The Impact of Graphing Calculator Use on Algebra I End of Course Examinations

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This study examined the impact of the use of graphing calculators on standardized end of course examinations in Algebra I courses. Researchers sought to answer questions regarding the relationships among the use of graphing calculators on standardized assessments and student achievement, levels of access, and classroom use of graphing calculators. The researchers recruited participation in the study by high schools in two states. Students took a pre- and post- version of a state standardized end-of-course examination without using a graphing calculator then took a second post-test using a graphing calculator. Researchers examined data with descriptive statistics and multiple linear regression, to investigate differences and relationships between mathematics achievement, graphing calculators, and student and teacher variables. Researchers found that students demonstrated higher levels of math performance when a graphing calculator was used. There was a positive correlation between the residual gain scores and students using a classroom set of graphing calculators.

In a meta-analysis of 54 studies of the use of any type of calculator in the classroom, Ellington (2003a) reports, "when calculators were included in testing and instruction, students in grades K-12 experienced improvement in operational skills as well as in paper-and-pencil skills and the skills necessary for understanding mathematical concepts" (p. 456). These findings were for classes of mixed ability students and were not sufficient to generalize to low or high ability classes. Use of calculators for longer periods of time (greater than 9 weeks) appeared to yield more positive effects.

In addition, Ellington's (2003b) preliminary findings in a meta-analysis of studies of the use of graphing calculators suggest positive effects of the use of graphing calculators on students' procedural skills, conceptual skills, combined skills, and skills retention. In all four areas, students using graphing calculators outperformed the students who did not have access to graphing calculators on mathematics achievement tests. In three studies, students using graphing calculators retained what they learned better than their non-graphing calculator counterparts. On mathematics tests of conceptual skills and overall math achievement, students who used graphing calculators during instruction outperformed the students who did not use graphing calculators during instruction. Comparison of the retention studies and the studies that lasted long term (16 or more weeks) with the short term studies (less than 16 weeks) revealed that students benefit from using graphing calculators for an extended period of time.

Several states (e.g., Texas, North Carolina, Mississippi, Maryland, and New York) now require the use of graphing calculators in their curriculum standards and on their standardized state assessments. Other states allow, but do not require, the use of graphing calculators on state assessments. In an examination of the use of graphing calculators in Texas high schools and the use of those calculators on the Texas Assessment of Knowledge and Skills (TAKS) (Dimock and Sherron, 2005), a linear regression analysis indicated that holding all else constant, scale scores on the TAKS test were 28 points higher in schools where teachers reported the use of graphing calculators for homework. A second significant positive correlation was found between scale scores and students supplying their own calculators. In schools where this was the case, the average scale scores were 36 points higher. Due to the chronology of the introduction of the TAKS test and the timing of this study, the ability to compare test data both with and without the use of graphing calculators on this test was not possible.

The current study examined the use of graphing calculators on a standardized end-of course examination with students enrolled in Algebra I courses in a state that requires the use of graphing calculators on state assessments and those enrolled in Algebra I in a state that does not require the use of graphing calculators on state assessments. The study sought to answer the following research questions:

1. Does the use of a graphing calculator on an Algebra I End of Course Exam by students influence student achievement as measured by that test?
2. Are there relationships among student achievement scores on an Algebra I End of Course Exam and level of students' access to, and use of, graphing calculators?

Method and Procedure

To answer these questions regarding the potential relationships among the use of graphing calculators on standardized assessments and student achievement, as measured by those assessments, and the possible relationships of levels of access and classroom use of graphing calculators with scores on this assessment, the researchers recruited participation in the study by high schools in Texas, a state that requires the use of graphing calculators on state assessments, and Arkansas, a state that allows but does not require the use of graphing calculators on state assessments. Teachers who were teaching Algebra I courses in these schools agreed to participate, as indicated by signed informed consent agreements. Parents of the students enrolled in these teachers classrooms signed informed consent for their children to participate.

A repeated measures design was used in which students took two forms of a standardized Algebra I End of Course examination without using a graphing calculator and a third form of that assessment using a graphing calculator. As a pre-test, Form A of an Algebra End Of Course exam was administered to Algebra I students at the beginning of the 2005–2006 school year. Since items can vary in their sensitivity, future usage should identify what percent are graphic calculator friendly and whether items are aligned in the curricula. This test was not used for purposes of determining student placement in a course or to determine any school ratings for adequate yearly progress or other high stakes accountability purposes. Testing situations where students know it doesn't count may affect their motivation and performance, so random assignment was used in the study. Students post-tested on a second form of the Algebra I End-of-Course examination without the use a graphing calculator and a third form of the examination with a graphing calculator. Students were randomly assigned to take one of the two versions of the posttest with and one without graphing calculators. Thus, each student took both versions, but were randomly assigned to whether they used the graphing calculator with Form B or Form C. This should help to eliminate any item or form bias in the student responses.

At the end of the 2006 academic school year, a survey was also administered to teachers and students to collect information regarding variables such as socio-economic status of students in the school, teachers' experience and professional development in the use of graphing calculators, and students' access to and use of graphing calculators in class. As an incentive in the study, teachers received stipends to participate in the study.

Researchers applied a multiple linear regression to examine data for differences and relationships between mathematics achievement, student graphing calculator use, and teacher variables to answer the research questions.

Data Preparation

Teachers administered the tests and then submitted the tests to researchers for scoring. All tests were administered in the regular classroom setting in a 45 minute class period. Correct answers received one point and incorrect answers were scored as zero. Missing values were also scored as incorrect response. A total score for each Test (Test Time1, Test Time 2, and Test Time 3) was created by summing the items q1-q40. Survey data was also coded and entered in to a data file. All data were screened and verified before analyses were performed.

Sample

Researchers recruited schools in two states that had different policies regarding the use of the graphing calculators on state assessments. Data were collected from 362 students, 13 teachers, and 4 schools. There were no significant differences between states with regard to the residualized gain scores. Therefore, the sample is reported in aggregate. Ninety-five percent of the students participating in the study were in the ninth grade. Four percent were tenth graders and 1% was in the eleventh grade. Students enrolled in a Texas high school made up 57% of the participants. Ten of the teachers were from Texas and three were not. The majority of the teachers taught four to six Algebra I classes per day. Eleven of the thirteen teachers indicated they taught 9th grade only. Five teachers indicated they teach in an urban setting and five reported they teach in rural setting. Only one teacher indicated s/he teaches in a suburban setting.

Results

Test Score Results

Table 1 illustrates the aggregate mean scores for all three tests across all students. Test Time 3, the test on which graphing calculators were used, had a significantly higher mean score than either of the two tests taken without a graphing calculator.

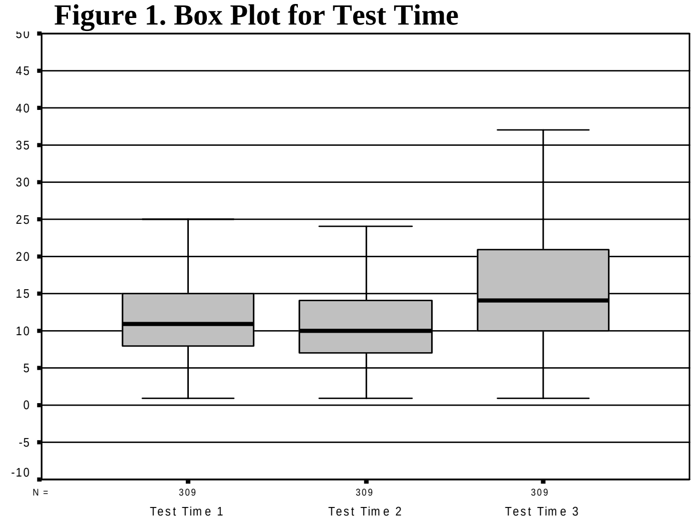
A simply but highly informative graphical method for displaying the spread of scores in a distribution is a box plot. This graphical summary illustrates both the central tendency and the dispersions of scores. The measure of central tendency used in the box plot is the median (although close in value to the mean); the measure of dispersion, which is illustrated by the length of the box, is the inter-quartile range which contains 50% of values (see Figure 1).

Table 1. Mean Test Scores

Mean Test Score	*N*	Mean	SD
Test 1 (without graphing calculators)	309	12.4	5.6
Test 2 (without graphing calculators)	309	11.9	6.9
Test 3 (with graphing calculators)	309	15.7	8.0

To answer the research questions a Linear Regression Analysis was performed to explore the individual contribution of the student variables. For this analysis, the dependent variable was a residualized gain score. That is, students' scores for Test Time 1 and Test Time 2 were regressed onto Test Time 3, calculating residualized or regressed gain scores. These scores were calculated by predicting posttest scores from the pretest scores on the basis of the correlations between Test Time1, Test Time 2 and Test Time 3 (posttest), and then subtracting these predicted scores from the posttest scores to obtain residual gain scores. The effect of the pretest scores is removed from the posttest scores; that is, the residual scores are posttest scores purged of the pretest influence. The residualized gain score has a mean of 0 and a standard deviation of 1. The minimum predicted value was 7 and the maximum was 35.

Figure 1. Box Plot for Test Time



Model Specification

To apply the regression procedure, researchers selected mathematics achievement (residualized gain score) as the dependent variable (Y) to be predicted and explained by independent variables representing availability, type of training, familiarity with a graphic calculator, class time, percentage of instructional activities, and types of use of graphing calculators in the classroom. Researchers specified a model with the following student variables as independent variables:

- Own/Lease my own graphing calculator (T2S2)
- I do not have my own graphing calculator but I use one that is part of the teacher's classroom set while I am in class (T2S4)
- I am eligible for the free or reduced lunch program at my school (T2S5)
- Self-taught without using manual – explored graphing calculator features on my own (q2)
- Self taught using manual (q3)
- Learned how to use as we go in the math course/s I am taking or have taken (q4)
- Graph a function (q5)
- Graph more than one function on the same screen (q6)
- Graph an inequality (q7)
- Graph a scatter plot (q8)
- Create a table (q9)
- Write a program (q10)
- Use the TRACE feature (q11)

- Use the ZOOM feature (q12)
- Use the WINDOW feature (q13)
- Use the INTERSECT feature (q14)
- Use the MAXIMUM and MINIMUM features (q15)
- Connect graphing calculators to motion calculators to motion detectors, computers, or other graphing calculator (q16)
- Teacher Presentation or explanation (q17)
- Whole class discussion (q18)
- Small group work (q19)
- Individual work (q20)
- percent of the instructional activities in your Algebra 1 class involve a graphing calculator (q21)
- To investigate graphs (e.g., to perform stretches, shifts, reflections) (q22)
- To find graphical solutions for different kinds of equations, functions, and relations (q23)
- To check answers (q24)
- To perform direct manipulations of graphs and numerical data (zooming, scaling, scrolling) (q25)
- To create tables (q26)
- To do the more difficult calculations (q27)
- To find maxima, minima, vertices, x- and y- intercepts, and other points on the graph of a function (q28)

The model below was specified and estimated. Note: The base group were students who: (1) did not report any training; (2) were unfamiliar with a graphing calculator; (3) did not estimate class time activities; and (4) did not report types of use.

$$\begin{aligned} MathGainScore_i &= \beta_1 + \beta_2 T2S2_i + \beta_3 T2S4_i + \beta_4 T2S5_i + \beta_5 q2_i + \\ &\beta_6 q3_i + \beta_7 q4_i + \beta_8 q5_i + \beta_9 q6_i + \beta_{10} q7_i + \beta_{11} q8_i + \beta_{12} q9_i + \beta_{13} q10_i + \\ &\beta_{14} q11_i + \beta_{15} q12_i + \beta_{16} q13_i + \beta_{17} q14_i + \beta_{18} q15_i + \beta_{19} q16_i + \beta_{20} q17_i + \\ &\beta_{21} q18_i + \beta_{22} q19_i + \beta_{23} q20_i + \beta_{24} q21_i + \beta_{25} q22_i + \beta_{26} q23_i + \beta_{27} q24_i + \\ &\beta_{28} q25_i + \beta_{29} q26_i + \beta_{30} q27_i + \beta_{31} q28_i + \varepsilon_i \end{aligned}$$

Under this analysis, 14% of the variance in the dependent variable (Residual mathematics achievement gain score) was accounted for and 4 of the 30 independent variables were statistically significant with *p*-values in the $p < 0.003$ to $p < 0.05$ range. An experiment wide error rate is plausible since a $p < .05$ level implies that a 1 in 20 chance of significance exists. Consequently, one or two variables may be significant by chance alone. See Table 2 for parameter estimates.

Parameter Interpretation

Interpretation of the parameter estimates is as follows:

There is a positive correlation between the residual gain score and students using classroom set of graphing calculators ($t = 2.065$, $p < 0.004$). In other words, the average student math residual gain scale scores increases by 0.369 residual points if the student remarked they used a classroom set of graphing calculators ($\beta_1 + \beta_3$).

Variable (q2) Self-taught without using manual – explored graphing calculator features on my own was statistically significant ($t = 2.35$, $p < 0.019$). That is, the average student math residual gain scale scores increases by 0.372 points if the student remarked they self-taught without using manual – explored graphing calculator features on my own ($\beta_1 + \beta_5$).

As the variable (q6) familiarity of graphing more than one function increases by 1 unit, math residual gain scale scores increases by 0.194 points, holding all else constant ($t = 2.02$, $p < 0.045$).

The variable q20 (Individual work) was statistically significant ($t = 3.03$, $p < 0.003$). That is, as the variable q20 Time spent on Individual work increases by 1 unit, math residual gain scale scores increases by 0.175 points, holding all else constant.

Table 2: Parameter Estimates

Model	Unstandardized Beta	Std Error	Standardized Beta	t	Sig
(Constant)	-1.788	.380	-	-4.70	.00
T2S2	.284	.154	.136	1.84	.07
T2S4	**.369**	**.178**	**.163**	**2.07**	**.04***
T2S5	-.008	.125	-.044	-.69	.49
Self-taught w/out manual	**.372**	**.158**	**.152**	**2.35**	**.02***
Learned as we go	.253	.168	.099	1.51	.13
Graph a function	.006	.116	.006	.06	.95
Graph more than one function	**.194**	**.096**	**.212**	**2.02**	**.05***
Graph inequality	.001	.079	.016	.22	.83
Graph a scatter plot	-.001	.070	-.013	-.17	.87
Create Table	-.003	.072	-.004	-.05	.96
Write a program	-.109	.080	-.093	-1.37	.17
Use the Trace	-.005	.070	-.059	-.71	.48
Zoom	.004	.083	.047	.54	.59
Window	-.003	.078	-.004	-.05	.96
Intersect	-.009	.071	-.104	-1.33	.18
MaxMin	.004	.072	.049	.66	.51
Connect to motion detector	-.003	.069	-.035	-.51	.61
Teacher pres/explain	-.008	.067	.085	1.28	.20
Whole class discussion	-.008	.062	-.101	-1.43	.15
Small group	-.009	.059	-.107	-1.61	.11
Individual work	**.175**	**.058**	**.189**	**3.03**	**.003***
% of instructional activities	.008	.070	.079	1.20	.23
Investigate graphs	.004	.142	.002	.03	.97
Find graphical solutions	.004	.176	.018	.27	.79
Ck answers	.233	.180	.088	1.29	.20
Perform direct manipulations	.104	.135	.054	.77	.44
Create tables	-.101	.166	-.046	-.61	.54
Find max/min	.008	.166	.038	.52	.60

Note. * Statistically significant

In conclusion, four of the 30 independent student variables positively correlated to the math residual gain scores. These four variables explained 14% of the variance in the math residual gain scale scores with 86% unexplained variance due to other factors (variables). Analysis revealed that: (1) The average student math residual gain scores increases if the student remarked they used a classroom set of graphing calculators; (2) The average student math residual gain scale scores increases if the student remarked they were self-taught without using manual – explored graphing calculator features on their own; (3) As familiarity of graphing more than one function increases by 1 standard deviation, math residual gain scale scores increase; and (4) As the amount of time spent on individual work increases by 1 standard deviation, math residual gain scale scores increase.

Conclusions

The purpose of this study was to investigate the impact of graphing calculator use on Algebra I end of course examinations. This study sought to answer two research questions:

1. Does the use of a graphing calculator on an Algebra I End of Course Exam by students influence student achievement as measured by that test?

2. Are there relationships among student achievement scores on an Algebra I End of Course Exam and level of students' access to graphing calculators?

Analysis did reveal that students scored higher on standardized assessments when a graphing calculator was used. Further, regression analysis indicated positive relationships among student achievement scores on an Algebra I End of Course Exam and level of students' access to graphing calculators. That is, (1) The average student math residual gain scores was higher if the student remarked s/he used a classroom set of graphing calculators, (2) The average student math residual gain scale scores was higher if the student remarked s/he was self-taught without using a manual, that is, s/he explored graphing calculator features on their own, (3) As familiarity of graphing more than one function increased by 1 unit, math residual gain scale scores increased, (4) As the amount of time spent on individual work increased by 1 unit, math residual gain scale scores increased.

Discussion

The lack of other significant variables may offer insight into the nature of the mathematics instruction on the campus. For example, socio economic status (SES) which is commonly reported when predicting student achievement was not a statistically significant predictor variable. It may also suggest the level of use or student familiarity with the graphing calculator. Nonetheless, this study adds evidence to the body of research suggesting that the use of a graphing calculator makes a significant and practical impact in mathematics achievement in Algebra I classes. Our findings are consistent with the findings of Ellington's (2003) meta-analysis indicating that the use of graphing calculators in testing significantly improved performance. Her findings were for classes of mixed ability students and were not sufficient to generalize to low or high ability classes.

The regression analysis demonstrated significant positive relationships among student achievement scores on an Algebra I End of Course Exam, use of a graphing calculator on that examination, and level of students' access to graphing calculators. Average student math gain scores were higher if the student remarked s/he used a classroom set of graphing calculators. The average student gain scale scores was higher if the student remarked s/he had explored graphing calculator features on her/his own by using the manual. As the mean score for student familiarity with graphing more than one function increased by 1 unit, student math gain scale scores increased. Finally, as the reported amount of time spent on individual work increased by 1 unit, math gain scale scores increased. Thus, factors that may impact student performance as measured by standardized assessments are student access to graphing calculators, student knowledge of how to use graphing calculator functions, and the use of graphing calculators on standardized assessments.

References

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