A Study of the Impact of Graphing Calculator Use in Algebra I

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This study examined the use of graphing calculators over a one year time frame with students enrolled 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 two tests without using a graphing calculator then took a third test using a graphing calculator. Researchers examined data with a Repeated Measures General Linear Model (GLM), Multiple Regression, and Hierarchical Linear Modeling (HLM) 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. Using HLM, researchers constructed a model where 12% of math achievement variability was statistically explained by: (1) student use of a graphing calculator; (2) student ownership of a graphing calculator; (3) student access and use of a classroom set of graphing calculator; (4) student familiarity in graphing more that one function; (5) teacher familiarity in writing a program using the graphing calculator; and (6) connecting graphing calculators to motion detectors, computers, or other graphing calculators.

A Study of the Impact of Graphing Calculator Use in Algebra I

In her meta-analysis of 54 studies of the use of any type of calculator in the classroom, Ellington (2004) 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 (2004) findings in a meta-analysis of studies of only the use of graphing calculator 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 Dimock and Sherron's (2005) 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), 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 over a one year time frame 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 seeks to answer the following research questions.

Research Questions:

1. Does the use of a graphing calculator on an Algebra I End of Course Exam by students who have been trained to use graphing calculators 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?

3. Are there relationships among student achievement scores on an Algebra I End of Course Exam and teacher familiarity with graphing calculators in Algebra classes?

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 another state that does not. Teachers who were teaching Algebra I courses in these schools agreed to participate, as indicated by signing informed consent agreements. Parents of the students enrolled in these teachers classrooms signed informed consent for their children to participate.

Method

Students took two tests without using a graphing calculator then took an 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. 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. During pre-testing, students did not use a graphing calculator on the assessment. Teachers submitted the tests to the researchers for scoring and these scores were entered into a data file for later comparison with post-test results. At the end of the 2006 academic school year, a survey was 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. Students post-tested on the Algebra I End-of-Course examination using a graphing calculator.

Analysis

Researchers examined data with a Repeated Measures GLM, Multiple Regression, and Hierarchical Linear Modeling to investigate differences and relationships between mathematics achievement, graphing calculators, and student and teacher variables.

Results

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. With regard to how they learned to use graphing calculators, Table 1 illustrates that most students reported that they have learned to use graphing calculators in their mathematics courses. Sixty-one percent of students indicated that they had learned how to use graphing calculators in class.

Table 1. How students learn to use Graphing Calculators

What training have you received in the use of graphing calculators?	f	Percent
None–know very little about how to use	22	4.6%
Self-taught without using manual–explored graphing calculator features on my own	64	13.4%
Self-taught using manual	25	5.2%
Learned how to use as we go in the math course/s I am taking or have taken	289	61%
Other	15	3%

θ Note. n=478. Students were directed to check all that apply.

Table 2 illustrates student responses to questions regarding the features of graphing calculators and how familiar they are with each. Over half the students reported that they were familiar or very familiar with graphing functions, graphing more than one function on the same screen, creating a table, using the ZOOM feature, and using the WINDOW feature. Students had the least familiarity with connecting graphing calculators to other devices, such as motion detectors or sensors, and write a program with the graphing calculator.

Table 2. Familiarity with Graphing Calculator features

2. How familiar are you with how to do each of the following with a graphing calculator?	n	Not familiar	Somewhat familiar	Familiar	Very familiar	Mean	SD
Graph a function	360	26 (7.2%)	88 (24%)	129 (36%)	117 (25%)	1.9	.93
Graph more than one function on the same screen	356	52 (15%)	78 (21%)	108 (30%)	118 (33%)	1.8	1.1
Graph an inequality	355	76 (21%)	131 (37%)	113 (32%)	35 (10%)	1.3	.92
Graph a scatter plot	351	74 (21%)	108 (31%)	112 (32%)	57 (16%)	1.4	.99
Create a table	348	51 (15%)	62 (18%)	112 (32%)	123 (35%)	1.8	1.1
Write a program	354	240 (68%)	72 (20%)	25 (7%)	17 (5%)	.48	.83
Use the TRACE feature	351	91 (26%)	93 (27%)	79 (23%)	88 (25%)	1.5	1.2
Use the ZOOM feature	355	52 (15%)	79 (22%)	113 (32%)	111 (31%)	1.7	1.0
Use the WINDOW feature	350	77 (22%)	90 (26%)	86 (25%)	97 (28%)	1.6	1.1
Use the INTERSECT feature	348	80 (23%)	88 (25%)	107 (30%)	73 (21%)	1.5	1.1
Use the MAXIMUM and MINIMUM features	355	119 (34%)	106 (29%)	85 (24%)	45 (13%)	1.2	1.0
Connect graphing calculators to motion calculators to motion detectors, computers, or other graphing calculators	349	213 (61%)	66 (19%)	44 (13%)	26 (8%)	.66	.96

Note. (Not familiar =0, Somewhat familiar = 1, Familiar = 3, Very Familiar = 4)

When students were asked how often they used graphing calculators in their Algebra I class, they overwhelmingly reported that they used graphing calculators over 50% of the time in class. Thirty five percent of the students reported that they used graphing calculators 75% to 100% of the time in their Algebra I class. Table 3 illustrates the results of this question.

Table 3. Instructional activities

Approximately what percent of the instructional activities in your Algebra 1 class involve a graphing calculator?	f	%
None – we do not use graphing calculators	2	.6%
1% to 9%	2	.6%
10% to 25%	22	6%
25% to 49%	48	14%
50% to 74%	153	44%
75% to 100%	120	35%

Note. n=347

Researchers also asked students to respond to questions regarding how much time in their Algebra I classes is spent in different types of learning activities. Table 4 illustrates these responses.

Table 4. Class time

Please estimate how much class time is spent on:	n	None	Some	Half	Most	All	Mean	SD
Teacher Presentation or explanation	357	8 (2%)	97 (27%)	119 (33%)	102 (29%)	31 (9%)	2.1	.98
Whole class discussion	359	41 (11%)	155 (43%)	78 (22%)	59 (16%)	26 (7%)	1.6	1.1
Small group work	355	50 (14%)	178 (50%)	59 (17%)	51 (14%)	17 (5%)	1.5	1.0
Individual work	358	5 (1%)	58 (16%)	76 (21%)	149 (42%)	70 (20%)	2.6	1.0

Note. (None =0, Some =1, Half =2, Most = 3, All = 4)

Individual work was reported as the most frequent type of activity by students, with 21% reporting they worked individually half the time, 42% most of the time, and 20% all of the time. Teacher's presentation or explanation was the next highest activity, reported by 33% of students as half of the time, 29% as most of the time, and 9% as all of the time by students.

Table 5 contains students' responses to questions regarding the purposes of graphing calculator use in their Algebra I classes.

Table 5. Use graphing calculators

In your Algebra 1 class, how do you use graphing calculators?	f	%
To investigate graphs (e.g., to perform stretches, shifts, reflections)	205	43%
To find graphical solutions for different kinds of equations, functions, and relations	284	59%
To check answers	286	60%
To perform direct manipulations of graphs and numerical data (zooming, scaling, scrolling)	161	34%
To create tables	253	53%
To do the more difficult calculations	262	55%
To find maxima, minima, vertices, x- and y-intercepts, and other points on the graph of a function	262	55%

Note. n=478. Students were directed to check all that apply.

Finally, students were asked if there were times in class when the teacher did not allow them to use a graphing calculator. Sixty one percent of students said that there were times when they were not allowed to use the graphing calculator and 39% reported that they had unlimited use of graphing calculators in class.

Results of teachers survey responses will be entered here on the final report.

Test Score Results

Table 6 illustrates the aggregate mean scores for all three tests across all students. Note the sample size is different because student survey data was contained missing data. The test taken with the graphing calculators had a significantly higher mean score than either of the two tests taken without a graphing calculator.

Table 6. Mean Test Scores

Mean Test Score	n	Mean	SD
Test 1 (without graphing calculators)	313	12.2	5.3
Test 2 (without graphing calculators)	313	11.3	7.3
Test 3 (with graphing calculators)	313	14.6	8.9

GENERAL LINEAR MODEL: REPEATED MEASURES

The two basic objectives in experimental design are the elimination of systematic bias and the reduction of error. The main reason for within-group variability is individual differences among subjects. Thus, even though subjects receive the same treatment, their scores on the measured variable can differ significantly because of preexisting individual differences. In repeated measures designs variability among the subjects due to individual differences is completely removed from the error term. This makes the repeated analysis more powerful than completely randomized designs, where different subjects are randomly assigned to different treatments.

To begin our investigation researchers performed a repeated measures analysis. Student math test scores were measured on three different occasions. The first two times students were not allowed to use graphing calculators and on the third test students were permitted to use calculators. In proceeding with the analysis we hypothesized:

Ho_1: $TestTime_1 = TestTime_2 = TestTime_3$
Ha_1: $TestTime_1 \neq TestTime_2 \neq TestTime_3$

Multivariate Test

The multivariate test for overall main effects was statistically significant as reported in Table 7 ($F = 14.8$, $p < .000$). The effect size (eta squared) is 14%.

Table 7. Multivariate test

Source	Value	df	Error df	F	Sig	Eta Squared	Observed Power[a]
Test							
Wilks' Lambda	.859	2	311	25.5	.000	.14	1.00

The within subject F-test indicated that there was a significant **test time** effect (F = 25.3, p < .000); in other words, student math performance scores changed across time. We know from the descriptive statistics that students scored the highest on Test Time 3 when they were allowed to use graphing calculators. The observed power was calculated at 1.00.

Table 8. Test of Within-Subjects

Source	Type III Sum of Squares	df	Mean Square	F	Sig	Eta Squared	Observed Power[a]
Sphericity Assumed	1779.06	2	889.54	31.14	.000	.091	1.00
Greenhouse-Geisser	1779.07	1.8	949.45	31.15	.000	.091	1.00
Error Test	17821.59	624	28.56				

a. Computing using alpha = .05

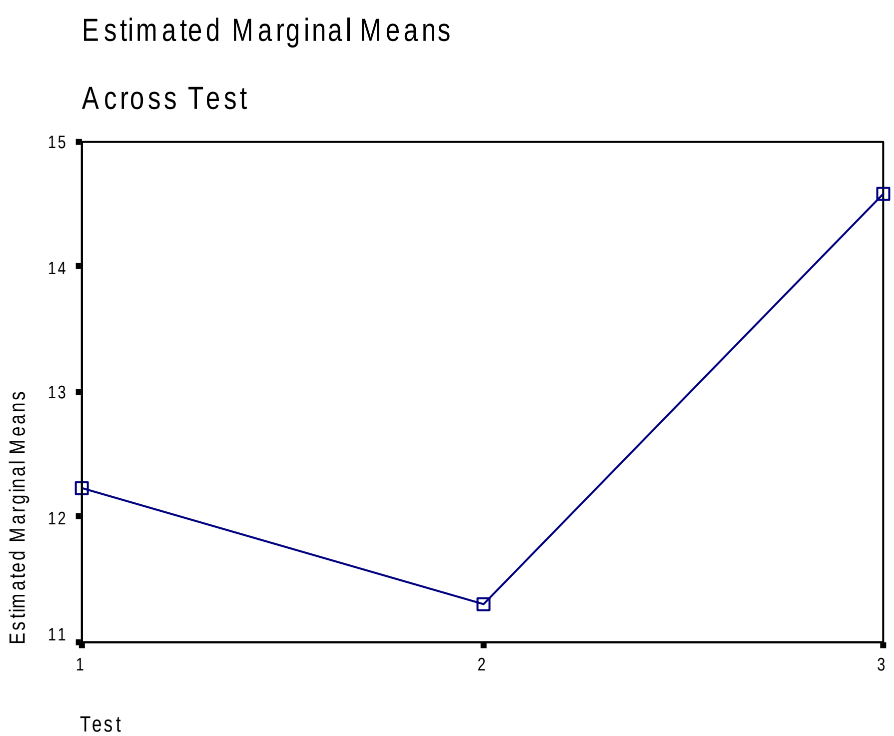
There is, a significant Test Time main effect, and in particular, quadratic trend is significant at the .05 level (F = 74.7, p < .000). The Observed Power was calculated at 1.0.

Table 9. Test of Within-Subjects Contrasts

Source	Type III Sum of Squares	Df	Mean Square	F	Sig	Eta Squared	Observed Power
Test							
Linear	858.29	1	858.28	27.17	.000	.080	.999
Quadratic	920.78	1	920.78	36.06	.000	.104	1.0

Error							
Linear	9856.21	312	31.59				
Quadratic	7965.41	312	25.53				

Let us now look at the estimated Marginal Means Profile Plot. In the graph we see that student scores slightly decrease on Test Time 2 and significantly increase on Test Time 3 when students use a graphing calculator on mathematics. In other words, students scored statistically significantly different across three test times. The mean score for Test Time 3 was higher than Test Time 1 and 2.



In conclusion, students demonstrate higher levels of math performance when a graphing calculator is used.

REGRESSION ANALYSIS

In order to better understand the growth in math performance when graphing calculators were used, researchers applied a multiple regression equation. Multiple regression analysis is a technique used to identify a "best-fit" combination of independent (predictor) variables that are correlated with a dependent variable, and minimally correlated with other independent variables. A regression analysis identifies those variables that are most strongly related to the dependent variable as well as parametric differences between binary variables.

For this analysis, the dependent variable was a residualized gain score. That is, students 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.

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 constructed a linear regression 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.

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

Under this analysis, 4 of the 30 independent variables were statistically significant at the $p <$ 0.003 to $p < 0.05$ alpha level in which 14% of the variance in the dependent variable (Residual mathematics achievement gain score). See Table 13 for parameter estimates.

Table 13: 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	.00*
% 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

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 < .004). In other words, the average student **math residual gain scale scores** increases by .369 **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 < .019). That is, the average student **math residual gain scale scores** increases by .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 **.194 points**, holding all else constant (t = 2.02, p < .045).
- The variable q20 (Individual work) was statistically significant (t = 3.03, p < .003). That is, as the variable q20 Time spent on Individual work increases by 1 unit, **math residual gain scale scores** increases by **.175 points**, holding all else constant.

In conclusion, four of the 30-predictor variables positively correlated to the math residual gain scores. These four variables explained 14% of the variance in the math residual gain scale scores. 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 unit, math residual gain scale scores increase, (4) As the amount of Time spent on Individual work increases by 1 unit, math residual gain scale scores increases.

MULTILEVEL MODELING

Multilevel modeling (MM), which includes *hierarchical linear modeling* or *random coefficients modeling* (RC) or *covariance components models*, is a form of hierarchical regression analysis developed since the 1980s, designed to handle hierarchical and clustered data. Such data involve group effects on individuals which may be assessed individually by traditional statistical techniques. That is, when grouping is present (ex., students in schools), observations within a group are often more similar than would be predicted on a pooled-data basis, and hence the assumption of independence of observations is violated. Multilevel modeling uses variables at nested levels (ex., school-level budgets) to adjust the regression of base level dependent variables on base level independent variables (ex., predicting student-level performance from student-level socioeconomic status scores). Multilevel modeling is related to structural equation modeling in that it fits regression equations to the data, then tests alternative models using a likelihood ratio test.

Two-Level Individual Growth Model

Researchers have three measures of math achievement therefore a growth model can be estimated. The two levels in this HLM include repeated measures (level one = 939) nested within students (level two =313). The final (full) multilevel equation is specified as:

$$Y_{ij} = \beta_0 + \beta_1 Time_{ij} + \beta_2 Time_{ij}^2 + \beta_3 T2S2_{ij} + \beta_4 T2S4_{ij} + \beta_5 Q2B_{ij} + \beta_6 Q3D_{ij} + \beta_7 TRQ5F_{ij} + B_8 TRQ5L_{ij} + u_{ij} + e_{ij}$$

Each parameter is identified as:

- Test 1, Test 2, or Test 3 (Time -Linear)
- Test 1, Test 2, or Test 3 ($Time^2$-Quadratic)
- 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).
- Graph more than one function on the same screen (Q2B)
- Individual work (Q3D)
- Teacher measure of familiarity in writing a program using the graphing calculator (TRQ5F)
- Teacher measure of familiarity in connecting graphing calculators to motion detectors, computers, or other graphing calculators (TRQ5L)

Multilevel Model Interpretation

The outputs for the Hierarchical Linear Models are summarized in Table 13 for the variance decomposition of the response variable; achieve (three repeated math test score measures). Model 1 provides a baseline model to compare additional models that might help in reducing the amount of variability in the outcome variable achieve. Model 2 with time added, substantially reduced the unexplained variability in achieve (χ^2=28.03, df=1, p =.05). Model 3 with $Time^2$ added, also significantly reduced the amount of unexplained variability in Math Achievement (χ^2=31.53, df=1, p =.05). Model 4 added a measure of graphing calculator ownership (T2S2) which also significantly reduced the amount of unexplained variability in Math Achievement (χ^2=19.53, df=1, p =.05). In Model 5 researchers added measure of graphing calculator use in classroom (T2S4) which significantly reduced the unexplained variability in the achievement outcome (χ^2=5.02, df=1, p =.05). Model 6 included a student measure of familiarity in graphing more than one function on the same screen (Q2B) which significantly reduced the unexplained variability in the dependent variable (χ^2=5.27, df=1, p =.05). In Model 7 a student estimate of how much classroom time is spent on individual work (Q3D) was added, however, it did not reduce the unexplained variance in the model (χ^2 =1.86, df=1, p =.05). In others word, Model 7 was not significantly different from Model 6. In Model 8, researchers next added a teacher measure of familiarity in writing a program using the graphing calculator (TRQ5F) which significantly reduced the unexplained variability (χ^2 =8.49, df=1, p =.05). Lastly, in Model 9, researchers added a teacher measure of familiarity in connecting graphing calculators to motion detectors, computers, or other graphing calculators (TRQ5L) which too significantly reduced the unexplained variability in Math Achievement (χ^2 =4.0, df=1, p =.05).

Effect Size

Snijders and Bosker (1999) suggested an approach to computing R^2 values in multilevel models by computing the model's associated mean square prediction error. The R^2 effect size is then computed as one minus the combined variance at both levels for the full model divided by the combined variance for the null model, or:

$$R_1^2 = 1 - \frac{\hat{\sigma}^2(full) + \hat{\tau}_0(full)}{\hat{\sigma}^2(null) + \hat{\tau}_0(null)} \tag{1}$$

$$R_1^2 = 1 - \frac{(49.2)}{(55.67)} \tag{2}$$

$$R_1^2 = 1 - .88 \tag{3}$$

$$R_1^2 = .12 \tag{4}$$

Therefore, 12% of math achievement variability was statistically explained by: (1) student use of a graphing calculator; (2) student ownership of a graphing calculator; (3) student access and use of a classroom set of graphing calculator; (4) student familiarity in graphing more that one function; (5) teacher familiarity in writing a program using the graphing calculator; and (6) connecting graphing calculators to motion detectors, computers, or other graphing calculators. Table 13 presents the results of the HLM Analysis.

Table 13. Summary Results for HLM Analysis Repeated Measures of Math Achievement

HLM Models	Model 1 Intercept Only	Model 2 Intercept + Time	Model 3 Intercept +Time + $Time^2$	Model 4 Intercept +Time + $Time^2$ + T2S2	Model 5 Intercept +Time + $Time^2$ + T2S2 +T2S4	Model 6 Intercept +Time + $Time^2$ + T2S2 +T2S4 +Q2B	Model 7 Intercept +Time + $Time^2$ + T2S2 +T2S4 +Q2B +Q3D	Model 8 Intercept +Time + $Time^2$ + T2S2 +T2S4 +Q2B +TRQ5F	Model 9 Intercept +Time + $Time^2$ + T2S2 +T2S4 +Q2B +TRQ5F +TRQ5L
Intercept Only (B_0)	12.70 (.24)	12.70 (.24)	17.36 (1.80)	16.46 (1.78)	15.05 (1.83)	14.40 (1.83)	13.81 (1.86)	13.45 (1.53)	12.33 (1.63)
Time (B_1)		1.17 (.29)	-7.23 (2.0)	-7.23 (2.0)	-7.23 (2.00)	-7.23 (1.99)	-7.23 (1.99)	-7.23 (1.49)	-7.23 (1.49)
$Time^2(B_2)$			2.10 (.51)	2.10 (.49)	2.10 (.49)	2.10 (.49)	2.10 (.49)	2.10 (.36)	2.10 (.37)
T2S2(B_3)				3.22 (.52)	3.89 (.56)	3.89 (.56)	3.84 (.56)	2.93 (.80)	2.81 (.80)
T2S4(B_4)					1.71 (.56)	1.75 (.55)	1.76 (.55)	2.05 (.75)	2.07 (.75)
Q2B(B_5)						0.40 (.12)	0.35 (.13)	0.42 (.17)	0.41 (.17)
Q3D(B_6)							0.26 (.11)	-	-
TRQ5F(B_7)								.99 (.22)	1.04 (.30)
TRQ5L(B_8)									.74 (.37)
Level 1 error variance	31.31	29.94	28.46	28.47	28.47	28.47	28.46	28.46	28.46
Level 2 error variance (u	24.36	24.82	25.31	23.21	22.69	22.15	21.96	21.13	20.74
Level 3									
Effect Size		.02	.03	.07	.08	.09	.09	.11	.12
Deviance (-2LL)	6275.63	6247.60	6216.07	6196.54	6191.52	6186.25	6184.39	6175.9	6171.9
Df	3	4	5	6	7	8	9	10	11
Chi-square Difference (df=1)		28.03	31.53	19.53	5.02	5.27	1.86	8.49	4.00

Note: χ^2 =3.84, df=1, p =.05

HLM Parameter Interpretation

- There is a positive correlation between math achievement and time^2 ($t = 4.31$, $p < .00002$) which is indicative of a quadratic trend. That is, student scored highest on Test 3 when graphing calculators were made available.

- Variable (T2S2) I own or lease my own graphing calculator was statistically significant ($t = 4.69$, $p < .000$). That is, student **scores** increase by 2.81 **points** if students own or lease a graphing calculator **(** $\beta_1 + \beta_3$ **)**.

- Variable (T2S4) 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 was statistically significant ($t = 3.83$, $p < .000$). That is, student **scores** increase by 2.07 **points** if student remarked they use a graphing calculator in class **(** $\beta_1 + \beta_4$ **)**.

- As the variable (Q2B) student familiarity of graphing more than one function increases by 1 unit, student **math scores** increase by **.410 points**, holding all else constant ($t = 2.81$, $p < .005$).

- The variable TRQ5F (Teacher familiarity in writing a program with a graphing calculator) was statistically significant ($t = 4.82$, $p < .000$). That is, as teacher's familiarity in writing a program with a graphing calculator increases by 1 unit, student **math scores** increase by **1.04 points**, holding all else constant.

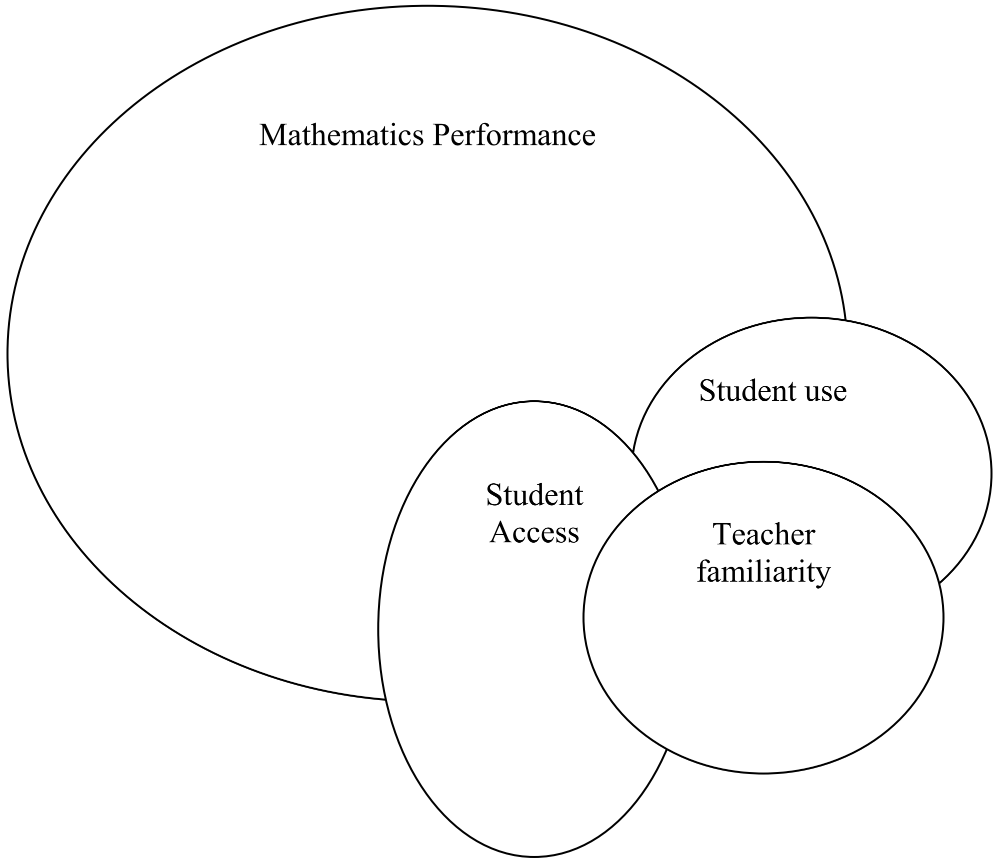
- The variable TRQ5L (Teacher familiarity in connecting graphing calculators to motion detectors, computers, or other graphing calculators was statistically significant ($t = 2.61$, $p < .009$). That is, as teacher's familiarity in connecting graphing calculators to motion detectors, computers, or other graphing calculators increases by 1 unit, student math **scores** increase by **.740 points**, holding all else constant.

DISCUSSION

Why do graphing calculators make a difference?

Are there relationships between the meta analysis and our research? What is consistent? What is different? Discuss how the independent variables are impacting math performance.

Major factors are student access to graphing calculators, student use and teacher knowledge of graphing calculator functions.


Mathematics Performance
Student use
Student
Access
Teacher
familiarity

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