Want/Use Calculator variable, by problem, per test.

Test 1	Prob #	Problem	WUCalc	Correct	Test 2	Prob #	Problem	WUCalc	Correct
	5	-7 × 8	15	44		18	-9 × -7	14	41
	8	-64 ÷ -8	12	55		7	-17 – -9	13	30
	19	17 + -8	11	52		13	-8 – -11	10	43
	13	-11 – -7	9	36		2	5 – -9	8	44
	7	-6 – -14	9	40		4	13 + -4	8	58
	10	48 ÷ 6	9	55		5	-12 ÷ -6	7	58
	18	-7 – 8	8	39		17	21 ÷ -3	6	52
	15	8 + -12	8	56		6	7 + -14	6	56
	12	3 – -9	5	44		12	-2 + -8	6	57
	9	-5 + -6	5	53		16	-8 – 4	5	43
	17	-5 + 13	5	57		14	-6 + 15	5	51
	1	-6 × -4	5	60		19	9 – 18	5	55
	3	-18 + 9	4	53		3	-16 ÷ 4	5	62
	20	8 × 8	4	62		20	4 × 8	5	62
	6	7 – 13	3	52		8	45 ÷ 9	5	66
	11	5 × -9	3	66		15	6 × -4	3	59
	14	-36 ÷ 6	2	64		1	-10 + 1	2	61
	16	15 ÷ -5	1	50		11	16 – 7	2	62
	2	12 – 7	0	67		9	-7 × 5	2	63
	4	7 + 7	0	70		10	8 + 4	1	69
Mean:			5.9	53.75				5.9	54.6
Median:			5	54				5	57.5
Max:			15	70				14	69
Min:			0	36				1	30

Test 3	Prob #	Problem	WUCalc	Correct
	19	-54 ÷ -6	31	58
	17	-7 – -16	28	58
	2	-4 × -9	23	65
	11	-42 ÷ 6	22	63
	9	-10 – -3	20	57
	3	-15 + 6	19	55
	15	6 – -8	19	61
	14	11 + -5	18	64
	20	-8 + -7	16	58
	18	9 + -18	16	63
	7	-9 – 9	15	54
	13	40 ÷ -8	14	50
	8	-4 + 12	14	60
	16	9 × 8	14	64
	10	8 – 14	13	57
	4	-8 × 3	11	66
	6	13 – 6	6	68
	12	7 × -5	3	61
	5	7 + 9	2	70
	1	10 ÷ 5	1	68
Mean:			15.25	61
Median:			15.5	61
Max:			31	70
Min:			1	50

Test 4	Prob #	Problem	WUCalc	Correct
	1	-9 – -13	19	58
	11	63 ÷ 9	19	66
	20	-8 + 17	16	62
	2	8 + -14	15	54
	5	-16 – -8	12	55
	15	-11 + 7	11	58
	3	8 × 6	11	65
	9	6 – 15	10	53
	14	2 – -9	9	62
	10	-9 + -3	9	64
	17	-49 ÷ -7	9	64
	4	-18 ÷ 2	7	64
	16	-9 – 1	5	56
	19	16 ÷ -8	4	57
	12	-5 × 9	4	65
	8	12 + -4	4	66
	13	5 × -8	4	66
	7	-7 × -5	3	63
	6	7 + 6	2	69
	18	10 – 1	1	69
			8.7	61.8
			9	63.5
			19	69
			1	53

Vita

John Jeremy Sneed received a Bachelor of Science in Mathematics from Louisiana State University, 2001. The following year he became a Certified Teacher (Grades 7-12) and began working in public high schools in Texas. As a high school teacher, he served a two-year term on the Campus Improvement Team, 2004-2006; was a member of the Textbook Selection Committee, 2007; developed and implemented a Dual-credit College Algebra Prep course for the high-school campus, 2008. Also in that time he served as a special instructor for the Math START Institute program at University of Houston – Downtown, 2006, and was co-author for Houston Community College remedial math modules, 2008. After ten years of service, he returned to college to earn a Master of Arts in Teaching Math from the University of Texas at El Paso, 2014.

Permanent address: 7532 Le Conte Dr

El Paso, TX 79912

This thesis/dissertation was typed by J. Jeremy Sneed.