Texas Instruments

Comments to the

National Math Panel

October 12, 2006

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TI COMMENTS

RESEARCH

October 12, 2006

Ms Jennifer Graban
Deputy for Research and External Affairs
National Math Panel
400 Maryland Avenue SW
Washington, DC 20202

Dear Ms. Graban:

Texas Instruments (TI) is pleased and honored to have the opportunity to submit our comments to the National Math Panel (NMP). As an educational business and a technology company, we applaud the NMP's mission to advance the teaching and learning of mathematics. In addition to our written comments, we would appreciate the opportunity to address the NMP in person at the November meeting. We look forward to serving as a resource for the NMP and helping further its goals and achievements.

In this document we want initially to acquaint the NMP with our company, its history, its experience in efforts to improve education, and investments of our money, our people, and our time in specific educational technology products that we belive offer promise in mathematics education.

We also specifically want to describe our experience and the lessons we have learned in three discrete areas. We have, over the years, reviewed available research and begun more scientific research about which we will report briefly to you. Based upon results we have observed in these areas we will offer suggestions for what we believe works. We urge you to review all the available research to explore what is known and proven in these areas and to encourage additional research, if needed, to test and generate stronger evidence about them.

First, we will share the general lessons we have learned from years of experience in working to improve math education. We believe strongly in a "systems approach" to reform and recommend scientific research to further evaluate this approach.

Second, we will discuss our efforts in promoting the Finding Common Ground team and its work. We recommend that the NMP focus much of its work on identifying solid research that supports their agreements.

Finally, we will discuss TI's involvement with graphing technology, the promise we believe it holds as an essential element of math education, initial research behind graphing calculators, and our own support of additional rigorous research to provide the strongest evidence for use of this promising technology.

TI AND ITS HISTORY OF EFFORTS TO IMPROVE EDUCATION

TI has a 75-year history of innovation. While our business portfolio has changed over the years, we have always been a company of engineers and scientists with a strong commitment to education. TI has over 35,000 employees worldwide. We are a global company, and most of our employees and manufacturing are located in the United States. Last year, the company had revenues of $13.4 billion, the majority from our semiconductor business where our focus is enabling communications and entertainment with digital signal processing, analog, and Digital Light Processing (DLP®) solutions. TI's business other than semiconductors is Educational and Productivity Solutions, known for over two decades for producing educational tools, including graphing calculators and teacher professional development for middle and high school mathematics and science educators and students.

TI's commitment to math and science education started with the company's founders and remains stronger than ever today. TI believes in investing in education in order to have the talent base needed to continue our legacy of innovation. An example of the founder's education commitment is beginning what later became the University of Texas at Dallas in 1961 to help supply the North Texas region and the company with master's level graduates in engineering.

From our involvement in education public policy at the local, state and national levels, it became clear that in order to support long-term industry growth and improve our competitiveness in a worldwide marketplace it was imperative that we invest in earlier stages along the K-12 education pipeline. Additionally, TI has learned the importance of taking a systemic approach to education issues: identifying a specific issue to address, partnering with other stakeholders to share investment and benefits, and developing and implementing a systemic solution. One example is TI's involvement in early childhood education that began with a 1990 partnership with the local Head Start and university administration. The partnership established the Margaret Cone Center to provide education, health and social services to disadvantaged children. Students' performance was longitudinally measured, and study students performed ahead of their peers throughout elementary school. The program was replicated in 1995 by establishing the Jerry R. Junkins Head Start Center, and TI's efforts and supporting data influenced statewide and nationwide initiatives in early childhood education.

TI's education business's mission is to improve math achievement for all students by fostering quality instruction in mathematics education. Our goal and commitment is to provide products, programs and services for math teaching and learning that can be components of an effective educational system in the classroom for teachers and students. We understand that our graphing technology products are not a stand-alone solution; rather we believe that they can be an effective component of a coherent system when used appropriately. We want teachers and education leaders to view us as an essential partner in improving the mathematics performance of all students.

LESSONS LEARNED AND THE NEED FOR A SYSTEMS APPROACH

INTRODUCTION

What follows is a careful, detailed attempt on our part to provide the NMP our views pertaining to the issues we believe you should consider. These views are based on our experiences, review of available research, and lessons learned. We understand that they are not grounded in scientific research, though, in certain circumstances, significant research, some of which we are sponsoring, is underway. We would be pleased to report results of further research as it is completed.

The key point we want to make, however, is that to achieve and sustain student performance improvement, we have learned that key elements of the mathematics education system must be addressed in a coherent, integrated way, and there is no "silver bullet" focused on a single system element.

We understand there is not fully developed scientific research to prove this hypothesis; rather, it is an observation from decades of experience and involvement in the field. Our hope is that you will uncover and publish, if it exists, scientific evidence on the proposition that systemic reform is necessary as well as the proven components of a comprehensive system that will effectively deliver mathematics education and improve student mathematics performance. If such scientific research does not currently exist, we strongly recommend that the NMP make such research a matter of the highest priority in its conclusions and report.

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Significant funds are invested in mathematics programs at the local, state, and federal levels of government. Without a research-based definition of effective mathematics education systems, these investments will remain below par and generally ineffective in creating any broad-scale improvement in U.S. students' math performance. The federal government is in a unique position to build the infrastructure of policy, technical assistance, and funding to scale and to sustain improvement in math education. But, to be successful, such efforts must be based on solid research.

Finally, in this section, we will describe a systematic effort we have begun with the Richardson Independent School District (RISD), in Richardson, Texas, to implement a series of interventions to decrease the achievement gap in middle school mathematics. This project is intended to demonstrate a systems approach to solving an important problem. The initial findings and preliminary research are reported. We are conducting longer term, more significant research on these strategies, which we hope to report to the NMP at a later date.

LESSONS LEARNED ABOUT INCREASING STUDENTS' MATHEMATICAL COMPETENCE

We believe that the following principles are critical and would benefit from the NMP's scrutiny of existing and further research.

What Students Need to Learn to Succeed in Algebra and Higher Mathematics

Mathematics is a subject where skills build one upon another. Any gap in knowledge has the potential of creating a situation where students are not prepared to acquire the competences need to be successful in algebra and in higher levels of mathematics.

Students learn more and deeper mathematics when conceptual, strategic, procedural, and calculation aspects are presented as complementary.

The success of the Singapore mathematics curriculum shows the fruitfulness of uniting all aspects of mathematics. In the US, when struggling students focus only on the calculation, they are too often deprived of opportunity to learn the conceptual and strategic aspects of mathematics and cannot proceed to the proficient level that is our national goal for all children. Concepts and strategies are needed for proficiency with procedures and calculations, and the procedures and calculations are needed for proficiency with strategies and concepts.

Students need automatic recall of basic number facts, and should be able to use the basic algorithms of whole number arithmetic, and understand the number meaning of fractions to be prepared for algebra.

In *Reaching for Common Ground in K-12 Mathematics Education* (Ball, D. L., Ferrini-Mundy, J., Kilpatrick, J., Milgram, R.J., Schmid, W., & Schaar, R. Notices of the American Mathematical Society*, 52(9) (2005), 1055 – 1058,)* the specifics of what PreK-8 students need to master in several specific areas are suggested:

<u>Basic number facts</u>: *"Certain procedures and algorithms in mathematics are so basic and have such wide application that they should be practiced to the point of automaticity."* Students must know their basic addition and multiplication facts both as a vital life skill and as a building block for future mathematics learning. If students have to stop and research the answers to basic computational questions, they cannot possibly be efficient in the tasks of problem solving or doing more complex mathematical problems.

<u>Learning basic algorithms of whole number arithmetic</u>: *Students need to be able to use these algorithms as well as understand how and why they work.* "Because they embody the structure of the base-ten number system, studying them can reinforce students' understanding of the place value system." In addition, these algorithms and the understanding of their inner workings can serve as a valuable early work in the path to the generalizations of algebra.

<u>Fractions</u>: "*Understanding the number meaning of fractions is critical*." Without the proper understanding of fractions, decimals, percentages, and proportions cannot be understood. In addition to the understanding of fractions, the arithmetic of fractions and rational numbers in general are another step in being prepared for algebra.

These three concepts need also to be put in the framework of the five strands of mathematical understanding as developed in *Adding It Up* (Kilpatrick, J., Swafford, J. and Findell, B. (Eds.). *Adding It Up: Helping Children Learn Mathematics*, Washington, DC: National Academy Press, 2001.) Rote memorization without thinking in terms of these principles will not get students where they need to be.

> **Procedural fluency** - skill in carrying out procedures flexibly, accurately, efficiently, and appropriately – is what many assume is the final point in the mathematics learning process.
>
> **Conceptual understanding** - comprehension of mathematical concepts, operations, and relations – is what must happen to get to the next step.
>
> **Strategic competence** - ability to formulate, represent, and solve mathematical problems – is critical for students as their progress through school and life.
>
> **Adaptive reasoning** - capacity for logical thought, reflection, explanation, and justification – is a major byproduct of a mathematical education.
>
> **Productive disposition** - habitual inclination to see mathematics as sensible, useful, and worthwhile, coupled with a belief in diligence and one's own efficacy – gives students the confidence to go on to high mathematics and other science and technology courses.

These five strands match with the five strands of the Singapore mathematics program which is one of the most successful in the world today: Procedural fluency is equivalent to skills; conceptual understanding, to concepts; strategic competence, to metacognition; adaptive reason, to processes, and productive disposition, to attitudes.

Algebraic reasoning, including symbols and generalization, needs to be introduced in grades K-8 to ensure students are fully prepared to be successful in Algebra I.

There is significant work going on in the specific area of algebraic reasoning as a prerequisite for a rigorous algebra course. *The Algebra Group Report at the Finding Common Ground Meeting*, Indianapolis, IN, March, 2006 (Bressoud, D., Bryant, C., Carter, J., Forman, S., Papick, I., Tucker, A., and Wu, H., http://www.maa.org/common-ground/iupui/algebra-report.html) details several recommendations in this area.

The key is starting to teach ideas of generalization and symbols much earlier than we do today in many circumstances. The understanding of whole number arithmetic needs to be reinforced through mathematical explanations of algorithms and their natural generalization. Use of generality and symbols can be developed through rational numbers and the operations on them. Linear relations, linear functions, and their graphs can be introduced, and their relationships can be explored. The use of well-structured patterns can help students build their capacity for generalization along with students' ability to explain their generalization process.

How Students Learn Math

TI has been privileged to be a long-term partner in efforts to improve mathematics learning. Research findings and extensive practical experience encourage our commitment to create research-based technologies that give educators a powerful resource for improving mathematics learning. Yet, our perspective on mathematics education is necessarily broader than technology. Our experience as a partner with educators and schools makes it clear to us that teaching practice, curriculum, and assessment are profound drivers of a whole system approach to improving mathematics learning. Technology, curriculum, pedagogy, and assessment improvement each can and should be driven by application of learning principles arising from scientific research.

We believe there are two basic principles about mathematics learning. On one hand, most children learn some mathematics without much effort. For example, most preschoolers readily learn simple concepts about number and simple procedures for using numbers (*e.g.* counting) from their parents. On the other hand, school-age children find much of mathematics increasingly difficult, frustrating, and alienating. Learning principles must seek to build upon the strengths all students bring to mathematics and overcome the obstacles that many students face as mathematics increases in complexity and conceptual difficulty.

Students learn more when tasks stay within the cognitive load and developmental capabilities appropriate for their level.

All people have limits to how much complexity they can tackle at once. Students cannot be expected to learn when they are overwhelmed by complexity occurring at different levels of mathematical challenge. Hence, instruction should seek to offload non-essential cognitive tasks so students can focus. Likewise instruction should provide structure (or "scaffolding") for more advanced aspects of the mathematics so students can succeed with the task at their level.

Another important set of limits comes from the fact that students are still developing full adult cognitive abilities as they progress through school. Developmental considerations give any description of an "ideal learning environment" a different shape in elementary, middle and high school. At the extremes, concrete manipulatives are especially appropriate in kindergarten and more abstract tools for graphing curves are especially valuable for learning calculus. Students can begin learning concepts that lead to algebra in elementary school and progress towards mastery of algebra in high school however resources must be designed differently at each development stage to support this.

Students learn more when mathematics is expressed in multiple representations.

We believe that more students learn more mathematics when both linguistic and graphical representations are available and are considered together. For example, many middle and high school students find graphs of algebraic functions to be an important complement to algebraic symbols. Other important representations in middle and high school include tables, physical manipulatives, technology-based simulations and models.

Students learn more when effective formative assessment is used to adjust instruction to their individual needs.

Providing students with appropriate feedback leads to more learning. Good feedback should go beyond "right" or "wrong." It should let students know what the right answer is (eventually). Feedback should guide improvements to student work and guide the teacher in planning, adapting, and differentiating instruction. For example, the teacher can adjust the pace as well as the content of instruction based upon formative assessment data. When feedback is implemented well, students also gain by increasing their ability to self-correct.

Students learn more when active engagement is encouraged and structured by the teacher.

We find that students learn more when teachers establish norms and structure for active engagement by all students in doing, discussing, and reflecting on mathematics. Active engagement occurs at individual, group, and full classroom levels. For example, individual students are engaged when they have meaningful mathematics to do during class and for homework. Likewise, collaborative and peer-assisted instruction can engage students in mathematical communication, argumentation and reflection. For peer learning to work, teachers must provide structure that guides students to help each other effectively, to build on each other's ideas and work together productively. In a full class setting, teachers set the expectation that all students can learn by providing direct instruction and organizing classroom discussions so that all students engage in doing, thinking, and reflecting on mathematics.

Design, Role, Application and Alignment of State Standards

Sound implementation of state standards with aligned curriculum and assessment creates a platform for improved student math performance.

Curriculum standards provide the foundation for what mathematics students should know and be able to do within a given grade level. The basis of what is taught frames the activities and methods that teachers select to use with students and drives the assessments given in the classroom. State standards provide the framework for instruction and assessment within a state and many states continue to revise standards to reflect the key areas of focus in a grade level. Districts use standards to align instruction, curriculum and assessments. They write benchmark assessments, aligned to state standards, to have a better indication of how students will perform on the state assessments given within grades 3-8 and at the high school level. With each revision of assessments, districts work to ensure the alignment of the state standards to the instruments used to measure the effectiveness of the instructional process. Improvements in student learning depend on how well assessment, curriculum, and instruction are aligned and reinforce a common set of learning goals and on whether instruction shifts in response to the information gained from assessments.

Curriculum coherence is critical.

Improving student learning relies on a *coherent* curriculum that includes the intentions of the standards and the content and skills to be taught and learned. The need for specificity within state standards has also caused organizations such as the National Council of Teachers of Mathematics (NCTM) to create new documents like the *Curriculum Focal Points for Pre-kindergarten through Grade 8 Mathematics* that provide additional clarity to NCTM standards. Coherence is important to avoid a mathematics system that is a "mile wide and an inch deep".

Standards need to be aligned with college and workplace demands.

National projects have been funded to evaluate state standards against college readiness indicators to determine if students will be prepared for college and the workplace. The American Diploma Project (*Achieve*, 2004) sought to validate whether state standards at the K-12 level prepared students for the high level mathematics required by universities as measured by assessments such as the ACT® and SAT®. To enable our students to be college and work-ready, schools must prepare students for the mathematics content they will encounter in the workplace, in high tech jobs, and at the university level. While students may not enter the university setting directly following graduation, they may in future years, and they deserve the opportunity to be ready for college level mathematics courses without having to participate in remedial or preparatory courses.

Role and Design of Systems Delivering Instruction/Instructional Practices, Programs and Materials

Education is an interconnected system, including the policies, infrastructure and practices for creating programs, delivering instruction, and adopting instructional materials and other tools for learning. While students are the central focus of any educational system, instructional practices and the quality and capacity of the teachers are the interface between the system and the student. This section addresses the key elements of the mathematics education system, their relation to student achievement, and strategies for leveraging them to improve mathematical understanding for all students.

Systemic interventions are required to improve student mathematics performance; a systems approach is needed to change results of mathematics education.

Because education operates in a system, making changes should focus on systemic interventions. The fundamental principle of systemic intervention is that, for an innovation to be effective, sustained and brought to scale, a coordinated set of targeted, proven practices must be brought together as an intervention. This approach aligns factors such as curriculum, assessment, instruction, and capacity of educators at every level of the system.

While no one method or program will be "the way" to achieve successful reform, researchers offer a relatively similar set of design characteristics necessary for successful efforts to improve mathematics teaching and learning. Key findings suggest that those elements most strongly related to above average mathematics performance are similar to the list below:

- Sound administrative practices
- Aligned curriculum
- Ongoing assessment
- Teacher knowledge
- Effective materials
- Teacher professional development
- End of year analysis

(Carnine, D. *The Ten Components of High Achieving, High Poverty School.* Unpublished manuscript, University of Oregon, 2002)

We have found some ways to make these school changes happen: outside expertise is brought to the school/staff; inside expertise such as reading coaches, grade level coaches, or research-based program implementation is increased systematically; adequate support (personnel, time, materials, mentoring, etc.) is provided; guidance is in place in the form of clear targets and deadlines, supervision, monthly data meetings, and public sharing of results to create a sense of accountability.

Comprehensive and coherent efforts must act on all parts of the system simultaneously to effect change in the system.

Because mathematics education is a system, all of the system's key elements need to be addressed for an intervention to achieve improved student performance in mathematics. Rather than concentrating on one specific strategy such as aligning curriculum with standards, working on instructional improvement or working with failing students in special programs, schools have to approach reform comprehensively. Those that educate all students at high levels address multiple factors, such as school culture, academic rigor, academic support, teacher preparedness, availability of resources, and time-on-learning. In addition to being comprehensive, effective interventions integrate efforts into a coherent math education experience for students: Curriculum is deeply aligned with state learning standards as is ongoing classroom formative assessment and end-of-year summative assessment.

Leadership is critical to successful systemic efforts to improve mathematics teaching and learning.

Strong leadership is essential to implement and sustain mathematics education improvement and for effective change to take hold. Leaders need to put structure in place to enable reform to secure and maintain resources that continue to support the vision they have of effective mathematics teaching and learning. They need to improve local capacity to select and implement best practices and to build the leadership and capabilities to achieve and sustain the results.

Professional Development

Effective professional development will lead to improved student achievement.

We have found that effective professional development typically:

- is focused on content
- is situated in sites of practice-what teachers do in the act of teaching
- takes place within a learning community or network-is collaborative
- is supported by qualified professionals in and outside of the school environment, and
- provides opportunities for long-term sustained work

We belive the most effective professional development programs reflect a programmatic design, conceptualized and implemented as an overall entity not as a laundry list of offerings.

Effective professional development will improve instructional practices in the classroom and make a difference in how teachers teach.

The teacher is the mediator between the content and student understanding. What teachers do makes a difference in what students learn; effective teaching causes learning to take place. This suggests there is a connection between how teachers teach and student achievement. Thus, whether students are working in groups, alone or taking part in whole class activities, the questions teachers ask, the kinds of tasks they pose, the way they manage discussions of the mathematics will have an impact on the mathematics students learn. Teachers must respond to student questions by providing guidance but not scaffolding a problem until it is reduced to a trivial response

Effective professional development will improve teachers' mathematical knowledge for teaching and deepen their knowledge of mathematics.

Considerable documentation exists about the fragile knowledge base of teachers of mathematics, at both the elementary and secondary grades. Emerging evidence suggests that teacher mathematical knowledge in the U.S. is not deep when compared to teachers at comparable levels in other countries. We have found that the type of mathematical knowledge needed in teaching differs from the mathematics that teachers typically learn in preservice mathematics courses. From another perspective, the main finding of analyses of Trends in International Mathematics and Science Study (TIMSS) was that the U.S. mathematics curriculum, especially in the middle grades, was less challenging and less coherent than the curriculum in high achieving countries around the world (Schmidt & McKnight, 1997). This might in fact, be partially due to the tenuous knowledge base of many middle school teachers, who often shape the implemented curriculum in terms of their own understandings.

Emerging evidence supports the fact that increasing teachers' knowledge of the mathematics they teach will lead to increased student achievement.

The Classroom System: Integrating Instruction, Curriculum, and Assessment

Within a systemic mathematics education improvement initiative, it is important to permanently improve what is happening in the classroom. Assuming teacher content knowledge has been addressed through professional development, we see the integration of these three components in the Carnine research model having great student improvement impact in the classroom: effective instructional practices, aligned curriculum, and ongoing assessment. From our experience applying evidence-based practices, the highest-performing classrooms are led by teachers with deep content knowledge who use effective and engaging instructional practices, and who integrate ongoing assessment with their instruction and modify their instruction based on individual student needs.

Integrating ongoing formative assessment with effective instruction and aligned curriculum improves teachers' understanding of student learning needs.

Teachers need to define what students know and do not know in order to develop instructional interventions that meet students' needs. This is an intentional process, and assessments need to serve as both providers of information for decision making and as teaching tools.

The use of pre-lesson diagnostic assessment helps teachers determine student need in order to expand or compact a unit of study based on student readiness with a given concept or set of skills.

Formative, or during-the-lesson assessment, has become increasingly important and teachers can utilize technology to capture students' understanding. Effective systems employ methods that allow teachers to collect data real-time on student understanding without having to wait for the results of homework or tests. The use of technology can make student thinking more visible to teachers and help teachers refine their instructional approach throughout each daily lesson.

Integration of assessment into instruction allows students the opportunity to learn through self-correction.

Real-time assessment also leads to increased levels of student accountability, and engages students in a more active role in their learning. In our work, teachers comment that students spend more time working with mathematical problems, are able to course correct faster and retain information when they use technology that enables the teacher to give them immediate feedback and allow for student discussion.

DEMONSTRATION PROJECT TO APPLY LESSONS LEARNED SYSTEMATICALLY

TI applied these lessons, along with available research, in an initiative with the Richardson Independent School District (RISD) to decrease the achievement gap in middle school math.

Improving Student Achievement by Applying Research, Promising Practices and Experience: Richardson ISD/TI Initiative to Decrease the Achievement Gap in Middle School Mathematics

In 2004, the RISD and TI entered into a partnership to decrease the achievement gap in middle school mathematics and increase student achievement. Relying upon the lessons described above, we sought to incorporate the following elements as the basis for the intervention design:

1. Sound administrative practices
2. Aligned curriculum
3. Ongoing assessment
4. Immediate intervention for students experiencing academic difficulty
5. Increased and effective use of instructional time
6. Teacher knowledge of mathematics content
7. Effective instructional materials and teaching techniques
8. Differentiated instruction to meet student needs
9. Focused professional development
10. End-of-year analysis of student performance

Experts in mathematics instruction and research conducted surveys and performed analysis to customize the components found in this study and adapt them to create an intervention for the RISD system. Teacher content knowledge of mathematics was assessed by using the Learning of Mathematics Teaching (LMT), developed by Dr. Deborah Ball and her colleagues from the University of Michigan.

The RISD/TI intervention identified and addressed the key components of the overall mathematics education system by:

- relying on mathematics teaching methods for which there was some evidence of success
- increasing teacher training on both mathematics content and technology,
- increasing instructional time and collaboration between teachers,
- closely aligning common assessments and curriculum, and
- implementing technology in a way that increases student engagement and gives teachers real-time feedback on which mathematics concepts their students have mastered and those concepts the teachers need to spend more time on that students don’t yet understand.

After one year of implementation, the RISD pilot intervention successfully increased mathematics achievement and decreased the achievement gap among at-risk students who participated in the program.

Students increased their achievement on the 2006 Texas Assessment of Knowledge and Skills (TAKS) significantly. One-third (33 percent) of students who participated in the intervention and had failed the 2005 TAKS mathematics exam successfully passed the 2006 TAKS test.

Other results include:

- Independent evaluation research showed a large effect size and a 33 percent pass rate on the TAKS vs. a 19 percent pass rate in a comparison group.

- Study students consistently performed above average during the entire 2005-2006 academic year. Those who participated in the intervention showed continual improvements on benchmark assessment exams given throughout the year. And, their final results on the TAKS were also above average.

- The large gains by students in the study narrowed the gap between at-risk students and majority students.

- The intervention contributed to RISD moving from acceptable to recognized under the Texas accountability rating system, and both the district and the participating middle school met Adequate Yearly Progress (AYP) in 2005-2006 under the No Child Left Behind rating system.

Equally important beyond one-year assessment measures, the intervention was also successful in addressing the key factors that contribute to student achievement and in growing the district's capacity to sustain these improvements:

- The RISD teachers reported professional development allowed them to increase their content knowledge, improve their teaching techniques and effectiveness.

- Alignment between the curriculum students were learning and the assessments used to measure performance was strengthened.

- TI's classroom learning network technology helped increase student participation and engagement. Teachers reported fewer behavioral problems; students spent more time working through problems, and were able to realize corrections more quickly.

- The RISD leadership at all levels, from the superintendent to the classroom teacher, provided an incredible support system essential to the program's success.

As a result of this promising first year experience, RISD is now working with TI to replicate the model in more schools and more grade levels, and we are working with additional districts in Texas, Ohio, and Florida to further bring the model to scale. We intend to conduct deeper research into this systematic model and will report findings to the NMP. In the meantime, we invite the NMP to review the initial independent research reports, which are enclosed.

FINDING COMMON GROUND

INTRODUCTION

While we at TI obviously place a lot of importance on our review of available research and our experience and the lessons we have drawn from them, we have been concerned about the lack of rigorous, scientific research in the field of mathematics education. To respond to this issue, we have taken several steps. First, we have more aggressively sought better research and are now beginning to sponsor it directly. Second, we are pleased about the formation of this NMP and offer our help to you in any way. Third, we decided it was important to help bring both sides of "the math war" together to discover where there was common ground in K-12 mathematics education.

Again, we do not suggest there is scientific proof for all of the findings of the Finding Common Ground (FCG) team. Rather, we believe that when mathematicians and mathematics educators who have disagreed in the past come together around key principles – there may be important lessons in this common ground.

We are submitting the paper this team produced. We urge you to review it and to search for current research that addresses its principles. To the extent that further scientific research would prove these principles or – importantly – flesh them out in more specific ways that would be valuable to teachers, we strongly recommend that the NMP call for such research as a matter of the highest priority.

The FCG team was born out of conversations between Richard Schaar and James Milgram. Schaar, a former President of the Educational and Productivity Solutions business at TI and a mathematician, had been active in NCTM, MAA and AMS. Milgram, a professor of mathematics at Stanford, had been active in Mathematically Correct, an organization that was involved in K-12 education, principally in California. These two experienced men, coming with different approaches, found much about which they agreed.

They concluded that if a few experienced, knowledgeable scholars on both sides and the middle of the conflict met in an informal setting, there might be some significant common ground.

Schaar and Milgram discussed the idea with stakeholders, and then formed the team, consisting of Schaar, Milgram, Deborah Loewenberg Ball, Joan Ferrini-Mundy, Jeremy Kilpatrick, and Wilfried Schmid. After a series of meetings, exploring key topics, the team produced the document which follows. The team continues to explore fruitful paths to continue the process. We are particularly pleased in this spirit of finding common ground by the recent publication from the NCTM of its *Focal Points* document.

REACHING FOR COMMON GROUND IN
K-12 MATHEMATICS EDUCATION

Deborah Loewenberg Ball, Joan Ferrini-Mundy, Jeremy Kilpatrick,
R. James Milgram, Wilfried Schmid, Richard Schaar

Over the past decade, much debate has arisen between mathematicians and mathematics educators. These debates have significantly distracted the attention of key players at all levels, and have impeded efforts to improve mathematics learning in this country. This document represents an attempt to identify a preliminary list of positions on which many may be able to agree.

Our effort arose out of discussions between Richard Schaar and major players in both communities. He suspected that some of these disagreements might be more matters of language and lack of communication than representative of fundamental differences of view. To test this idea, he convened a small group of mathematicians and mathematics educators.[1]

We tried to bring clarity to key perspectives on K-12 mathematics education. W e began by exploring typical “flashpoint” topics and probed our own positions on each of these to determine whether and where we agreed or disagreed. For the first meeting, held in December 2004, we began with summary statements drawn from prior exchanges among the members of our group. We affirmed some agreements in this meeting, and “discovered” others. We listened closely to one another, frequently asking for clarification, or for examples. We tested our understanding of others’ points of view by proposing statements that we then examined collectively. We drafted this document as a group, composing actual text as we worked. One of us typed, and our emerging draft was projected onto a screen in the meeting room. The process enabled us to take issue with particular words and terms, and then reshape them until all of us were satisfied. We were forced to look closely at our own language and to seek common ground, not only in the terms we used, but even in their nuanced meaning.

This document was completed at our second meeting, in June 2005. All of us are encouraged by the extent of our agreements. The document treats only a subset of the controversial issues, many of which arise in K-8 mathematics. We expect to continue the process by examining a wider range of major issues hi mathematics education. We have necessarily limited ourselves to questions depending primarily on disciplinary judgment, as opposed to those requiring empirical evidence.

We begin with three fundamental assertions and continue with a list of areas in which we found common ground. For each, we have written a short paragraph that captures the fundamental points of our agreement. Our next step is to explore how others respond to the document, and to use their responses to decide how best to make progress on the aims of this project. Our goal is to forge new alliances, across

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[1] We are grateful to the National Science Foundation and Texas Instruments Inc. for funding this portion of our work.

communities, necessary to develop effective solutions to the serious problems that plague mathematics education in this country.

Fundamental Premises

All students must have a solid grounding in mathematics to function effectively in today's world. The need to improve the learning of traditionally underserved groups of students is widely recognized; efforts to do so must continue. Students in the top quartile are underserved in different ways; attention to improving the quality of their learning opportunities is equally important. Expectations for all groups of students must be raised. By the time they leave high school, a majority of students should have studied calculus.

1. Basic skills with numbers continue to be vitally important for a variety of everyday uses. They also provide crucial foundation for the higher-level mathematics essential for success in the workplace which must now also be part of a basic education. Although there may have been a time when being to able to perform extensive paper-and-pencil computations mechanically was sufficient to function in the workplace. this is no longer true. Consequently, today's students need proficiency with computational procedures. Proficiency, as we use the term, includes both computational fluency and understanding of the underlying mathematical ideas and principles.[2]

2. Mathematics requires careful reasoning about precisely defined objects and concepts. Mathematics is communicated by means of a powerful language whose vocabulary must be learned. The ability to reason about and justify mathematical statements is fundamental, as is the ability to use terms and notation with appropriate degrees of precision. By precision, we mean the use of terms and symbols, consistent with mathematical definitions, in ways appropriate for students at particular grade levels. We do not mean formality for formality's sake.

3. Students must, be able to formulate and solve problems. Mathematical problem solving includes being able to (a) develop a clear understanding of the problem that is being posed; (b) translate the problem from everyday language into a precise mathematical question; (c) choose and use appropriate methods to answer the question; (d) interpret and evaluate the solution in terms of the original problem, and (e) understand that not all questions admit mathematical solutions and recognize problems that cannot be solved mathematically.

Areas of Agreement

Discussions of the following items are often riddled with difficulties in communication, making it sometimes confusing to determine whether and how much disagreement. exists. Issues also arise from a confounding of a mathematical idea with its implementation in the classroom. For example, the fact that algorithms have often been taught badly does not imply that algorithms themselves are bad. We worked to clarify issues and terms and arrived at statements with which we agreed.

[2] Kilpatrick, J., Swafford, J. and Findell, B. (Eds.). Adding It Up: Helping Children. Learn Mathematics, Washington, DC: National Academy Press, 2001.

A. Automatic recall of basic facts: Certain procedures and algorithms in mathematics are so basic and have such wide application that they should be practiced to the point of automaticity. Computational fluency in whole number arithmetic is vital. Crucial ingredients of computational fluency are efficiency and accuracy. Ultimately, fluency requires automatic recall of basic number facts: by basic number facts, we mean addition and multiplication combinations of integers 0 - 10. This goal can be accomplished using a variety of instructional methods.

B. Calculators: Calculators can have a useful role even in the lower grades, but they must be used carefully, so as not to impede the acquisition of fluency with basic facts and computational procedures. Inappropriate use of calculators may also interfere with students' understanding of the meaning of fractions and their ability to compute with fractions. Along the same lines, graphing calculators can enhance students' understanding of functions, but students must develop a sound idea of what graphs are and how to use them independently of the use of a graphing calculator.

C. Learning algorithms: Students should be able to use the basic algorithms of whole number arithmetic fluently, and they should understand how and why the algorithms work. Fluent use and understanding ought to be developed concurrently. These basic algorithms were a major intellectual accomplishment. Because they embody the structure of the base-ten number system. studying them can reinforce students' understanding of the place value system.

More generally, an algorithm is a systematic procedure involving mathematical operations that uses a finite number of steps to produce a definite answer. An algorithm can be implemented in different ways; different recording methods for the same algorithm do not constitute different algorithms. The idea of an algorithm is fundamental in mathematics. Studying algorithms beyond those of whole number arithmetic provides opportunities for students to appreciate the diversity and importance of algorithms. Examples include constructing the bisector of an angle; solving two linear equations in two unknowns; calculating the square root of a number by a succession of dividing and averaging.

D. Fractions: Understanding the number meaning of fractions is critical. Ratios, proportions, and percentages cannot be properly understood without fractions. The arithmetic of fractions is important as a foundation for algebra.

E. Teaching mathematics in "real world" contexts: It can be helpful to motivate and introduce mathematical ideas through applied problems. How-ever, this approach should not be elevated to a general principle. If all school mathematics is taught using real world problems, then some important topics may not receive adequate attention. Teachers must choose contexts with care. They need to manage the use of real-world problems or mathematical applications in ways that focus students' attention on the mathematical ideas that the problems are intended to develop.

F. Instructional methods: Some have suggested the exclusive use of small groups or discovery learning at the expense of direct instruction in teaching mathematics. Students can learn effectively via a mixture of direct instruction, structured investigation, and open exploration. Decisions about what is better taught through direct instruction and what might be better taught by structuring explorations for students should be made on the basis of the particular mathematics, the goals for learning, and the students' present skills and knowledge. For example, mathematical conventions and definitions should not be taught by pure discovery. Correct mathematical understanding and conclusions are the responsibility of the teacher. Making good decisions about the appropriate pedagogy to use depends on teachers having solid knowledge of the subject.

C. Teacher knowledge: Teaching mathematics effectively depends on a solid understanding of the material. Teachers must be able to do the mathematics they are teaching. but that is not sufficient knowledge for teaching. Effective teaching requires an understanding of the underlying meaning and, justifications for the ideas and procedures to be taught, and the ability to make connections among topics. Fluency, accuracy, and precision in the use of mathematical terms and symbolic notation are also crucial. Teaching demands knowing appropriate representations for a particular mathematical idea, deploying these with precision, and bridging between teachers' and students' understanding. It requires judgment about how to reduce mathematical complexity and manage precision in ways that make the mathematics accessible to students while preserving its integrity.

Well-designed instructional materials, such as textbooks, teachers' manuals. and software, may provide significant mathematical support. but cannot substitute for highly qualified, knowledgeable teachers. Teachers' mathematical knowledge must be developed through solid initial teacher preparation and ongoing, systematic professional learning opportunities.

THE USE OF GRAPHING CALCULATORS IN MATHEMATICS EDUCATION

INTRODUCTION

As mentioned previously, TI has been active for over two decades in developing educational technology, included the graphing calculator. Educational and Productivity Solutions within TI now principally produces graphing calculators and teacher professional development for middle and high school mathematics and science educators and students.

We want to provide the NMP with research that is relevant to the graphing calculator, including a recent Empirical Education, Incorporated (EEI) meta-analysis of eight individual research studies specific to graphing calculator use. Further, we are sponsoring with EEI a three-year randomized controlled trial study to provide additional evidence. We believe and recommend that graphing technology can be a constructive and valuable element of well-designed systems to improve mathematics education. We encourage the NMP to look at all available evidence on graphing calculators. Further, we support additional research to add to the evidence that supports this recommendation.

TI's Involvement in Graphing Calculators

Our products

Our education technology products include graphing calculators for middle school and high school. Graphing calculators have been widely adopted: they are required on state exams in nine states and strongly recommended/recommended or permitted in 28 states. Approximately four million graphing calculators are purchased each year by students and schools, with many students using them throughout their high school careers.

In 2004, we added a complementary classroom network and formative assessment solution for our graphing calculators, the TI-Navigator®. TI-Navigator is now in several thousand math classrooms across the U.S. The TI-Navigator's formative assessment tools provide educators with immediate feedback on student understanding and enhance classroom engagement and interaction. During TI-Navigator's development, a guiding component was an SRI conducted analysis of 26 empirical research studies that identified effective practices related to improved student achievement, engagement, and interest. We believe using effective practices as the foundation for our product development increases the probability they will add more value to a successful teaching and learning process.

Teacher Professional Development

We supplement our products with professional development provided by Teachers Teaching with Technology (T^3), an organization of approximately 300 math and science educators. T^3 has delivered training on the effective use of graphing calculators for more than 20 years, reaching more than 100,000 teachers. We have found professional development to be an essential component for teachers to realize the full benefits technology enables in the classroom by integrating technology with strong mathematics content knowledge and sound instructional and assessment practices.

TI uses research to drive improvements to the T^3 professional development offering. The Institute for Advancement of Research in Education describes nine central components of professional development that lead to better teaching:

(1) addresses student-learning needs,
(2) incorporates hands-on technology use,
(3) is job-embedded,
(4) has application to specific curricula,
(5) addresses knowledge, skills, and beliefs,
(6) occurs over time,
(7) occurs with colleagues,
(8) provides technical assistance and support to teachers, and
(9) incorporates evaluation.

Based on these findings, we have modified the T^3 programs and services to ensure that the majority of our professional development offerings are research-based.

Content
We also work with publishers and authors to offer standards-aligned content for teacher's use with our products. To address specific math student achievement goals, we work with districts and major programs in intervention design to define and customize professional development, content, and assessment to meet the unique needs of each educator.

Effectiveness Research – Results and In-Progress

Research results
We have asked the NMP to carefully review graphing technology effectiveness research. We recently retained EEI to complete a review of existing independent research on graphing calculators. Following is a top-level summary of their attached report:

A meta-analysis of eight individual studies specific to graphing calculator use found a large pooled effect size (.85) that is statistically significant This systemic review addressed the impact of graphing calculator use on student achievement and found strong evidence that student use of graphing calculators increased performance in algebra.

Research in-progress
Beyond commissioning the review of the existing independent effectiveness research on graphing calculators, TI also retained EEI to conduct a three year randomized controlled trial study to determine the effectiveness of the use of graphing calculators, TI-Navigator and professional development in Algebra 1. The study is being conducted in two school districts in California and the final report will be available in early 2007.

Commitment to research
Applications of research defined above are examples of how we use research as a strategic and critical element in the development of our products and programs. We advocate for definition and funding of research needed to address areas that have minimal to no research. Recognizing that our products, programs and services can be more effective as a component of a comprehensive system that improves student achievement, we elevated our research commitment to include new systemic initiatives like the RISD/TI partnership.

Additional Findings and Expert Opinions on Math Learning Technology

In addition to the above effectiveness research, one area of agreement in the *Reaching for Common Ground in K-8 Mathematics Education* document (included in a previous section in these comments) addressed the use of graphing calculators in math education:

Calculators: Calculators can have a useful role even in the lower grades, but they must be used carefully, so as not to impede the acquisition of fluency with basic facts and computational procedures. Inappropriate use of calculators may also interfere with students' understanding of the meaning of fractions and their ability to compute with fractions. Along the same lines, graphing calculators can enhance students' understanding of functions, but students must develop a sound idea of what graphs are and how to use them independently of the use of a graphing calculator. (Reaching for Common Ground in K-12 Mathematics Education, 2005)

The 2001 National Center of Educational Statistics (NCES) report on the National Assessment of Educational Progress (NAEP) further supports the appropriate use of graphing calculators in secondary mathematics education in the following excerpt:

> *Eighth-graders whose teachers reported that calculators were used almost every day scored highest. Weekly use was also associated with higher average scores than less frequent use. In addition, teachers who permitted unrestricted use of calculators and those who permitted calculator use on tests had eighth-graders with higher average scores than did teachers who did not indicate such use of calculators in their classrooms.*

Further analysis has found that association between frequent graphing calculator use and high achievement holds for both richer and poorer students, for both girls and boys, for varied students with varied race and ethnicity, and across states with varied policies and curricula.

TI supports these positions and statements on the appropriate use of calculators in mathematics education.

CONCLUSION

We believe the NMP’s work on these three recommendations, the systems approach, the Finding Common Ground work and graphing technology can move the country forward toward systemic and sustainable improved student mathematics performance.

My staff will follow up with you regarding further actions. Of course, please feel free to contact me personally at (972) 917-4662.

Sincerely,

Melendy Lovett

Melendy Lovett
President, Educational & Productivity Solutions
Senior Vice President, Texas Instruments

RESEARCH REPORT

Effectiveness of Graphing Calculators in K–12 Mathematics Achievement:
A Systematic Review

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November 21, 2005

About Empirical Education Inc.

Empirical Education Inc. is an independent research company based in Palo Alto, California. It was founded in 2003 with the mission of helping school districts make cost-effective decisions in adopting new instructional and professional development programs. Empirical Education Inc. uses rigorous quantitative research methods combined with qualitative data collected from teachers and classrooms. For a program being piloted in a school district, these methods quantify its potential impact in terms of the improvement in student achievement that a school can expect. Empirical Education Inc. provides research services to K–12 school districts, as well as to commercial and nonprofit developers and publishers, to determine the effectiveness of programs. The company draws on the expertise of world-class researchers and methodologists, assuring that the research is objective and takes advantage of current best practices in experimental design and analysis.

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Executive Summary

In this report we systematically review research that examines the effect of calculator use, including the graphing calculator, on K–12 students' mathematics achievement. Our goal was to determine whether there is scientific evidence of effectiveness of graphing calculator use on students' mathematics learning. A thorough review of the research literature and a careful examination of the methods used narrowed our selection of reports to those that used acceptable methods and adequately reported quantitative findings. We summarize a total of 13 studies. For four of these studies, which address the impact of graphing calculators specifically on algebra achievement, we conducted a meta-analysis, yielding evidence of a strong effect of the technology.

Selection of Qualified Research

To support the emphasis of the No Child Left Behind Act of 2001 (NCLB) on teaching methods with evidence of effectiveness, the U.S. Department of Education established the What Works Clearinghouse (WWC) in 2002. The clearinghouse has established the WWC Study Review Standards, which research studies must pass to be included in their reviews. Our work on this review makes use of a study-screening and classification procedure that closely parallels the one used by the WWC. These criteria were the following:

- The research should assess the effect of calculator (scientific and graphic) use on mathematics achievement.
- The research should be experimental (randomized control or quasi-experimental). The research should be analyzed quantitatively and provide information for calculating effect sizes.
- The research should be conducted in elementary to secondary schools (K–12) levels.
- The research should be published within the past 20 years, i.e., since 1985.
- The research paper should be accessible.

The search led to six published research papers and seven unpublished dissertations. The following list provides the author, publication date, sample student grade levels and mathematics topics covered by the studies.

1. Ruthven, K. (1990) Upper secondary students in England. Symbolization and interpretation. .
2. Graham, A.T., and Thomas, M. O. J. (2000) Year 9 and 10 students in New Zealand. Algebra
3. Thompson, D. R., and Senk, S.L. (2001) Grades 10 and 11 in Chicago. Second-year algebra
4. Hollar, J. C., and Norwood, K. (1999) University freshmen in U.S. Intermediate algebra
5. Autin, N. P. (2001) Grade 12 students in U.S. Trigonometry
6. Drottar, John F. (1998) Grades 10, 11, and 12 U.S. Algebra II
7. Rodgers, K. V. (1995) Algebra II class students U.S. Quadratic equations
8. Wilkins, C. W. (1995) Grade 8 students in U.S. Factoring quadratic equations
9. Szetela, W., and Super, D. (1987) Grade 7 students in Canada. Translation process and complex problems
10. Loyd, B. H. (1991) Grades 8, 9, and 10 in U.S. Subsets of 4 different item types
11. Liu, S. (1993) Grade 5 students in Taiwan. Mathematics computation problem-solving ability

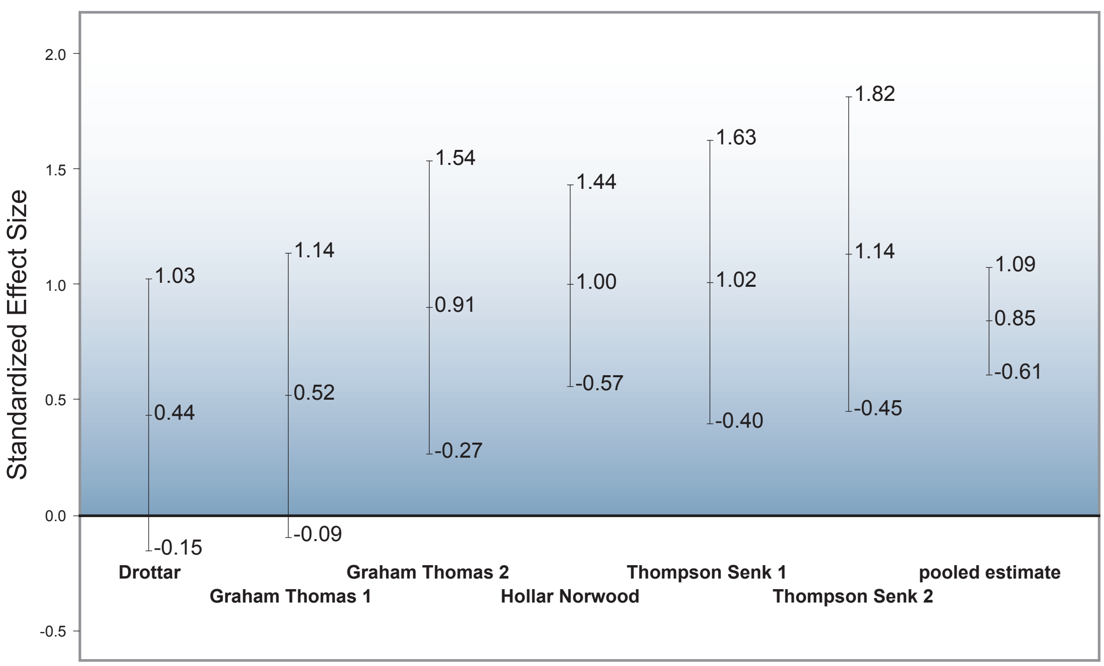
12. Ellerman, T. B. (1998) Grades 7 and 8 students in U.S. Mathematics concepts and applications
13. Glover, M. A. (1991) Grades 5, 6, 7, and 8 students with Learning Disabilities, U.S. Computation and problem solving

Meta-analysis of Graphing Calculator Impact on Algebra Achievement

A meta-analysis gives us a way of combining the impact of multiple studies to arrive at a single estimate of the impact. Impact is expressed as an effect size, which uses the metric of the standard deviation.

A meta-analysis requires that the studies being combined be studies of the same or closely related educational problems or interventions. First, studies are selected that address similar problems based on researcher judgment. Second, a statistical test of homogeneity is used to verify that the studies have reasonably similar effect sizes. Since our initial focus of the review was on graphing calculators, we restricted the meta-analysis to these studies. There are four published research papers and four unpublished dissertations that investigated the effect of graphing calculators. Among these studies, the researchers measured the impact on a variety of skills and abilities, most commonly on algebra. We judged that four of the studies that met the inclusion criteria measured the effect of using graphing calculators on algebra skills. Our meta-analysis addresses these studies only. Two of the studies report two separate effect sizes. We treated these as separate outcomes, so we worked with six outcomes in the meta-analysis.

We computed standard errors for the effect sizes. We then carried out a statistical test of homogeneity to determine that the studies can reasonably be described as sharing a common effect size . The point estimates for the effect sizes for the six results are displayed in the figure below.



Each point estimate is centered on its 95% confidence interval. The rightmost confidence interval represents the result for the pooled estimate, which has an effect size of .85 and a 95% confidence interval that does not contain zero. This result gives us strong evidence that the use of graphing calculators is associated with better performance in algebra.

Contents

Effectiveness of Graphing Calculators in K-12 Mathematics Achievement: A Systematic Review

The objective of this report is to systematically review the research that examines the effect of calculator use, including the graphing calculator, on K–12 students' mathematics achievement. Our goal was to determine whether there is scientific evidence of effectiveness of graphing calculator use on students' mathematics learning. A thorough review of the research literature and a careful examination of the methods used narrowed our selection of reports to those that used acceptable methods and adequately reported quantitative findings. We summarize a total of 13 studies. For four of these studies, which address the impact of graphing calculators specifically on algebra achievement, we conducted a meta-analysis, yielding evidence of a strong effect of the technology.

Selection of Qualified Research

Policymakers in education have been duly concerned about the undersupply of mathematicians and scientists who are critical for global economic leadership and innovation. The No Child Left Behind Act of 2001 (NCLB) was a major effort to improve proficiency of K–12 students through strong accountability for results and an emphasis on teaching methods that have been shown to work through scientifically based research. To support NCLB's emphasis on teaching methods with evidence of effectiveness, the U.S. Department of Education's Institute of Education Sciences established the What Works Clearinghouse (WWC) in 2002. The objective of WWC is to facilitate informed decision-making in education. It does this by providing a central source for referral by policymakers, educators, researchers, and the public on educational interventions (programs, products, practices, and policies) that have been shown to improve student outcomes. Although it does not endorse particular interventions, the clearinghouse has established the WWC Study Review Standards, which research studies must pass to be included in their reviews.

Our work on this review makes use of a study-screening and classification procedure that closely parallels the one used by the WWC. The WWC reviews a study in three stages:

- Stage 1: Screening for relevance.
- Stage 2: Determination of whether a study provides strong evidence of causal validity, weaker evidence of causal validity, or insufficient evidence of causal validity.
- Stage 3: Review of other important study characteristics.

The studies for review in this report were selected following the WWC Study Review Standards, including the following:

1. The research should assess the effect of calculator (scientific and graphing) use on mathematics achievement.
2. The research should use randomized control or quasi-experimental methods.
3. The research should be analyzed quantitatively and provide information for calculating effect sizes.
4. The research should be conducted in elementary to secondary schools (K–12)
5. The research should be published within the past 20 years, i.e., since 1985.
6. The research paper should be accessible.

The search for appropriate research reports was done at the library at the University of Illinois at Urbana-Champaign. Priority was given to published journal articles. The following electronic databases were used for the search:

- Educational Resources Information Center (ERIC)
- PsycInfo
- WorldCat
- EBSCO

The references and bibliographies in the research papers that met the above WWC criteria were also used as sources for locating other potential research studies. This search led to six published research papers and seven unpublished dissertations. The objective of most of these studies was to evaluate the benefits of graphing calculators on students' understanding of a particular topic in algebra. Sample student grade levels and mathematics topics covered by the studies are summarized in Table 1. The sample sizes and the interventions of these studies are summarized in Table 2.

Table 1. Sample Student Grade Levels and Mathematics Topics

Study	Student Grades	Math Topics
Ruthven, K. (1990)	Upper secondary students in England	Symbolization and interpretation
Thompson, D. R., and Senk, S.L. (2001)	Grades 10 and 11 in Chicago	Second-year algebra
Hollar, J. C., and Norwood, K. (1999)	University freshmen in U.S.	Intermediate algebra
Graham, A.T., and Thomas, M. O. J. (2000)	Year 9 and 10 students in New Zealand	Algebra
Szetela, W., and Super, D. (1987)	Grade 7 students in Canada	Translation process and complex problems
Loyd, B. H. (1991)	Grades 8, 9, and 10 in U.S.	Subsets of 4 different item types
Autin, N. P. (2001)	Grade 12 students I in U.S.	Trigonometry
Drottar, J. F. (1998)	Grades 10, 11, and 12 in U.S.	Chapter 6 and 7 in Algebra II
Wilkins, C. W. (1995)	Grade 8 students in U.S.	Factoring quadratic equations
Rodgers, K.y V. (1995)	Algebra II class students in U.S.	Quadratic equations
Glover, M.I A. (1991)	Grades 5, 6, 7, and 8 students with Learning Disabilities, U.,S.	Computation and problem solving
Ellerman, T.e B. (1998)	Grades 7 and 8 students in U.S.	Mathematics concepts and applications
Liu, S.. (1993)	Grade 5 students in Taiwan	Mathematics computation problem-solving ability

Table 2. Sample Sizes and Interventions

Study	Sample Size	Intervention
Ruthven, K. (1990)	47 in treatment group; 40 in comparison group	Different teachers in treatment and comparison groups but same curriculum. Treatment group with regular access to calculators.
Thompson, D .R., and Senk, S. L. (2001)	22 and 16 in treatment classes vs. 24 and 23 in comparison classes	UCSMP and regular algebra curriculum. UCSMP group with access to graphing calculators. Different teachers.
Hollar, J. C., and Norwood, K. (1999)	46 in treatment group; 44 in comparison group	Textbook with graphing calculator activities and access to graphing calculator for treatment group vs. regular textbook without calculator in control group. Different teachers.
Graham, A.T., and Thomas, M. O. J. (2000)	21 in treatment and 21 in comparison in each of two sets of classes	“Tapping into Algebra” module with graphing calculator in treatment group vs. normal teaching in control group. Different teachers.
Szetela, W., and Super, D. (1987)	290 students in 14 classes in CP group; 195 in 10 classes in P group; 338 in C group	Problem-solving strategies with calculators (CP), problem-solving strategies without calculators (P), and no problem-solving strategies and no calculator group (C).
Loyd, B.a H. (1991)	4 groups of 40 examinees, 70 with calculator, 90 without	Four subsets of items, some favoring calculator use and others problematic with calculator use
Autin, N. P. (2001)	29 in treatment and 29 in comparison groups. All male students.	Researcher and classroom teacher team-taught both classes. Same syllabus and textbook except graphing calculator use for treatment group.
Drottar, J. F. (1998)	22 in treatment and 23 in comparison group for first part, 19 and 21 in second	Both treatment and comparison groups were taught by the researcher and used the same UCSMP textbook. Graphing calculator to treatment group.
Wilkins, C. W. (1995)	75 in treatment group; 24 in comparison group	Researcher taught the treatment group; second teacher taught control groups. Same textbook but treatment group had graphing calculators.
Rodgers, K. V. (1995)	17 in treatment class; 21 in comparison class	Both classes taught by the same teacher using same textbook, content and activities. Calculator group used graphing calculators.
Glover, M.I A. (1991)	35 in treatment group; 33 in comparison group. Learning-disabled students.	Experimental students trained in Math Explorer calculator prior to calculator instruction in regular class. Control students with no Math Explorer training.
Ellerman, T. B. (1998)	579 in treatment group; 491 in control group	Teachers required to provide calculators to treatment group on the day of the test.
Liu, S. (1993)	43 in T group; 50 in C group; 53 in P group; 47 in C plus P group	Four classes randomly selected as Traditional (T) group, Calculator group (C), Problem-solving group (P), Calculator plus Problem-solving group (CplusP)

Summaries of Research on Graphing Calculators

There were only four published research studies and four unpublished dissertations examining the effect of graphing calculators on mathematics achievement. Each of these research studies is summarized below.

(1) Ruthven (1990)

K. Ruthven compared the performance of students of upper secondary school mathematics classes with graphing calculators to other students who were matched based on similar background and curriculum but without graphing calculators used to improve their understanding of algebraic functions. Such matched classes were identified in four English secondary schools. Of the two classes in each school, students in one class had regular access to graphing calculators (treatment), while students in another class did not have access to graphing calculators (comparison). Students were tested on two sets of problems—one set consisting of symbolization items (requiring students to write the equation for a given graph) and another of interpretation items (requiring students to extract information from a given graph).

The Graphic Calculators in Mathematics project in England had enabled each teacher in six small groups of classroom teachers to work with at least one class of students with calculators for a two-year advanced-level mathematics course. The participating teachers did not have any previous experience with graphing calculators. These teachers were not required to follow any prescribed program of calculator activities and planned their own classroom work, but met periodically to exchange ideas and review progress. Four schools in the project identified classes (comparison group) that were parallel to a project class (treatment group), similar in previous attainment and following the same mathematics course, but differing only in their access to graphing calculators. In addition to some background information, including their mathematics grade in GCSE (an external examination taken before attending the current course), a 40-minute test containing 12 graphing items was administered. The resulting sample consisted of 87 students; 47 were in the treatment group and 40 were in the comparison group. However, 7 students in the comparison group who had their own graphing calculators were dropped from the group. Based on background information, the two groups were comparable (similar) in their abilities. Scores on symbolization and interpretation items on the test administered near the end of the first year of the course constituted outcome measures.

Several considerations were taken into account in designing the test. First, the test covered materials drawn from two topic areas central to any advanced-level course, where the use of graphs is normal practice. Second, the test items were designed to test competencies for which there is no automatic graphing calculator procedure.

At the end of the first year of the two-year advanced-level mathematics course, the students were administered a 40-minute test. Of the 12 items in the test, the first 6 were symbolization items and the second 6 were interpretation items.

The covariance analysis of students' test scores indicated significant treatment effect on symbolization items but not on interpretation items. The treatment group outperformed the control group in symbolization items, with the effect size of 1.81. Moreover, there was also a significant treatment gender interaction for symbolization items. The female students outperformed male students in the treatment group but were outperformed by male students in the comparison group.

(2) Graham and Thomas (2000)

A.T. Graham and M. O. J. Thomas were motivated by the research findings of Tall and Thomas, 1991, which demonstrated improvements in students' algebra performance using computer activities. Since a graphing calculator is portable and an affordable alternative to computers for many schools, this study sought to analyze whether students' performance in algebra can be significantly improved by using graphing calculator activities. The researchers used the "Tapping into Algebra" module—a classroom-based research program that uses an experimental design to compare the teaching of the concept of 'variables' in algebra with and without the use of a graphing calculator. The students in the treatment and comparison groups were similar in ability and background. The study compared the pretest and posttest performances of treatment and comparison groups of students in two schools in New Zealand. The tests were designed to measure understanding of the use of letters as specific unknowns, generalized numbers, and variables in elementary algebra. The treatment groups significantly outperformed the comparison groups on the posttest, even though there were no differences on the pretest.

Although teachers from six New Zealand schools volunteered to take part in this research project, comparison groups similar to the treatment groups in ability and background were found only in two schools. Of the 147 treatment students in six classes and 42 students in two comparison classes, 118 were from year 9 (age 13 years) and 71 from year 10 (age 14 years), and covered different ability groups. Since comparison classes similar to treatment classes were found in only two schools, the results reported here are based on those four classes—two treatment and two comparison classes. Each of these classes had 21 students. The students in these classes did not differ much in their abilities based on pretest results. The "Tapping into Algebra" module was taught during terms one and two of 1996 by the classroom teachers, and a graphing calculator was provided to each student in the treatment class. The comparison classes received algebra work similar to the treatment group but were taught by different teachers using their normal teaching program. The researchers were not present in any of the classrooms, and the teachers were encouraged to use their normal teaching approach.

Both the treatment and comparison groups were administered a pretest and posttest based on Kuchemann's (1981) study comprising 68 questions. Students were not given their papers or any answers to the questions until after the posttest. Student scores on the posttest constituted the outcome measures in this study. The maximum possible score was 68. The outcome measures were compared between the treatment and comparison groups separately for each of the two schools with control groups.

The research design for this study can be considered quasi-experimental. The sample students in the treatment group were the students in classes of six teachers who volunteered to take part in this research. Since comparison groups similar to treatment groups in ability and background were found only in two schools, t-tests were used to compare the posttest performance between the treatment and comparison groups separately for each of these two schools only. In each school, the treatment group significantly outperformed the control group ($p<0.05$). The posttest scores of the remaining treatment classes in four other schools, used as a triangulation group, showed similar gains. The information about the means and standard deviations in the pretest and posttest were used to calculate the effect sizes following Chen (1994, p.91). The effect size was 0.249 for school A and 0.485 for school B[1]. The study did not report detailed gender information about students.

[1]The effect sizes reported here are computed using a method that adjusts for discrepancies in performance between the treatment and comparison groups prior to intervention. This yields a more conservative estimate than the commonly used measure of effect size, which is based on the posttest only. For purposes of meta-analysis, the more commonly employed estimates are used. For this study they are .52 and .91, respectively.

(3) Thompson and Senk (2001)

D. R. Thompson and S. L. Senk compared student achievement in second-year algebra between the University of Chicago School Mathematics Project (UCSMP) classes and comparison classes.

Participants in the study were recruited through advertisements in UCSMP and NCTM publications. A school needed at least four sections of second-year algebra, two UCSMP classes, and two comparison classes, and the staff had to promise to keep classes intact for a full year. UCSMP and comparison classes were expected to have “similar students who have had the same previous work.” The evaluators used a matched-pair design for the study. A pretest measuring entering algebra and geometry knowledge was given over two days to assess the proficiency of the students. This pretest developed by UCSMP is composed of 46 multiple-choice items. This test was used to match UCSMP and comparison classes in the same school. Two well-matched pairs were formed in each school. Even though UCSMP and comparison classes were not assigned randomly, the teachers of the two groups of students had comparable academic backgrounds The difference in the pretest score means of the two classes (within each pair) was not significant even at $p=0.25$. Students using UCSMP materials were expected to have continual access to graphing technology (calculators or computers). The research design for this study can be considered quasi-experimental.

Four schools that participated in the study represented a broad range of educational and socioeconomic conditions in the United States. These four schools were one each from Georgia, Illinois, Mississippi, and Pennsylvania. In each school, two classes used advanced algebra materials produced by the UCSMP, and two other classes used regular textbooks. The texts used in the comparison classes and in UCSMP advanced algebra overlap considerably. To eliminate potential teacher selection bias, in each school each teacher had to agree to teach either curriculum before assignment. In each school, two teachers were assigned to two sections using UCSMP advanced algebra, and the other two teachers were assigned to two comparison classes which used the textbook currently in place at the school.

UCSMP advanced algebra is compatible with a variety of instructional styles. Instead of depending primarily on lecture to introduce content, teachers are also asked to pose problems, engage students in class discussion, and encourage students to learn to read their textbooks. UCSMP advanced algebra and the comparison texts treat technology very differently. The UCSMP developers assume that graphing calculators are available for student use at all times. The comparison texts’ authors do not assume that any calculators will be used, although optional activities are included for use with scientific calculators.

A total of 150 students were in the UCSMP classes, and 156 students were in the comparison classes. The performance of students is measured in eight pairs of second-year algebra classes that had been matched on the basis of pretest scores at the start of the school year. Since only the comparison students in the school in Chicago did not own calculators, only the results from this school are considered. In this school, one treatment class had 22 students compared to 24 students in its matching comparison class. Similarly, another treatment class had 16 students compared to 23 in its matching comparison class.

About two weeks before the end of the school year, teachers administered several instruments, including a multiple-choice posttest to assess students’ knowledge of the content of second-year algebra. The posttest contained 36 items. However, both UCSMP and comparison teachers at the Chicago school reported that their students had the opportunity to learn the needed content only for 26 items, and so a test containing these 26 items was called a fair test. The reliability of the fair test was 0.635. Similarly, there were 15 items for which all the teachers in the study indicated that their students had opportunities to learn the needed content, and so a test containing these 15 items was called a conservative test. The reliability of the conservative test was 0.635.

The results of a matched-pairs t-test indicated significant ($p<0.05$) differences between two curricula. The UCSMP students outperformed comparison students in the fair and conservative test in the Chicago school. The USCMP group outperformed the control group in the fair test, and the effect size was 1.02 in one matched pair of classes and 1.14 in the second matched pair. Similarly, the USCMP group outperformed the control group in the conservative test, The effect size was 0.80 in one matched pair of classes and 0.82 in the second matched pair.

(4) Hollar and Norwood (1999)

J.C. Hollar and K. Norwood extended O'Callaghan's study by comparing students using a graphing approach to the curriculum with the aide of TI-82 graphing calculators with students using a traditional approach. The function concept in mathematics is one of the most central concepts. O'Callaghan studied the effects of the Computer-Intensive Algebra (CIA) curriculum on college algebra students' understanding of the function concept by comparing students using CIA with students using a traditional curriculum. He developed a test to assess students' understanding of functions. Each question on the test was designed to assess one of the following aspects of conceptual knowledge: (1) modeling a real-world situation using a function; (2) interpreting a function in terms of a realistic situation; (3) translating among different representations of functions; and (4) reification (transitioning from the operational to the structural phase of using functions). O'Callaghan (1998) found that CIA students were better than traditional students in understanding modeling, interpreting, and translating concepts but no different in reification. The objective was to examine the effects of using a graphing approach to the curriculum on each of the four aspects of conceptual knowledge of functions.

The participants in this study were students enrolled in Intermediate Algebra at a large state university. These students scored the lowest on the university's mathematics placement examination. Four sections of a semester-long intermediate algebra course taught by two instructors were used in this study. Of the two instructors, each taught one treatment and one control class. A sample of 90 students participated in this study—46 in the treatment group and 44 in the control group.

One of the two simultaneous morning sections and one of the two simultaneous afternoon sections were selected to use the experimental curriculum. To determine any initial differences among the four classes, researchers used ANOVA procedures to compare the classes in terms of the following outcomes: results of the O'Callaghan Function Test pretest, math background (number of previous algebra courses); mathematics ability (math SAT scores); and predicted grade-point average in mathematics calculated by departmental formula. The analysis indicated that the four classes were similar. Similarly, pretest scores indicated no significant differences among the four classes on prior knowledge of functions.

The instructors followed the same plan of study, adhering to the course syllabus. From interviews and random observations of the classes, the researchers concluded that the instructors were not biased to (in favor of) any approach.

In the treatment group, the college text Intermediate Algebra: A Graphing Approach (Hubbard & Robinson, 1995) included calculator activities and was used in conjunction with the TI-82 graphing calculator. The text consists of both the graphing calculator activities and traditional algebra work. The students had access to calculators and were able to explore, estimate, and discover graphically and to approach problems from a multi-representational perspective. However, the students did not have access to calculators for the O'Callaghan Function Test or the traditional final examination.

In the comparison class, the text Intermediate Algebra: Concepts and Applications, fourth edition (Bittinger, Keedy, & Ellenbogon, 1994), was used, and the text covered the same topics as the experimental text. The focus of the text was on simplifying and transforming expressions and solving equations. The comparison group had no known access to graphing calculators.

The O'Callaghan Function Test was administered without access to calculators, first as the pretest at the beginning of the semester and later as a posttest at the end of the semester. Each question on the test was designed to assess one of the following aspects of conceptual knowledge: (1) modeling a real-world situation; (2) interpreting a function in terms of a realistic situation; (3) translating among different representations of functions; and (4) reifying functions. To evaluate students' traditional algebra skills, a departmental final examination consisting of a 50-question test of conventional algebra skills was used. The traditional final examination was administered to all four classes during the final week of the semester.

MANOVA was used to analyze students' understanding of the function concept on the four component scores and the total score on the O'Callaghan Final Posttest. MANOVA results indicated that the treatment classes outperformed the comparison classes in O'Callaghan's Function Test and also in each of the four components of the test. The effect size for the total test was 1.00. The effect sizes for the four components are 0.60 for modeling a real-world situation, 0.70 for interpreting a function in terms of a realistic situation, 0.64 for translating among different representations of functions, and 5.03 for reifying functions.

(5) Autin (2001)

Nancy P. Autin investigated the impact of the use of graphing calculators on both students' understanding of inverse trigonometric functions and on their problem-solving approaches. It is an effort to investigate topics for which integrating graphing technology in mathematics teaching is well-suited. Students in two 12th-grade trigonometry classes at a large, metropolitan, all-male private high school in Louisiana constituted the sample in this study. Each of these students had completed full-year state-approved courses in algebra I, algebra II, and geometry. One of the two classes involved in this study was randomly chosen as the treatment class, and the other as the comparison class. Each of the two classes contained 29 students for a total of 58 students: 55 white, 5 black, 2 Vietnamese, and 1 Hispanic. The researcher and the classroom teacher team-taught both classes for two weeks, following the same syllabus and using the same textbook, except that the treatment class was allowed to use a graphing calculator.

A pretest was administered to measure students' understanding of the general nature and behavior of functions. An F-test indicated no significant difference in pretest scores between the two classes. Students' algebra II grades and ACT math scores were used to further investigate whether students in the two classes had a similar understanding of functions at the beginning of the study. An independent samples t-test indicated no significant differences between the classes. A posttest consisting of two parts was administered on the final day of instruction. Part 1 consisted of 20 short-answer questions; Part 2 had six free-response questions. The six free-response items required students to justify their responses in a variety of ways, including through the use of graphs, and algebraic arguments. Scores on the posttest were the sum of raw scores in Part 1 and Part 2 of the test. The maximum possible score on the pretest is

60, on the posttest Part 1 it is 72, on the posttest Part 2 it is 30, and for the total posttest it is 102.

Analysis of covariance was used to test for a difference in understanding of inverse trigonometric functions at posttest between the treatment and comparison classes. The pretest scores were used as the covariate in the study in order to account for preexisting differences that may have existed between the intact groups. ANCOVA was chosen since it is considered to be an appropriate procedure for adjusting for preexisting differences between two intact groups. Further, ANCOVA, which combines regression and analysis of variance, controls for the effects of extraneous variables, and increases the precision of the research by reducing error variance (Hinkle, Wirsman, and Jurs, 1998, p. 518).

F-tests indicated significant differences in the total posttest scores between the treatment and control classes. The treatment class significantly outperformed the comparison group in both total posttest scores and scores in Part 2 of the posttest. However, there was no significant difference between the two classes in Part 1 of the posttest. The effect sizes were 0.64 for Part 1 of the posttest, 1.02 for Part 2 of the posttest, and 0.91 for the total posttest.

(6) Drottar (1998)

John F. Drottar compared the impact of graphing calculator on both the overall math performance and four particular aspects of student understanding as defined by the University of Chicago School Mathematics Project (UCSMP): Skills, Properties, Representations, and Uses. Both the treatment and comparison groups were taught by the same teacher following the same curriculum, except that the students in the treatment class were allowed to use graphing calculators.

Students from two intact algebra II A-level (with average to above average ability) classes at a four-year suburban high school in eastern Massachusetts participated in this study. Using the flip of a coin, one of the two classes was chosen as the treatment group and the other, as the comparison group. Both groups used the UCSMP advanced algebra textbook and were taught by the same teacher (the researcher of this study). The content and pacing as well as instructional strategies were the same for both classes. The treatment group differed from the control group only in its access to graphing calculators (TI-83). Chapters 6 and 7 were covered in the study. To measure performance, for both Chapters 6 and 7, Form A was used as a pretest and Form B as a posttest. These chapter tests have specific questions relating to each of the four components: skills, properties, uses, and representations. The study compared the treatment group with the control group on overall performance and on each of the four components.

The treatment group for the first part of the study included 22 students (10 males and 12 females), of whom 9 were in grade 10, 10 in grade 11, and 3 in grade 12. Similarly, the comparison group included 23 students (16 males and 7 females), of whom 13 were in grade 10, 7 in grade 11, and 3 in grade 12. Based on t-test results on Chapter 6 pretest scores, the treatment group was not significantly different from the comparison group. The issue of ability equivalency between the groups was further explored by comparing students' previous year's math grades. A t-test indicated no significant difference between the two groups in the students' previous year's math grades. Some students dropped out of the school in the second part of the study when the treatment and control groups were switched for Chapter 7 tests. As a result, in the second part of the study, the treatment group included 19 students and the control group, 21 students. One male Caucasian student in the control group and four students (1 female Caucasian, 2 male Caucasian, and 1 Hispanic male) in the treatment group dropped out. A t-test on Chapter 7 pretest data indicated no significant difference between the two groups.

In the first part of the study, students' performance on the Chapter 6 posttest constituted the outcome measure. The test also identifies the questions related to each of the four components of understanding: skills, properties, uses, and representations. Similarly, the Chapter 7 posttest performance constituted the outcome measure in the second part of the study. The test also identifies the questions related to each of the four components of understanding. In each of these chapter posttests, 10, 4, 10, and 4 questions were related to skills, properties, uses, and representations, respectively, for a total of 28 questions.

In the first part of the study based on the Chapter 6 posttest, the treatment group outperformed the control group, and the effect size was 0.440. However, the calculated t-statistic of 1.50 for the difference was not statistically significant. Of the four components of understanding, the treatment group significantly outperformed the control group only in the area of the representations component.

Similarly, in the second part of the study based on the Chapter 7 posttest, the treatment group also outperformed the control group, and the effect size was 0.303. However, the calculated t-statistic of 1.05 for the difference was not statistically significant. Of the four components of understanding, the treatment group significantly outperformed the control group only in the area of the skills category.

(7) Rodgers (1995)

Kathy V. Rodgers analyzed the impact of supplementing the traditional algebra II curriculum with graphing calculator activities on achievement scores, retention scores, and students' attitudes towards mathematics for average ability students. The students in two intact standard (average ability) algebra II classes at a four-year high school in rural western Kentucky are the study participants. Students in these classes were of average ability (based on their past performance in math) and were randomly assigned to one of the two classes by the school's computer-scheduling program before the beginning of the classes. The same teacher taught both classes, and one of the classes was randomly assigned (by a flip of a coin) to be the treatment class and the other to be the comparison class. Both the treatment and control classes were taught by the same teacher; the content, examples, assignments, and activities were identical for both classes except the treatment class was allowed to use graphing calculators (TI-82). The research was focused on the study of quadratic equations.

The treatment class consisted of 17 students; the control class, 21 students. The differences in the achievements of these students in the pretest and posttest constituted the dependent variable. A maximum score of 100 was possible for both the pretest and posttest. All the problems in the tests could be solved without the use of a graphing calculator. Students were required to solve the first three items in the tests using the traditional method and display paper-and-pencil calculations, while other items could be solved with or without graphing calculators. Treatment and comparison classes were also compared separately on their achievement in paper-and-pencil items and other problem-solving items. KIRIS (Kentucky Instructional Information System) scores (based on a combination of performance-based questions and traditional multiple-choice questions) of these students constituted the covariate in the analysis of covariance (ANCOVA). The maximum possible score for the paper-and-pencil items as well as for problem-solving items in the test was 18. Students' semester averages from the fall semester were also used separately as the covariate in the ANCOVA. The treatment and comparison classes were equivalent in terms of their KIRIS scores and also their previous fall semester averages.

This study utilized ANCOVA to test for a difference between pretest and posttest achievement on items related to quadratic equations. Students' KIRIS scores and previous fall semester averages were separately used as the covariates. ANCOVA results with KIRIS scores as a covariate indicate that supplementing the traditional algebra II curriculum with graphing calculator activities improved overall achievement. The treatment class therefore outperformed the comparison group in overall achievement. The effect size of 0.75 indicated that the treatment group outperformed the control group by 0.75 of a standard deviation. Similarly, ANCOVA results with students' previous fall semester averages as a covariate indicate that supplementing the traditional algebra II curriculum with graphing calculator activities improved overall achievement. The treatment class outperformed the control group in overall achievement.

ANCOVA results for the difference scores in paper-and-pencil items between the pretest and posttest achievements with KIRIS scores as a covariate indicated that supplementing the traditional algebra II curriculum with graphing calculator activities worsened paper-and-pencil achievement. The comparison class outperformed the treatment class. The effect size of –1.11 indicated that the control group outperformed the control group by 1.11 standard deviations. On the other hand, ANCOVA results for difference scores on problem-solving items with KIRIS scores as a covariate indicated that supplementing the traditional algebra II curriculum with graphing calculator activities improved achievement on problem-solving items. The effect size of 6.79 indicated that the treatment group outperformed the comparison group by 6.79 standard deviations.

(8) Wilkins (1995)

Cynthia W. Wilkins examined the effect of integrating graphing calculator use into the study of factoring in an eighth-grade algebra I program of study. The objectives of the study included investigating two research questions: (1) whether students who are taught to factor by using a graphing calculator perform significantly better than students taught traditionally without a graphing calculator, and (2) whether the effect of graphing calculator use is different between male and female students. Since the National Council of Teachers of Mathematics (NCTM) has recommended the use of graphing technology beginning in eighth grade at the pre-algebra level of math instruction, this study examined whether the graphing calculator was helpful to students at that level.

The sample included eighth-grade students enrolled in two schools in Mississippi. Seventy-five students in three classes in a public school constituted the treatment group; 24 students in a class in a parochial school constituted the control group. Of the 75 students in the treatment group, 40 were female and 35 male. Similarly, of the 24 in the control group, 14 were female and 10 male. The researcher taught all three classes in the treatment group, while another teacher taught the comparison group. The researcher selected the comparison group teacher based on that teacher's attitude, teaching style, teaching philosophies, and collaborative work experience. The researcher and comparison group teacher had different approaches to presenting the unit in factoring. Both teachers used the same textbook, but the researcher developed a unit consisting of 10 lessons that integrated the graphing calculator (TI-81) into her instruction; the textbook was used only as a reference tool. The comparison group teacher followed the lesson order and format in the textbook. The comparison group teacher also supplemented the text with some additional materials. The researcher trained the comparison-group teacher in factoring methods that were used in the treatment group. The comparison group also had access to graphing calculators; however, the comparison group teacher as well as all the teachers in his/her school were not trained in how to incorporate graphing calculators into the factoring unit, so the risk of experimental diffusion was low.

Both the treatment and comparison groups took the same pretest, the Stanford Achievement Test, and the same posttest. A panel of experts and an outside evaluator established the content validities of the pretest and posttest. No reliability estimates for the pretest and posttest were given. Both groups were given the pretest immediately prior to the five week period devoted to this unit of study. Of the 25 multiple-choice problems in the pretest, 12 problems in Section A were designed to measure basic factoring skills; 3 word problems in Section B were designed to measure basic applications of factoring skills; and 10 problems in Section C were designed to measure concepts and understanding beyond the basic level.

The independent sample t-test indicated a significant difference in prior ability in Section A of the pretest (basic factoring) between the treatment and comparison groups but not in Sections B (basic applications of factoring skills) and C (concepts and understanding beyond the basic level). The groups were also significantly different in prior ability in basic math skills as measured by Stanford Achievement Test scores. These scores were used as covariates in the analysis of covariance. The last day of the five-week study period was used to administer the posttest. The posttest was an alternate form of the pretest.

ANCOVA was used to test for a difference in scores in sections A, B and C of the posttest, with pretest scores and Stanford Achievement Test scores used as covariates to account for preexisting differences between the intact groups. The results indicated that the treatment and comparison groups differed significantly in basic applications of factoring skills (Section B), and concepts and understanding beyond the basic level (Section C) but not in basic factoring skills (Section A of the posttest). The treatment group outperformed the comparison group in Sections B and C but not in Section A. Since the adjusted means were not reported, the effect sizes were based on posttest means and standard deviations. The effect sizes were –0.25 in Section A, 0.41 in Section B, and 2.42 in Section C. T-tests also indicated no significant differences between male and female students in either the pretest or posttest scores.

Summaries of Research on Non-Graphing Calculators

The National Council of Teachers of Mathematics has recommended the use of graphing technology beginning in eighth grade at the pre-algebra level of math instruction. Since the council as early as 1980 had recommended the use of calculators at all grade levels, this review also included a few studies examining the effect of other calculator use on elementary and middle school children’s mathematics achievement. One study specifically investigated the effect of calculator use on mathematics achievement of students with learning disabilities. Each of these is summarized as follows.

(9) Szetela and Super (1987)

W. Szetela and D. Super compared performance in mathematics for three groups of seventh-grade students in British Columbia, Canada. Teachers adopted problem-solving strategies with calculators (CP group) with the first group, problem-solving strategies without calculators (P group) with the second group, and no problem-solving strategies and no calculators (C group) with the third group. The following instruments were used in the study:

- Operations with Whole Numbers Test (PREOP) and Operations with Rational Numbers Test (RAT). Each of these tests was a 40-item multiple-choice test used in British Columbia. The reliability indices were 0.88 for PREOP and 0.91 for RAT.

- Translation Problems Tests (TRAN1 and TRAN2). Each of these tests, which consist of 20 translation problems, was constructed and pilot-tested by the authors and was aimed at measuring the performance on elementary school math problems. TRAN1 was administered at midyear and TRAN2 at the end of the year. Reliability indices were 0.75 for TRAN1 and 0.72 for TRAN2.

- Process Problem Tests (PROP1 and PROP2). Each of these tests consists of 20 process problems and was constructed and pilot-tested by the authors. Strategies taught in the two problem-solving groups—CP and P—were needed to solve these problems. Reliability indices were 0.78 for PROP1 and 0.77 for PROP2.

- Complex Problems Test (COMP). A four-item test of complex problems was constructed and pilot-tested by the authors to determine whether teaching problem-solving strategies resulted in superior performance in the complex problems than in the translation and process problems.

PREOP was administered at the beginning of the year, TRAN1 and PROP1 were administered midyear, and the three tests (TRAN2, PROP2 and COMP) were administered in one sitting at the end of the year. The performance data were analyzed by using a partially nested analysis of covariance with treatment and sex nested within class. The pretest scores on PREOP were used as the covariate. This method of analysis effectively treats the class as the unit of analysis. The CP group scored significantly higher than the C group on TRAN1 and TRAN2 tests.

The study involved a total of 42 classes. Of these, 14 classes with 290 students were in the CP group, 10 classes with 195 students in the P group, and 18 classes with 338 students in the C group. Although test results were available for 42 classes for the midyear tests, the results for only 36 classes were available for the end-of-year tests. Three teachers in the C group, one teacher in the P group, and two teachers in the CP group dropped out of the study. Based on the results of a pretest, the three groups were not significantly different in their knowledge of whole-number operations.

This study used analysis of covariance with treatment by sex nested within class to analyze test score differences between groups. The outcome measures that were collected at the end of the year consisted of scores on two tests—TRAN2 and PROP2—which tested translation and process problems, respectively. Each test consisted of 20 items. PREOP scores were used as the covariate in the analysis of covariance of mathematics achievement data.

The ANCOVA results indicated significant treatment effects for TRAN2 and PROP2. The information about the means and standard deviations in the report were used to calculate the effect sizes. Following Glass, McGaw, & Smith (1981), the standard deviation of the comparison group was used to calculate the effect size. The effect size for TRAN2 between CP and P groups was 0.17 and between CP and C groups was 0.374. Similarly, the effect size for PROP between CP and P groups was 0.152 and between CP and C groups was 0.434.

The calculator effect was also compared between gender groups. There were no significant differences in TRAN2 and PROP2 scores between boys and girls in each group.

(10) Loyd (1991)

Brenda H. Loyd examined four item types on which performance was expected to vary differentially depending on conditions of calculator use. The identification of item subtypes as they relate to calculator use could be used to increase predictability of test score results with and without calculator use in a standardized testing situation. The study was motivated by previous research that had provided conflicting findings about whether using calculators changes the difficulty of mathematics tests or the time needed to complete them.

One hundred and sixty students attending a summer enrichment program at a state university during the summer of 1988 participated in this study. Twenty-seven students were 13 years old, 64 were 14 years old, 50 were 15 years old, 18 were 16 years old, and 1 was 17 years old. In the group 45% were in the eighth grade, 36% were ninth grade, 18% were 10th grade, and 1% was in 11th grade. Of the 160 students, 69 were boys and 91 female. Ten percent were black, 83% were white, and 7% were of other races. Ninety percent of the students owned their own calculators.

The math test administered to students was a composite of four subsets of items. The first subset of eight items was developed to favor examinees who were allowed to use calculators. This set included items that involved a more difficult level of computation as well as items requiring estimation, for which calculators could be used to approximate results. The second subset of eight items was developed as items that could be answered using a calculator, but could also be answered without using a calculator. These items were designed so that use of a calculator did not provide an advantage over the non-calculator group. The third subset of eight items required examinees to select the correct strategy or setup rather than a numerical answer. For this set of items, the use of a calculator would not be applicable. The fourth subset of eight items was more difficult or problematic for those using the calculators.

Four groups of 40 examinees were administered the 32-item test. Eighteen identical TI-1706 II solar-powered calculators were available for the study. Within each group, half of the students were allowed to use a calculator. Among the students seated for the test, half were randomly selected and assigned calculators. The students with calculators were permitted to use them, but there was no requirement that the calculator be used.

To examine whether there was a difference in the performance on the four subsets of items between students who were allowed use of the calculator and those who were not, a two-group discriminant analysis was used with the group variable consisting of an indicator of calculator use or nonuse. The four predictor variables were the scores on the four subsets. A significant discriminant function was followed up with t-tests for each subset.

Of the 160 students, 70 were allowed to use a calculator and 90 were not allowed to use a calculator. The results of the discriminant analysis indicated that the two groups could be distinguished in terms of their performance on the four subsets. The t-tests indicated a significant difference between the two groups on the first set of items but not in the other three subsets. The findings of the study support the contention that high school students' performance on math tests is affected by calculator use. The effect of calculator use also differs by item types.

(11) Liu (1993)

Shiang-tung Liu examined the effects of teaching calculator use and problem-solving strategies on attitudes towards mathematics, mathematics computation ability, and problem-solving ability of fifth-grade male and female students in Taiwan. Certain professional organizations, like the National Advisory Committee on Mathematics Education (NACOME) and National Council of Teachers of Mathematics (NCTM), recommend the use of calculators for instruction, while other researchers like Elliott (1981), Higgins (1990), and Suydam (1979) argue against calculator use. This study was an effort to investigate whether there were advantages to calculator use in elementary school classrooms.

The subjects in the study were students in four fifth-grade classes from four schools in Taiwan. Each of the four classes was randomly selected and assigned to one of the four treatment groups: traditional, calculator use, problem solving, and calculator plus problem solving. Of the four treatment groups, the traditional group had 43 students (24 males and 19 females); the calculator group had 50 students (23 males and 27 females); the problem-solving group had 53 students (32 males and 21 females); and the calculator plus problem-solving group had 47 students (24 males and 23 females).

Each teacher of the four classes received specific teaching instructions from the researcher. .The teachers were asked to maintain the same teaching pace and to give the same amount of practice to students. The researcher occasionally visited the classroom of each teacher to observe the progress of instruction. The Arlin-Hills Attitude Survey (AHAS), the Test of Prior Computation Skills (TPCS), and the Mathematics Problem Solving Ability Scale (MPSAS) were used to examine differences between groups in attitude and ability prior to the intervention.

Students in the calculator use group and calculator plus problem-solving group had access to calculators. The teacher in the traditional group was asked to follow a traditional teaching style. The teacher in the calculator use group was instructed on how to teach students to use calculators and to encourage calculator use in solving problems. The teacher in the problem-solving group was taught Polya's four steps to problem solving and was instructed to have students write down their problem solving processes. The instructions given to the teacher of the calculator use group and the teacher of the problem-solving group were given to the teacher of the calculator use plus problem-solving group. At the end of the nine-week intervention, the students were administered the TCA and posttests of MPSAS and AHAS. The students' scores on these posttest were compared across the four treatment groups.

Students' performance on the three posttests—the Arlin-Hills Attitude Survey (AHAS), the Test of Computation Ability (TCA), and the Mathematics Problem-Solving Ability Scale (MPSAS)—constituted the outcome measures. AHAS measures attitudes towards mathematics, TCA measures computation ability; and MPSAS measures problem-solving ability.

AHAS was developed by Arlin and Hills (1976) to assess fourth-grade to sixth-grade students' attitudes toward mathematics. The AHAS, consisting of 15 questions, was first translated into Chinese, and an English teacher was asked to translate this version back into English. Another English teacher was asked if the translation was appropriate to make sure the two versions were equivalent. The scores for AHAS range from 0 to 15, and the reliability of the pretest Chinese AHAS based on student scores from the four groups was 0.88 and that for the posttest was 0.91.

The TPCS consisted of 28 paper-and-pencil items that were used to measure students' computation skills before the intervention. These items were adapted from textbooks, and the scores ranged from 0 to 28. The reliability for this test was 0.93.

The TCA was designed to measure students' computational ability at the end of the study. The TCA also consisted of 28 items that were adapted by the researcher from students' textbooks. The scores ranged from 0 to 28 and the reliability for the TCA was 0.93.

Similarly, the MPSAS was developed by Liu (1989) to assess the mathematics problem-solving abilities of fifth-grade to eighth-grade-level Taiwanese students. There were two forms of this test: A and B. Form A had 16 items (64 sub-questions) and Form B had 15 items (64 questions). The scores in each form ranged from 0 to 64, and the reliability coefficients for Form B were 0.77 (based on the pretest) and 0.87 (based on the posttest).

The pretest scores on the Arlin-Hills Attitude Survey, the Test of Prior Computation Skills, and the Mathematics Problem-Solving Ability Scale constituted baseline data. These scores were used to examine differences in ability among the groups prior to the intervention.

This study utilized a three-factor analysis of covariance to test for differences on the posttest across the four treatment groups. This was done separately for each posttest. The three factors consisted of treatment status, achievement level, and gender. The researcher ranked the sum of two semesters-worth of mathematics scores for each group from highest to lowest and divided them into three achievement levels—high, middle and low. If the ANCOVA results indicated significant differences across the four treatment groups, then Dunnett's one-tailed follow-up test was performed to find out which of the groups were different from one another.

Based on the F-ratios from the ANCOVA summary table, the mathematics computation scores for the groups without calculators (traditional and problem-solving) were not significantly higher than those of the calculator use groups (calculator use and calculator use plus problem-solving). This finding indicates that calculator use did not hurt students' computation ability. However, findings indicate that the calculator use plus problem-solving instructional approach is likely to be the best of the four teaching methods. In addition to comparing posttest scores across the four treatment groups, separate comparisons were also made between males and females. The posttest scores were not significantly different between genders.

(12) Glover (1991)

Michael A. Glover examined the effects of handheld calculator usage on the computation and problem-solving achievement of children with learning disabilities in grades five, six, seven, and eight. Students with learning disabilities tend to lack computational skills that are foundational at the upper elementary and beginning secondary school levels(McLeod and Armstrong, 1982). Therefore, these skills were targeted in the intervention.

All students in this study had been identified by their school district as having a learning disability and were attending regular mathematics classes. The treatment group received mathematics instruction with calculators. Students in this group used the calculator for all homework, quizzes, and tests in the regular math class. They also received instruction in the use of the calculator. The comparison group students with learning disabilities attended regular math classes but didn't have access to calculators.

Students with learning disabilities in a small (2500 students) rural school district in western New York participated in this study. They were attending regular mathematics classes. The number of students in the treatment group was 8, 9, 8, and 10 in grades five, six, seven, and eight, respectively. Similarly, there were 7, 11, 9, and 6 controls in grades five, six, seven, and eight, respectively. Both the treatment and comparison group students received assistance from their special education teachers, who accompanied them to the regular math classes. The treatment group students were trained in the use of the TI Math Explorer calculator prior to the implementation of calculator instruction in the regular class. Throughout the project, the special education teacher provided the students with calculator instruction as it pertained to the regular mathematics curriculum. The treatment students used the calculator each day during classroom math instruction, while the control group students continued to use paper-and-pencil algorithms to complete assignments. Both the treatment and control group students received assistance from their special education teachers, who accompanied them to the regular math classes.

A 23-item computation test and a 7-item problem-solving test were administered to all students. The items tested addition, subtraction, multiplication, and division of integers and fractions. The treatment and comparison groups were administered the same test both before and after the intervention. Students completed one form of the test using paper and pencil methods and another form using the calculator.

The performance of the students in the treatment group was compared to those of the comparison group. Mean scores of students on pre- and posttests were compared to measure the effect of intervention.

Both the treatment and comparison groups scored higher on both the computation and problem-solving tests when using the calculator than when using pencil and paper methods. Posttest comparisons indicated that the treatment group had significantly higher computation scores when using the calculator. The treatment groups exhibited greater amounts of growth than the control groups. At each grade level, the treatment group outperformed the control group when a calculator was used during posttesting. In three of the four treatment groups, the pencil-and-paper posttest scores were higher than the pencil-and-paper pretest scores. This supports Roberts' (1980) contention that calculator instruction does not harm pencil-and-paper performance, and therefore, the calculator must be introduced early in a child's education.

(13) Ellerman (1998)

Tracie B. Ellerman examined the effects of calculator usage on the mathematics achievement of seventh- and eighth-grade students and also students' and teachers' attitudes towards mathematics. Students from two North Central Louisiana School systems constituted the sample for this study. Students' mathematics achievement was measured by administering California Achievement Tests, Fifth Edition, Form A, Level 17 and 18, Mathematics Concepts and Applications section. Level 17 was designed for seventh graders and Level 18 for eighth graders. The reliability of the 50-item Level 17 test was reported by the test publisher to be 0.77 and that of the Level 18 test was 0.75.

Data for this study were collected during the first semester of the 1997-98 school year. TI-108 calculators were used. The researcher and the school principal randomly assigned the intact classes into treatment or control groups on the day of the test by flipping a coin. Teachers were required to allow the use of calculators in the tests for the treatment group, regardless of how well-integrated calculator use was in the class. Of 1,070 students, 491 were in the control group and 579 in the treatment group; 446 were in seventh grade compared to 624 in eighth grade; 525 were black, 534 white, and 11 others Asian or Hispanic. Of the 33 teachers involved, 28 were females and 5 were males.

The mean scores of the treatment and comparison groups were examined for differences in the number of correct responses in the mathematics concepts and applications section of the CAT. A T-test indicated that the treatment group outperformed the controls in the number of questions answered correctly. This result was statistically significant. The effect size was 0.13. Further, the mean score for male students was significantly higher than for females , with an effect size of 0.05. Results of this study indicate that calculator usage during assessment has a positive influence on student mathematics achievement. Student and teacher survey responses supported calculator usage for both instructional and assessment purposes.

Causal Validity

The causal validity and other characteristics of the studies reviewed in this report are summarized in Table 3 for published research papers and in Table 4 for unpublished dissertations.

Table 3. Causal Validity and Other Study Characteristics: Published Research Papers

Study	Causal Validity	Intervention Fidelity	Outcome Measured	People, Settings & Timing	Testing within SG	Analysis	Statistical Reporting
Ruthven, K. (1990)	Y	○	○	○	●	○	●
Thompson, D. R., and Senk, S. L. (2001)	Y	○	●	○	Ø	○	●
Hollar, J. C., and Norwood, K. (1999)	Y	○	○	○	Ø	○	●
Graham, A.T., and Thomas, M.O. J. (2000)	Y	○	○	○	Ø	○	●
Szetela, W., and Super, D. (1987)	Y	○	●	○	○	○	●
Loyd, B. H. (1991)	N (Not an acceptable design.)						
	Note: Y = Meets WWC evidence standards with reservations; N = Does not meet WWC evidence standards ● = Fully meets criteria; ○ = Meets minimum criteria; Ø = Does not meet criteria						

Table 4. Causal Validity and Other Study Characteristics: Unpublished Dissertations

Study	Causal Validity	Intervention Fidelity	Outcome Measured	People, Settings & Timing	Testing within SG	Analysis	Statistical Reporting
Autin, N. P. (2001)	Y	○	●	○	Ø	○	●
Drottar, J. F. (1998)	Y	○	○	○	Ø	○	●
Wilkins, C. W. (1995)	Y	○	○	○	○	○	Ø
Rodgers, K. V. (1995)	Y	○	●	○	Ø	○	●
Glover, M.I A. (1991)	N (Not an acceptable design.)						
Ellerman, T. B. (1998)	N (Not an acceptable design.)						
Liu, S. (1993)	Y	○	●	○	●	○	●
	Note: Y = Meets WWC evidence standards with reservations; N = Does not meet WWC evidence standards ● = Fully meets criteria; ○ = Meets minimum criteria; Ø = Does not meet criteria						

Meta-analysis of Graphing Calculator Impact on Algebra Achievement

A meta-analysis gives us a way of combining the impact of multiple studies to arrive at a single estimate of the impact. Impact is expressed as an effect size, which is in standard deviation units. Specifically, we calculate this value by taking the mean of the treatment group minus the mean of the control group and dividing this difference by the pooled standard deviation.

However, a meta-analysis requires that the studies being combined be studies of the same or closely related educational problems or interventions. First, studies are selected that address similar problems based on researcher judgment. Second, a statistical test of homogeneity is used to verify that the studies have reasonably similar effect sizes.

To begin, the effect sizes for our 13 studies are summarized in Table 5 for published research papers and in Table 6 for unpublished dissertations.

Table 5. Effect Sizes in Published Research Papers

Study		Group	Sample Size	Mean	SD	Effect Size
Ruthven, K. (1990)		T	47	57	17	1.81
		C	33	28	16	
Thompson, D. R., and Senk, S.L. (2001)	Class 1	T	22	66.8	12.8	1.02
		C	24	53.5	12.9	
	Class 2	T	16	68.3	15.6	1.14
		C	23	51.2	14.1	
Hollar, J. C., and Norwood, K. (1999)		T	46	21.02	5.87	1.0
		C	44	15.62	4.70	
Graham, A.T., and Thomas, M. O. J. (2000)	School A	T	21	0.476[a]		0.52
		C	21	0.227[b]		
	School B	T	21	0.924[a]		0.91
		C	21	0.439[b]		
Szetela, W., and Super, D. (1987)	TRAN2	T^c	12	11.59		0.37
		C^d	15	10.00		
	PROP2	T^c	12	9.81		0.43
		C^d	15	8.02		
Loyd, B. H. (1991)		X				

Note: T = Treatment Group, C = Comparison Group, X = Does not meet WWC evidence standards, [a] = Posttest Effect Size, [b] = Pretest Effect Size, T^c = Problem solving strategies with calculators, C^d = No problem-solving strategies and no calculators

Table 6. Effect Sizes in Unpublished Dissertations

Study		Group	Sample Size	Mean	SD	Effect Size
Autin, N. P. (2001)		T	29	81.31	11.46	0.91
		C	29	70.79	15.12	
Drottar, J. F. (1998)		T	22	11.82	6.35	0.44
		C	23	9.09	5.80	
Wilkins, C. W. (1995)		T	75	Adjusted Means Not Reported		
		C	24	Adjusted Means Not Reported		
Rodgers, K. V. (1995)	Paper-and-Pencil	T	17	12.29	3.70	-1.11
		C	21	15.95	3.28	
	Problem-Solving	T	17	7.58	4.08	6.79
		C	21	0.45	1.05	
Glover, M. A. (1991)		X				
Ellerman, T. B. (1998)		X				
Liu, S. (1993)		T^e	47	28.47	7.39	0.02
		C^f	42	28.28	7.19	

Note: T = Treatment Group, C = Comparison Group, X = Does not meet WWC evidence standards, T^e = Calculators plus problem solving, C^f = Traditional and no calculators

Since our initial focus of the review was on graphing calculators, we restricted the meta-analysis to these studies. There are four published research papers and four unpublished dissertations that investigated the effect of graphing calculators. Among these studies, the researchers measured the impact on a variety of skills and abilities, most commonly on algebra. We judged that four of the studies that met the inclusion criteria measured the effect of using graphing calculators on algebra skills. Our meta-analysis addresses these studies only. Two of the studies report two separate effect sizes which were considered independent since they involve separate classes or schools. Thus, we worked with six outcomes in the meta-analysis.

The procedures are as follows. We computed standard errors for the effect sizes. We then carried out a statistical test of homogeneity to determine whether the studies can reasonably be described as sharing a common effect size (Hedges & Olkin, 1985). Under the null hypothesis that the effect sizes are equal, the test statistic, $Q = \sum_{i=1}^{k} \frac{(d_i - d_+)^2}{\hat{\sigma}(d_i)}$, (where d_+ is the estimated pooled effect size and d_i are estimated study-specific effect sizes,) has an asymptotic chi-square distribution with k–1=5 degrees of freedom. In the current meta-analysis, Q has a value of 4.37. A value of Q as large as that obtained would occur between 25 and 75% of the time if the effect sizes are equal. Hence, we do not reject the hypothesis of homogeneity of effect size, and we consider pooling the data to obtain an estimate of the common effect size.

The point estimates for the effect sizes for the six results are displayed in Figure 1. Each point estimate is centered on its 95% confidence interval. The rightmost confidence interval represents the result for the pooled estimate. The 95% confidence interval does not contain zero, therefore,we reject the hypothesis that the common effect size is zero at the α=.05 level of significance. The point estimate is .85 with a confidence interval (0.61, 1.09), which gives strong evidence that the use of graphing calculators is associated with better performance in algebra. A fixed effects model is assumed in the computation of the standard error of the pooled estimate. (Note that outcomes for quasi-experiments may be biased, and this caution should be kept in mind when interpreting results.)

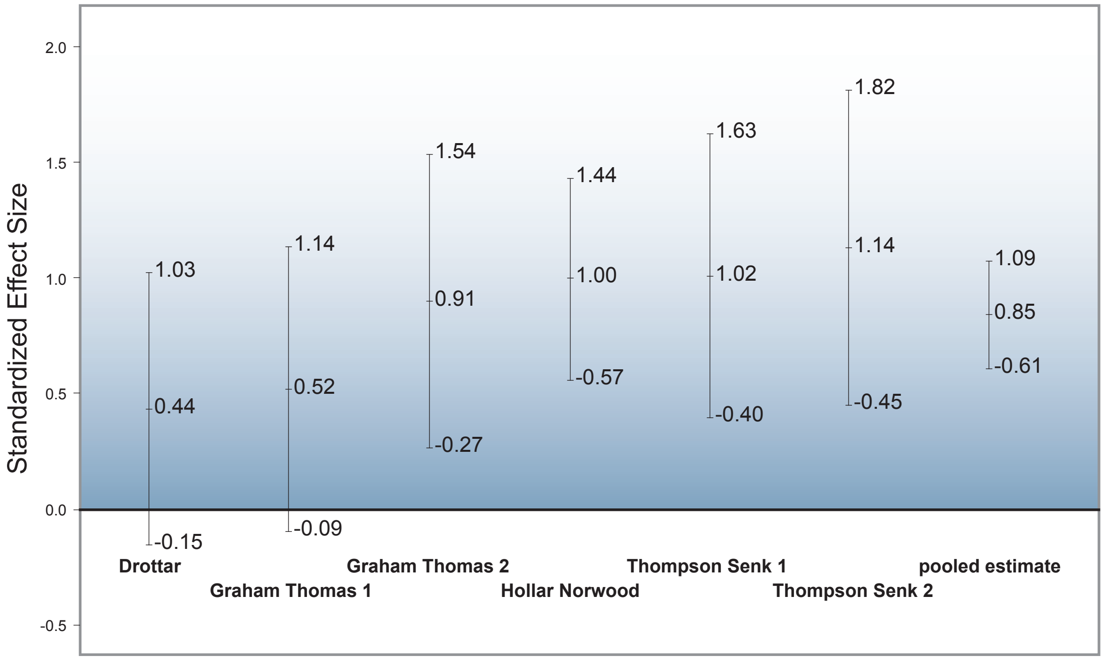


Figure 1: For studies of algebra: Estimates of the size of the difference between treatment and control groups indicating the 95% confidence interval

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Year 1 Assessment of the RISD-TI Intervention Model

Prepared by

Winick & Lewis Research, LLC

June 22, 2006

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Executive Summary

- Initial TAKS results show that Lake Highlands Junior High School's 2006 mathematics scores improved over 2005's. Almost 33% of the students who participated in the intervention passed the 2006 TAKS after failing the previous year, a number that was larger than would normally be illustrated by this at-risk group.

- Students within the block-classes had a large gain in their percent correct TAKS score while students in regular mathematics courses fell back on average.

- The LHJH teachers' math knowledge, as measured by pre- and post-intervention LMT assessments, significantly increased after a year of collaboration and professional development sessions provided by TI.

- Year-end teacher mathematics knowledge as measured by the LMT, and growth in LMT scores in the intervention teachers were both positively associated with the TAKS performance of their students.

- Teachers reported increased expectations for student performance and improved teaching after receiving content training in math. Teachers stated that the math training sessions improved their understanding as they could better explain connections to students and were able to understand sequencing of the proofs underlying a process.

- Parents noted a positive difference in children's math performance and attitude. Students who had not been successful in math made noticeable progress.

- The more immediate availability of diagnostic data helped teachers improve instruction by allowing them to determine frame length and starting point, spiral in concepts not mastered sooner and provide extra practice through warm-ups. Some teachers reported misalignment between unit benchmarks and the district curriculum on the TEKS, and unit diagnostics and the district curriculum or the TEKS.

- Some teachers were critical of site administrative support and increasingly so across the intervention. Many thought the administrators did not realize the day-to-day planning and learning activities necessary for a successful intervention. Teachers were most critical of site administrators for not managing discipline better as students who constantly disrupted class were not removed.

- Teachers agreed that use of the TI-Navigator increased student engagement, reduced many behavioral problems in class, and shifted responsibility for learning to the students. Teachers commented that students spent more time working through problems, were able to realize corrections more quickly and retain information. The calculator experience also increased their algebra readiness.

- The real time data and anonymous features of the technology increased student participation dramatically, including group work and student support for one another.

The technology allowed teachers more time and they were able to focus on questioning skills and student discussion while more and higher level concepts could be covered.

- The power block (extra 50 minutes of instruction) helped create relationships, provided more hands-on learning and development of problem solving strategies while engaging students in more activities. Teachers reported that the increased time changed problem solving effort and approach, and increased student expectations and performance.

- Important shifts occurred in teacher perceptions from mid-intervention to year-end. Teachers grew more critical of the administration and the seeming lack of appreciation for their increased efforts. It became clear to all teachers that the power-block and the real time data and anonymity features of the TI-Navigator were essential to increasing student effort and performance. While four to six of the teachers were positive about the intervention components at mid-year, 6 to 8 were confident of improvements in their own and student performance by year end.

Year 1 Assessment of the RISD-TI Intervention Model

Overview

During this past year, Lake Highlands Junior High School, the Richardson Independent School District and Texas Instruments, Inc. partnered to develop a focused intervention that would improve mathematics instruction and test outcomes at Lake Highlands. Utilizing a block schedule class design, additional instruction time, more collaboration between teachers throughout the year, focused professional development sessions, and the employment of the TI-Navigator, the school sought to increase the passing rate of at-risk students enrolled at Lake Highlands.

Lake Highlands' Performance

Students who failed to pass the TAKS mathematics assessment in 2005 were placed in 100 minute block classes which employed the TI-Navigator system to assist in instruction. Teachers assigned to these classes met frequently to develop and share their knowledge and solve problems, and these teachers also received additional professional development sessions with a math expert from Texas Instruments.

To get a sense of Lake Highlands Junior High School's standing, we can view the school against other junior highs in the Richardson Independent School District. Table 1 provides comparative data on demographic categories for RISD junior high schools, listing the total number of students tested this year, the ethnic group percentages and proportion of the student body classified as economically disadvantaged. Lake Highlands had the second largest percentage of African American students, somewhat fewer white students, and an above average proportion of economically disadvantaged students taking the TAKS this year.

Table 1: Response Totals by Campus for 2006 TAKS testing period (overall, ethnic group and economic disadvantaged percentages)

Campus	Total tested	Asian	Afr. Amer.	Hispanic	White	Other	Econ. Dis.
Apollo	752	16%	18%	20%	46%	0%	35%
Forest Meadow	577	4%	50%	22%	23%	1%	62%
Lake Highlands Junior High	588	2%	42%	19%	37%	0%	42%
Liberty	648	18%	38%	22%	21%	1%	60%
North	527	4%	7%	25%	63%	1%	29%
Parkhill	461	3%	7%	23%	66%	1%	26%
West	518	5%	21%	39%	35%	0%	47%
Westwood	545	6%	23%	32%	39%	0%	43%

Let us consider TAKS results across the RISD junior high schools for 2006. In table 2 below, the percentage of students in the 7^{th} and 8^{th} grades who met the minimum passing standard can be seen along with the percentage change from the 2005 results for each group at the schools (note that these numbers reflect all students tested and including those who joined the district as hurricane evacuees).

Table 2: 2006 TAKS Met Minimum Percentage by Grade
(with percentage change from 2005 in parentheses)

Campus	Overall	Afr. Amer.	Hispanic	White	Econ. Dis.
7^{th} Grade					
Apollo	85 (+9)	73 (+29)	73 (-2)	92 (+12)	71 (+8)
Forest Meadow	58 (+5)	43 (+12)	53 (+3)	92 (+2)	48 (+13)
Lake Highlands JH	70 (+6)	51 (+11)	65 (+12)	92 (0)	54 (+8)
Liberty	69 (-3)	51 (-14)	70 (+16)	89 (-3)	61 (-3)
North	90 (+8)	71 (+26)	77 (+1)	96 (+7)	78 (+9)
Parkhill	92 (0)	68 (+4)	86 (+8)	97 (-2)	78 (+8)
West	78 (+4)	72 (+5)	71 (+8)	87 (+1)	67 (+1)
Westwood	83 (+2)	73 (+3)	73 (-1)	97 (+4)	72 (+1)
8^{th} Grade					
Apollo	78 (+1)	51 (+1)	74 (+4)	86 (+3)	67 (+2)
Forest Meadow	53 (-2)	36 (-6)	43 (+16)	92 (+2)	38 (+1)
Lake Highlands JH	63 (+3)	43 (+2)	46 (+6)	92 (+4)	47 (+6)
Liberty	71 (0)	54 (+5)	63 (+2)	86 (+8)	62 (+3)
North	81 (-4)	48 (-5)	70 (+7)	90 (-4)	65 (0)
Parkhill	93 (+4)	54 (-21)	88 (+19)	98 (+3)	82 (+9)
West	80 (+6)	70 (+1)	72 (+9)	94 (+8)	73 (+8)
Westwood	93 (+14)	56 (-17)	68 (+7)	95 (+6)	63 (0)

Lake Highlands showed improvement this year as the percentage of students meeting the minimum passing standard increased over last year for both the 7^{th} and 8^{th} grade. In addition, improvements were also made in each of the relevant subgroups in each grade level, although the 7^{th} grade seems to show better performance overall and a more dramatic improvement for African American and Hispanic students.

A comparison of results across campuses over the past two years is informative since the intervention was focused on students who did not pass the TAKS in the previous year. Table 3 shows the 2005 performance of students who failed the TAKS in 2004 across the junior high schools. At every campus, less than a third of the students who did not make the standard in 2004 went on to pass in 2005, and Lake Highlands had the least success with this group of students. This comparison illustrates the performance prior to the implementation of this intervention project.

Table 3: 2005 TAKS Math Performance by Students who did not meet 2004 minimum

School	Number of Students not meeting 2004 minimum	Met 2005 Minimum	Did not meet 2005 minimum
Lake Highlands Junior High	101	13.9 %	86.1 %
Richardson Junior High	55	16.4 %	83.6 %
Richardson West Junior High	59	23.7 %	76.3 %
Richardson North Junior High	28	14.3 %	85.7 %
Forest Meadow Junior High	116	14.7 %	85.3 %
Westwood Junior High	48	22.9 %	77.1 %
Liberty Junior High	62	24.2 %	75.8 %
Apollo Junior High	67	28.4 %	71.6 %
Parkhill Junior High	25	28.0 %	72.0 %

Using the 2006 results, table 4 shows a similar comparison, using students who were assigned to the block classes at Lake Highlands and comparing their 2006 TAKS performance with students at other campuses who failed the 2005 TAKS.

Table 4: 2006 TAKS Math Performance by Students who did not meet 2005 minimum

School	Number of Students not meeting 2005 minimum	Met 2006 Minimum	Did not meet 2006 minimum
Lake Highlands Junior High	119	32.7 %	67.3 %
Richardson West Junior High	82	36.6 %	63.4 %
Richardson North Junior High	50	36.0 %	64.0 %
Forest Meadow Junior High	139	19.4 %	80.6 %
Westwood Junior High	70	28.6 %	71.4 %
Liberty Junior High	115	31.3 %	68.7 %
Apollo Junior High	106	43.4 %	56.6 %
Parkhill Junior High	27	63.0 %	37.0 %

Overall, Lake Highlands made great progress in increasing the pass rate of this at-risk group and now places in the middle rather than the bottom of the district's junior high schools in mathematics.

A comparison can also be made within Lake Highlands that looks at the gain in the percentage of correct responses made by students in the block classes and those in regular (non-AP) mathematics classes. The following table reports scores for students in the 7th and 8th grade at Lake Highlands during 2006, listing their average percent correct in 2005 and 2006 as well as the gain made across the period. As this table includes only students that had scores in both 2005 and 2006, hurricane evacuees are not included in these averages.

Table 5: TAKS Percentage Correct Growth from 2005 to 2006 at Lake Highlands JH for Block and Regular Mathematics Classroom Students

Classroom Assignment	Number of Students	2005 Percent Correct	2006 Percent Correct	Percentage Gain
7th Grade Block Classes	22	45.5%	47.4%	1.9%
8th Grade Block Classes	57	44.3%	54.5%	10.2%
Block Classes Overall	79	44.6%	52.5%	7.9%
7th Grade Regular (non-AP) mathematics classes	69	76.6%	64.6%	-12.0%
8th Grade Regular (non-AP) mathematics classes	50	67.2%	66.8%	-0.4%
Regular (non-AP) mathematics classes overall	119	72.7%	65.6%	-7.1%

The results in Table 5 show that students in the block classes made gains while students in regular mathematics classes lost ground on this year's test. The seventh grade regular class scores show a pattern similar to one we saw when we reported last year's results as students once again have the scores drop as they transition from the elementary schools in 6th grade to the middle school environment in 7th grade, yet the block students did not show this drop off. In 8th grade, while regular classroom students showed little change, the block students greatly increased their scores. While interpreting gain scores can be problematic given pre-existing score differences in the groups during the initial testing year, the patterns of gains found illustrates that the TI-RISD intervention is off to a promising start.

The TI-RISD intervention also focused on improving teacher knowledge, using professional development opportunities and collaborative sessions to assist the Lake Highlands mathematics teachers. The impact in this area can be seen in the teachers' scores on the Learning Mathematics for Teaching project assessment (the LMT) that was administered prior to this year and then again after the TAKS testing period. Table 5 lists the LMT averages for the mathematics teachers participating in the intervention program at Lake Highlands across 2005 and 2006, along with the growth illustrated on each LMT domain. Note that the LMT scores are represented in standard deviation units and are normalized in line with a national sample of mathematics teachers who completed the LMT measures over the last two years. The average score is calibrated to zero, and scores can be negative or positive in value, representing results that would be below (negative) or above (positive) average.

Table 6: LMT Averages and Growth from 2005 to 2006 at Lake Highlands Junior High School

LMT Dimension	Average	Standard Deviation	Range
2005 Numbers and Operations domain	-0.0244	0.707	2.07
2005 Patterns, Functions, and Algebra domain	-0.2905	0.772	2.01
2006 Numbers and Operations domain	0.8323	0.673	2.22
2006 Patterns, Functions, and Algebra domain	0.3968	0.592	1.49
Growth in Numbers and Operations score, 2005-06	0.8567	0.300	0.95
Growth in Patterns, Functions, and Algebra score, 2005-06	0.6874	0.462	1.14

All but one of the teachers who completed the pre- and post-intervention assessment showed growth on the LMT domains, with the outlier showing a number of anomalies on the second part of the questionnaire. With her data excluded, the growth from pre- to post-test is significant for both domains (for Numbers and Operations, $\mathbf{t}_{(5)} = 7.14$, $\mathbf{p} < .001$; for Patterns, Functions and Algebra, $\mathbf{t}_{(5)} = 3.64$, $\mathbf{p} < .01$).

The end-of-year LMT scores and growth LMT scores for these teachers also relate to their students' performance on this year's TAKS. The following charts graphically illustrate how each LMT domain and growth in the domains over the year relate to class performance on the 2006 TAKS for these block classes.

Chart 1: Numbers and Operations 2006 LMT Scores by TAKS Math Met Minimum Percentage (r = .38)

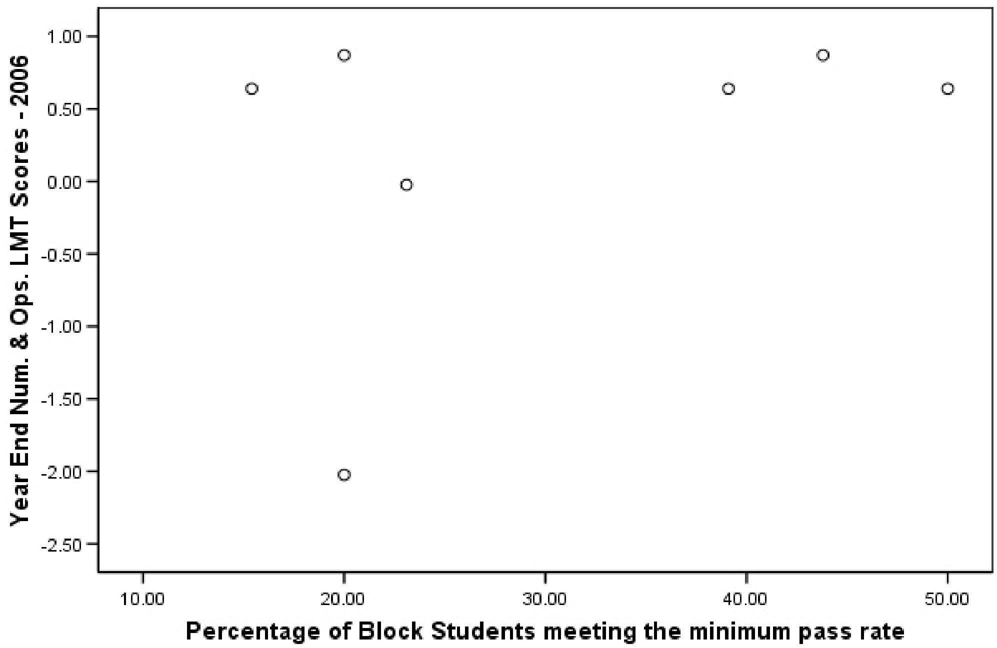


Chart 2: Patterns, Functions and Algebra 2006 LMT Scores by TAKS Math Met Minimum Percentage (r=.56)

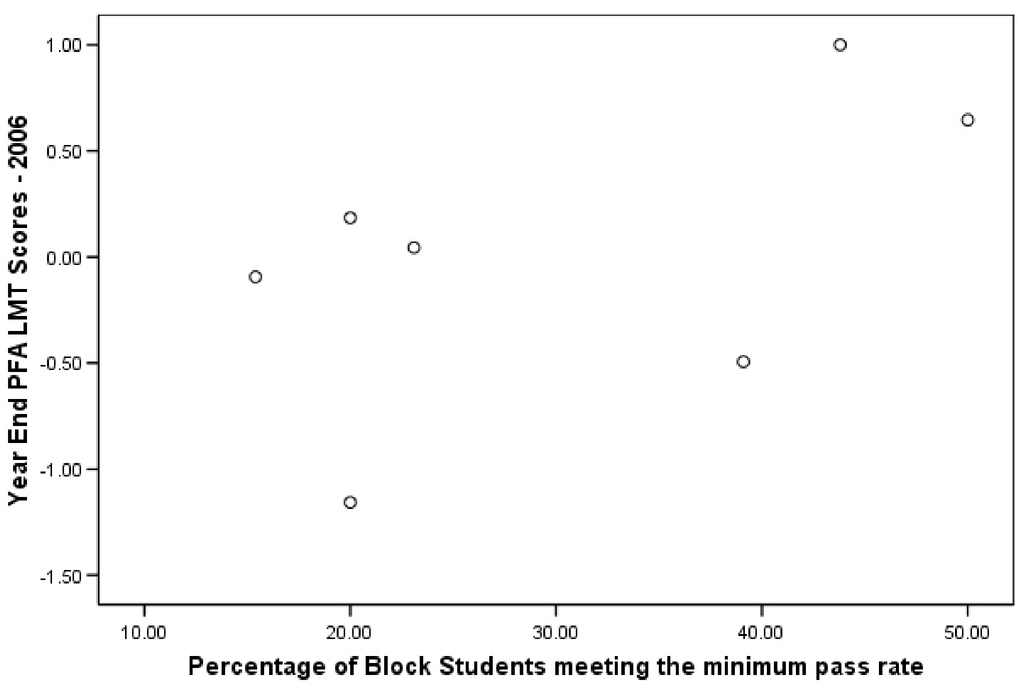


Chart 3: 2006 Number and Operations LMT Score Growth by TAKS Math Met Minimum Percentage (r = .53)

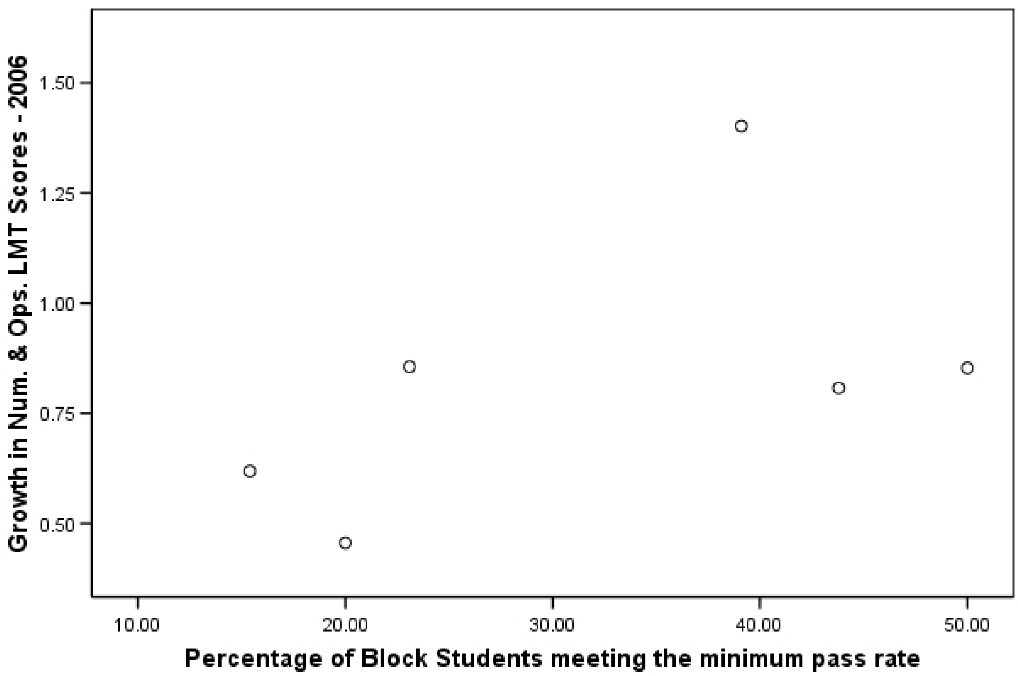
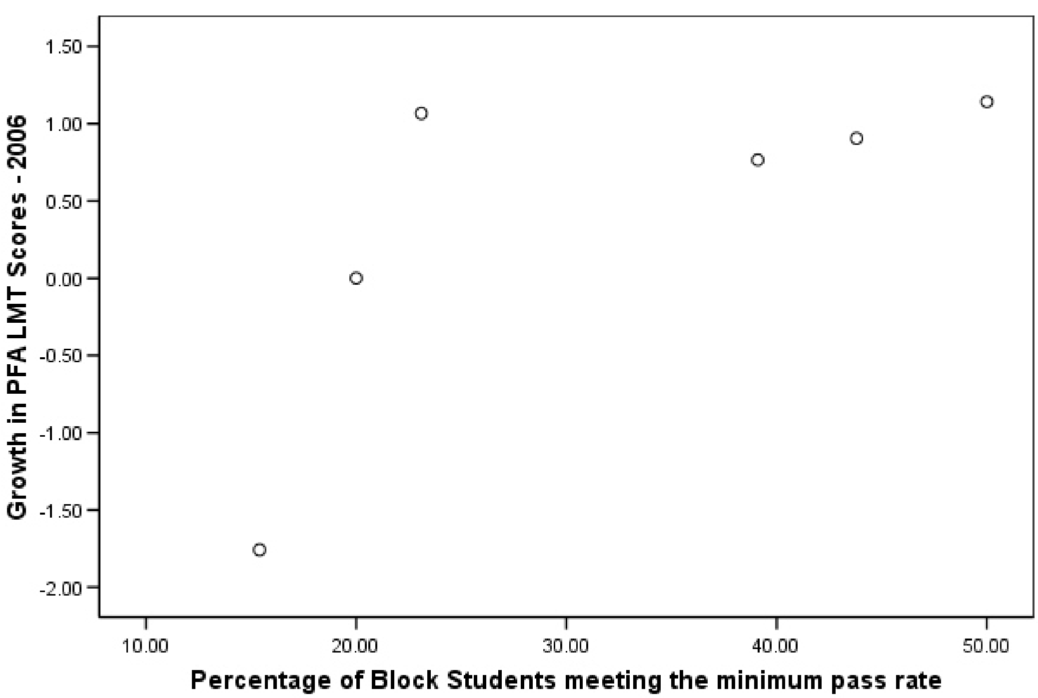


Chart 4: 2006 Patterns, Functions and Algebra LMT Score Growth by TAKS Math Met Minimum Percentage (r = .72)



The patterns in both the year-end scores and growth measures show a positive trend with teachers scoring higher or showing more growth on the domains also having classes with a higher percentage meeting the minimum passing level on the TAKS.

Teacher Perceptions

The teachers completed a survey at mid-year and year-end that addressed the effectiveness of the intervention components. They were asked to detail successes and challenges while providing suggestions for improvement. The survey appears at the end of this report in appendix A, and full tables of the results appear in appendix B.

Problem solving activities and grouping

In the mid-year analysis, the teachers reflected on problem solving and grouping activities. It was unclear whether problem-solving activities used by students in the classroom were different from last year or not. The four new teachers could not make this comparison and of the remaining four, two suggested that the practices were not different. Types of problem solving activities used appeared to vary across teachers.

The labels used to identify grouping strategies seem to vary as well, although the described activities often included reviews and assessments, less so learning new concepts or pursuing higher level thinking.

Teachers noted changes in student behavior as a result of grouping strategies; one suggested a deeper understanding of the subject matter, another commented that leadership skills emerge as over achievers tried to excel. Two teachers mentioned increased student (social) motivation or willingness to listen to peers. Three commented on difficulties: students only wanting to do the work they are assigned, students needing to wait on the previous person’s work to do their part, students just visiting and then copying work while one carries the group, students abusing the group format.

Teachers mostly reported using flexible grouping without labeling of groups, followed by flexible grouping between groups when a skill is mastered. Students were assigned to groups in various ways: skill level and personality, seating proximity, randomly, self selection and typically 2-4 in size, although one teacher reported assigning groups of 4-6 students. While teachers agree that competitive and cooperative settings are useful for learning math, they mostly report creating cooperative settings of 3 to 4 students.

Efficacy and the TI Intervention Model

Research suggests that students perform to their own and others expectations. So following teacher expectations for student success in math across this study is important. When we sampled the broader population of RISD math teachers in April 2005 we found expectations in the district to be low overall, yet the eight math teachers at Lake Highlands reported surprising confidence both prior to the study and at mid-intervention. Furthermore, at the end of year one, 100% reported that they can successfully teach 90% or more of their students grade level math.

One teacher moved from uncertainty at mid-year to confidence about teaching math and doing so with ELL by year end. All but one agreed that 90% or more of their students can learn grade level math. The outlier respondent reports confidence with her own performance but not that of the students, the administration or the intervention.

The teachers further reported at mid-year and year-end establishing a significant relationship with students who have difficulty in math and that they inspire their students. Perhaps most importantly, six teachers agreed that their expectations for student performance have increased since receiving training this past summer and fall. Two were uncertain.

Some unexpected but perhaps noteworthy shifts in perceptions surfaced from mid-year to year-end about teaching success. Four teachers reported not feeling valued by the administration at year-end verses two at mid-year. Furthermore, from mid-year to year-end teachers noted that instructional support has changed, with at least half uncertain if it is based on benchmark data and three suggesting that they do not receive support in time to deliver content successfully.

How has the TI intervention model assisted those teaching math? At mid-year teachers mention aspects of the training that helped them. One spoke of the class on equitable classroom by Harris. Two mentioned the staff development sessions with Damaske, the common planning time and the technology as being helpful. Another spoke of the laid-back feeling of the sessions, of feeling comfortable asking questions. Another spoke of how she viewed math instruction differently now, namely that helping students look at new concepts in different ways and following concept introduction with technological application had made a marked difference in learning.

At year-end the teachers spoke more about practices in the classroom, the technology, and student performance. Teachers commented that the technology had engaged students who were not otherwise, allowed for monitoring and immediate assessment, accelerated content and increased student responsibility. One commented, “students can create and learn visually.” The teachers reported that the power block (extra 50 minutes of instruction) had helped to create relationships, provided more hands-on-learning and problem solving strategies while it engaged students in more activities. One teacher noted that the intervention “has given me better ideas for teaching lower level students and made learning more interesting.” Another reported, “the students seem to have become better problem solvers”.

At mid-year one teacher reported not using the technology and needing help. By year-end this teacher noted success with the technology, but was critical of the training sessions (not being included), block composition, instructional and administrative support, but not of her progress or that of her students even though neither were relatively good.

Teachers reported that components which have raised their confidence include the common planning time, talking about the lessons, having the technology to demonstrate lessons, support in the classroom, having someone to call with questions, the unit diagnostics and weekly meetings with Paula Moeller. Each of these factors was mentioned by a teacher at mid-year. At year-end the focus shifted as teachers spoke of the importance of the training sessions, but also the power block and instant feedback on student work. One even noted increased performance: “Going from 0 to 53% passing TAKS!” that raised teacher confidence.

Campus Administration

While half the teachers reported feeling valued by the administration throughout the intervention, two at mid-year and four at year-end did not. At mid-year teachers complained about an increased work-load without administrative support or the lack of encouragement for increased performance from students. At year-end five of the teachers made comments about the administration not understanding the amount of time required to plan and execute the intervention. While one suggested administrators seemed resentful, others commented that administrators knew of the extra training involved and Saturday sessions but did not realize the day to day planning and learning activities necessary. Others commented, however, on reduced duties. When asked about additional administrative support, four teachers requested improvements in handling discipline, specifically better procedures or support in removing students who constantly disrupt.

Parent Understanding and Response

It is common for teachers to report low efficacy based upon projections made from parent involvement and economic status. This is generally not the case with Lake Highlands where the math teachers reported at mid-year and year-end that parents understand the importance of learning math. In addition, several teachers provide positive comments from parents. Parents have called to report that their child has shown interest in math this year, in part because of the new technology; others are pleased with the block format suggesting that their child was never good in math before. Parents have e-mailed teachers describing a change in their child because of the model. “The parents tell me how excited their child is now about succeeding in mathematics.” The pulse from parents is positive; they are excited.

Instructional Support and Content Knowledge

At mid-year several teachers suggested that they did not have the instructional support necessary to teach all students. Only one teacher agreed that content sessions with the mathematician increased her mathematical understanding and that the sessions helped her teach effectively. This changed dramatically by year-end where all but one teacher reported having the instructional support necessary to successfully teach all students math. Six teachers stated that the content sessions had increased their mathematical understanding while five found the sessions had improved their teaching; one is uncertain. Across the intervention the focus of teacher meetings appears to shift away from lesson planning and teaching strategies to math content sessions for several of the teachers. This does raise several questions. Do the teachers continue to work together on lessons plans and strategies? Do they perceive the purpose of the sessions differently at year end?

Most disagreed at mid-year and year-end that regular and tutoring teachers plan content together while half agreed that weekly meetings are used to align district curriculum with the TEKS.

In the open-ended responses about the math content sessions teachers, feedback at mid-year was more negative than positive. While two reported that the sessions made them more aware of additional representations available to them or different ways to look at things, others suggested that the sessions were helpful, but that the mathematician spoke at the wrong level. Several commented that the sessions were a waste of time. One who reported that they were helpful asked that the teachers plan with a component for ELL in their lessons. Another asked for extra or different lessons for the block classes. She suggests that they should be focused on planning for class and reviewing while someone who is an expert at writing lesson plans should be doing that for the whole group, instead of everyone reinventing the wheel. Finally a teacher requested more ideas for teaching pieces, not activities.

The open-ended comments about the math content sessions at year end were mostly positive. In essence, the teachers suggested that they gained depth of understanding so they could explain connections, understand sequencing or the proofs underlying a process. One teacher spoke of feeling overwhelmed by the material and thus better able to understand struggling student feelings. When asked about additional content that would be of use, two teachers requested more weekly planning meetings, another asked to discuss other teacher experiences with each unit or for the curriculum to be connected with the mathematician's content, or more and different use of manipulatives.

Assessment and Indicator Alignment

The level of agreement over the alignment of unit benchmarks to the district curriculum and the TEKS, and unit diagnostics to the district curriculum and the TEKS shifts slightly from mid-year to year-end. At mid-year, one to two teachers disagreed or were uncertain about alignment whereas by year end, two to three fell into this category with a fourth not responding.

Uncertainty about unit diagnostics helping teachers tailor instruction remained constant at two teachers (five agree) from mid-year to year-end. All teachers agreed at year-end that the more immediate availability of data had helped them improve instruction. One had been uncertain at mid-year.

Six of the teachers commented on using the diagnostic data to tailor instruction, re-teach or identify students who need more monitoring. Teachers commented that the diagnostic data helps them tailor their instruction by knowing what concepts require more (or less) time, to identify material that students should already know, and to design warm up's around what students don't know. The teachers reported that the unit diagnostics had changed instruction by allowing them to determine frame length and starting point, to move a weaker student closer to them or adjust the warm up's and quizzes to cover more review. Teachers commented that the immediate availability of data allowed them to spiral in concepts not mastered sooner and to provide extra practice through warm-ups. One teacher reported that the more timely feedback allowed her to conference with students quickly while trying to get them back on track.

While respondent agreement is often our focus, it may be helpful to know how many teachers are hesitant about the assessments or even resistant. At mid-year, one or two teachers seemed to question the usefulness of the unit diagnostics and increased number of benchmarks. At year-end two teachers out of eight questioned the usefulness of increased assessment.

Let us consider performance expectations for the assessment vehicles. In the Efficacy section above we reported surprisingly high confidence among teachers about their ability to successfully teach as well as students' likelihood of learning. Teachers' confidence about student performance shifted from mid-intervention to year-end, with slightly more uncertainty about TAKS performance but far more confidence about district TEKS performance. In all six teachers were confident that students will do well on both.

Use and Impact of Technology

Teachers reported positive experiences with TI technology at mid-intervention and year-end. They used the TI-Navigator to collect data and help students understand math. Teachers reported being able to modify instructional strategies based upon real time data. They stated that student motivation has increased with the use of TI technology and that fewer behavioral problems must be referred to the office when the technology is used in the classroom. The number of teachers using the technology grew from six at mid-year to eight at year-end. Seven agreed that the use of technology has enhanced the district curriculum (up from six at mid-year).

When asked how the technology has changed classroom culture, teachers reported that anonymous submission of responses garners 100% participation, increased group participation and sharing of responses, and support in helping one another with the technology. Students were rarely tardy; they were more engaged and more was covered in class. Classroom management (screen capture) and immediate feedback (class analysis slide show) changed the culture.

How was teaching impacted by the technology? Teachers suggested that control shifts to the student, and that students' responsibility and confidence were boosted. Teachers reported better being able to manage time, focus on questioning skills and student discussion. More and higher level concepts were covered, more hands on activities and variety in activities were performed.

How was performance impacted by the technology? Teachers noted positive differences in focus at mid-year. "Students love to use the calculator, they get into a routine, so that keeps them focused on what is in front of them. The screen captures help as well." By year-end teachers reported that students spend more time working through a problem, were able to realize corrections more quickly and retain information. One commented, "their algebra readiness has increased with calculator experience." Another remarked, "they are learning more without even knowing it."

The 100 Minute Power Block

Reflections on the Power Block were positive and increasingly so as we move from mid-year to year-end. All the teachers agreed that the daily warm-up help students solve problems more effectively. At mid-year, however, there was less certainty that additional time made a real difference to student approaches to problem solving or to student self-esteem than at year end, where teachers showed strong agreement that the increased time had changed problem approach and esteem.

The open ended responses provided by four of the teachers at mid-year suggested positive results from the Power Block, namely new found success by students in math, more student effort and questions, fuller understanding, increased quality of work and more time for class discussion. One teacher reported considerable frustration in claiming that teaching 29 low level students was very difficult. “I don’t have any kids that have motivation.”

At year-end comments about the power block were only positive with one teacher stating, “the extra time has given students the opportunity to truly grasp the content and apply it.” Other comments addressed improvements in motivation and higher student expectations of themselves. Several teachers noted better performance and improved problem solving skills. “Their scores have gone way-up!” Teachers explained that students are more comfortable with class participation and thus more willing to attempt a problem. They suggested that because of the extra time, students will ask questions.

Project Support

The support that teachers list as most critical to this project included (in order of frequency mentioned) technology and technology training; Paula Moeller, her response to questions and ideas in the classroom; staff development including work with Jane Demaste, weekly planning meetings, activities and assessments, T3, the immediate help received and positive reinforcement.

What kinds of additional support would be helpful from TI?
(Suggestions at mid-year)

- Learning how to run block classes successfully
- Easy reading and explanations for first year teachers going through alternative certification.
- More training with the technology
- Manuals and lesson plans using TI-Navigator
- Instruction for using study cards including additional ways to use TI-Navigator.

What kinds of additional support would be helpful from TI?
(Suggestions at year-end)

- Opportunities to observe Navigator proficient teachers, not other adults
- Mock teaching of a block class, while teachers are students
- Easier access to curricular help, not just hardware. For example, uses for different applications and the easiest way to run them.
- More time in the classroom and team teaching
- Zero segregation within the department.

What kinds of additional support would be helpful from the district? (Suggestions at mid-year)

- Learning how to run block classes successfully
- Smaller class sizes
- Rearranging block classes so there are some high achievers, not all at risk students*

- Stricter administrative discipline*
- Prewritten lesson plans for new teachers
- Curriculum that matches the benchmarks more closely
- More ways to use manipulatives
- Navigator support within curriculum

(* Comments made by more than one teacher)

What kinds of additional support would be helpful from the district? (Suggestions at year-end)
- A curriculum that is better aligned with TEKS
- Understanding exactly what teachers are doing and that they are being successful
- Providing ideas, questions and explanations about how to teach with the curriculum planner

What kinds of additional support would be helpful from your principal and vice principal? (Suggestions at mid-year and year-end)
- More disciplinary support*
- Smaller blocks
- Mixing up the classes*
- Empathy for the teacher who is doing considerable extra work

(* Comments made by 4 or more teachers)

At mid-year, teachers commented that the class should seem more like a privilege, that the project is hard to implement with discipline problems where students cannot be sent to the office. A teacher asked that students be held accountable. The teacher remarked, “it seems like most kids are low achieving, have no aspiration or basic math skills… They have no idea what they are doing.” Another reported that her students have “no one to look up to or strive to be”. Many are repeating 8th graders, all failed TAKS and are low achievers. “I feel like these kids were set up to fail. The block classes were too large from the start. Also, kids should not be added to the class mid-year because their growth cannot be measured well.

At year-end, negative comments were about discipline and to a lesser degree about mixing up the blocks, as well as lack of administrative support and appreciation. Many teachers addressed the lack of disciplinary support and administrator appreciation.

Final Comments

Several of the teachers spoke of their gratitude for being able to learn from the TI employees, who are “so knowledgeable”. Another remarked, “I really enjoyed being part of the program and even though frustrated at times, I was able to work through it because I had tons of TI support.” Several spoke of enjoying the program. One remarked, “I love it! Love it! Love it! It is such a disservice to the rest of the classes that won’t have the experience of the TI project and all its power. Hopefully, this will grow into the high schools in the very near future.”

Another teacher reported feeling alienated, and one had difficulty connecting the high-level math content sessions to the curriculum. One reported that the equipment (the dongles and knobs) do not work all the time, which was very frustrating. Finally, a teacher reminded the researchers, “the project needs to be in the hands of a capable teacher who is willing to learn and change their style of teaching. There are so many components to the intervention” that a capable worker is required.

Other potential issues that we need to address:

1. Is the interventions success due to factors besides the technology? This has two aspects, and as we move on to a larger number of schools we will be able to see if we can rule out other explanations. At this point however, the positive effects we are seeing may be due to simply moving to the double-block (100 minute) schedule, or they may be due to having Paula Moeller on-site and her additional efforts pushed this through. Subsequent evaluation should be able to tease apart the factors and give us firmer ideas on what it contributing to the improvement, but until we have more sites and an ability to isolate potential contributing factors, we will not be able to definitively state that the technology intervention has a main effect here.
2. Related to this, we will need to be sure that each site has someone that plays Paula’s role as an evangelist of sorts, acting as a central coordinator and making sure that what Paula has done gets transferred to each new site. As we expand to more schools, Paula will not be able to be everywhere at once, but with the right amount and type of training she should be able to train successors. For next year, this is something that we will have to build into the planning process, to make sure that the district has a point person assigned to each new school, and that there is always a district level person who can provide assistance and funnel help and planning assistance from TI to the schools.
3. What is the best way to get teacher buy-in? The teachers at Lake Highlands now all seem to be behind the intervention, and we want to get this same amount of positive regard at the new campuses. We will need to be sure that there are enough chances for teachers to visit and experience the program, and that there is full acceptance during the summer months. The Lake Highlands principals suggested that we let their teachers communicate with other teachers about the program, schedule the observations time while students are working with the technology (and let students show the potential teacher recruits how things work so they get the students’ point of view), and plan at least one event that might get the “buzz” started regarding this program more widely through the district.
4. As the project is expanded to other campuses, it will be important to remember that teacher expectations of themselves and their students are much lower at some campuses than Lake Highlands. Prior exposure, demonstration and support will be especially important.
5. While TI made excellent progress in adjusting the math content session mid-year, some teachers continue to ask that the sessions be tied more closely to the curriculum.

Appendix A: Year-End Teacher Survey

Identifying Components of Effective Mathematics Programs in RISD

Consent Form

The Richardson Independent School District and Texas Instruments Inc. has asked us to conduct a research study to extend previous work identifying components of successful mathematics programs while also helping the schools to better design the way mathematics is taught and technology utilized. We hope that through your participation, we will be able to provide valuable information to your district, identify ways that the district can better assist schools and teachers, and discover how schools can be more effective. Over the next few weeks, teachers, principals, mathematics specialists, and district personnel will all be asked to complete surveys that assess the characteristics of RISD schools and programs that relate to successful mathematics education nationally.

Participation requires the following:

• Completion of a survey on math practice and policy by all fourth and fifth grade teachers, middle school math teachers, all elementary and middle school principals, and district specialists in mathematics.

• Completion of a survey on mathematical knowledge by all teachers involved in math education for grades 4-8 at the campuses.

At the end of the study, a report will be sent to the district office and information will be sent to the schools' principals and mathematics specialists for dissemination.

The procedures here involve no or minimal risk to the participants. Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission or as required by law. Some tracking identification tied to assessments of mathematics knowledge and practices will be kept by the researchers to allow for future program evaluation. After deciding to participate, you are free to withdraw your consent and discontinue participation at any time without penalty. If you have any questions regarding the research, please feel free to Mara Winick (mara_winick@redlands.edu) or Jeffrey Lewis (jeff_lewis@pitzer.edu or 909-792-5594).

Your signature indicates that you have read and understand the information provided above, that you willingly agree to participate, that you may withdraw your consent at any time and discontinue participation without penalty, that you will receive a copy of this form, and that you are not waiving any legal claims, rights or remedies.

Name ____

Signature _____________________________________ Date _________________

Teacher & Student Practices for Learning Math at RISD

1. Please respond to the following statements about teaching success by circling your level of agreement or disagreement.	**Strongly Disagree**	**Disagree**	**Uncertain**	**Agree**	**Strongly Agree**
a) I can successfully teach grade level math to 90% or more of my students.	SD	D	U	A	SA
b) I know which strategies work best for teaching math for English Language Learners.	SD	D	U	A	SA
c) I know which strategies work best for teaching African American students who are falling behind.	SD	D	U	A	SA
d) I am confident that 90% or more of my students can learn grade level math.	SD	D	U	A	SA
e) I have the instructional support necessary to be successful teaching all students math.	SD	D	U	A	SA
f) I receive instructional support in time to deliver math content successfully.	SD	D	U	A	SA
g) The instructional support I receive is based upon benchmark data.	SD	D	U	A	SA
h) It would be accurate to say that I inspire my students.	SD	D	U	A	SA
i) It is accurate to say that I establish a significant relationship with students who are having difficulty learning math.	SD	D	U	A	SA
j) I feel valued by the administration at this school.	SD	D	U	A	SA
k) My expectations for student performance have increased since receiving additional training this past summer and Fall.	SD	D	U	A	SA

l) Please comment on how the TI intervention model has assisted you in teaching mathematics to all students in class.

m) Which components of the TI intervention, if any, have helped raise your level of confidence in teaching all students?

2. Please respond to the statements below concerning teacher content knowledge and support, by circling your level of agreement or disagreement.	**Strongly Disagree**	**Disagree**	**Uncertain**	**Agree**	**Strongly Agree**
a) Our teachers meet weekly to plan lessons and discuss teaching strategies for meeting the needs of all learners.	SD	D	U	A	SA
b) Content sessions with the mathematician have increased my mathematical understanding.	SD	D	U	A	SA
c) Content sessions with the mathematician have helped me teach more effectively.	SD	D	U	A	SA
d) Weekly meetings are used to align the district curriculum with the TEKS.	SD	D	U	A	SA
e) Our teachers meet weekly to design grouping strategies for struggling students.	SD	D	U	A	SA
f) Regular and tutoring (CATS) teachers plan content together.	SD	D	U	A	SA

g) How, if at all, have the math content sessions changed what you know about math?

h) How have the math content sessions changed the way you teach math?

i) What other content, if any, would you like included in the weekly planning meetings?

3. Please respond to the following statements about assessment by circling your level of agreement or disagreement	**Strongly Disagree**	**Disagree**	**Uncertain**	**Agree**	**Strongly Agree**
a) Our unit benchmarks for assessing student growth are aligned to the district curriculum and the TEKS.	SD	D	U	A	SA
b) Our unit diagnostics are aligned to the district curriculum and the TEKS.	SD	D	U	A	SA
c) Our unit diagnostics help me tailor instruction to meet student needs.	SD	D	U	A	SA
d) Students in my class know the learning goals for each unit of study.	SD	D	U	A	SA
e) My students' parents know what is expected of their child during the school year.	SD	D	U	A	SA
f) The increased number of benchmarks has helped me improve instruction.	SD	D	U	A	SA
g) The more immediate availability of benchmark data has helped me improve instruction.	SD	D	U	A	SA
h) I feel confident my students will do well on the district TEKS checks assessments.	SD	D	U	A	SA
i) I feel confident that my students will master grade level content, measured by the TAKS, by the end of the school year.	SD	D	U	A	SA
j) Students in this school are held accountable for mathematics instruction.	SD	D	U	A	SA

k) Please explain how the use of unit diagnostic data has changed your teaching.

l) How does the diagnostic data enable you to tailor instruction to better meet student needs, if at all?

m) Please explain how the more immediate availability of benchmark data has changed your teaching, if at all.

4. Please respond to the statements below concerning parent involvement by circling your level of agreement or disagreement	**Strongly Disagree**	**Disagree**	**Uncertain**	**Agree**	**Strongly Agree**
a) I frequently communicate learning expectations to parents.	SD	D	U	A	SA
b) My students' parents understand the importance of learning math.	SD	D	U	A	SA
c) My students' parents feel welcome at this school.	SD	D	U	A	SA
d) Please share comments made by parents regarding the TI intervention model.					

5. Please respond to the below about use of technology in teaching by circling your level of agreement or disagreement	**Strongly Disagree**	**Disagree**	**Uncertain**	**Agree**	**Strongly Agree**
a) I use the TI Navigator to collect student data.	SD	D	U	A	SA
b) I use the TI-73 graphing calculator to help students understand mathematics content.	SD	D	U	A	SA
c) I am able to modify instructional strategies for individual students based on real time data collected through the TI Navigator.	SD	D	U	A	SA
d) I have found that student motivation has increased with the use of the TI technology.	SD	D	U	A	SA
e) I have found that fewer students are sent to the office for to behavioral problems when I use technology in my classroom.	SD	D	U	A	SA
f) It is clear to me that the use of technology has enhanced our district curriculum.	SD	D	U	A	SA
g) Please explain how the use of technology has changed your classroom culture or learning environment.					
h) How has the use of technology changed your teaching, if at all? Please explain.					

i) How has the use of technology changed student performance, if at all? Please explain.

6. Please respond to the statements below about the 100 minute power block for teaching math.	**Strongly Disagree**	**Disagree**	**Uncertain**	**Agree**	**Strongly Agree**
a) The daily warm-up is helping students solve problems more effectively.	SD	D	U	A	SA
b) The additional time spent on problem solving has made a real difference in how students approach solutions to difficult problems.	SD	D	U	A	SA
c) Additional class time has increased my students' self esteem in mathematics.	SD	D	U	A	SA

d) Please comment on any changes you have noticed in student performance as a result of the 100 minute power block.

7. What types of support from this project have been most critical to increasing student performance in your classrooms?

8. What kinds of additional support from TI would make a difference to your success in teaching math?

9. What kinds of additional support from the district would make a difference to your success in teaching math?

10. What additional administrative support from your principal and vice principals is needed to help you implement the goals of the TI project?

11. Do the administrators on your campus understand the amount of time that is required to plan and execute the goals of the TI project? Please explain.

12. Do you have particular concerns about the project that the researchers would benefit from knowing? Has participation brought moments of joy, frustration? Please comment.
13. Finally, is there any other information that you would like to share with the researchers about the TI project?

Thank you for taking the time to help math educators learn from one another.

Appendix B: Survey Response Detail for closed-end questions (Lake Highlands only)

1. Please respond to the following statements about teaching success by circling your level of agreement or disagreement.

		Strongly Disagree Percent	Disagree Percent	Uncertain Percent	Agree Percent	Strongly Agree Percent	Total Count
Lake Highlands	I can successfully teach grade level math to 90% or more of my students.				50%	50%	8
	I know which strategies work best for teaching math for English Language Learners.		13%	25%	63%		8
	I know which strategies work best for teaching African American students who are falling behind.			38%	38%	25%	8
	I am confident that 90% or more of my students can learn grade level math.		14%		43%	43%	7
	I have the instructional support necessary to be successful teaching all students math.		13%		63%	25%	8
	I receive instructional support in time to deliver math content successfully.		38%		38%	25%	8
	The instructional support I receive is based upon benchmark data.		13%	38%	38%	13%	8
	It would be accurate to say that I inspire my students.			13%	63%	25%	8
	It is accurate to say that I establish a significant relationship with students who are having difficulty learning math.			13%	25%	63%	8
	I feel valued by the administration at this school.	38%	13%		38%	13%	8
	My expectations for student performance have increased since receiving additional training this pas summer and Fall.			25%	63%	13%	8

2. Please respond to the statements below concerning teacher content knowledge and support, by circling your level of agreement or disagreement.

		Strongly Disagree Percent	Disagree Percent	Uncertain Percent	Agree Percent	Strongly Agree Percent	Total Count
Lake Highlands	Our teachers meet weekly to plan lessons and discuss teaching strategies for meeting the needs of all learners.	13%	25%	25%	38%		8
	Content sessions with the mathematician have increased my mathematical understanding.		13%	13%	75%		8
	Content sessions with the mathematician have helped me teach more effectively.		25%	13%	63%		8
	Weekly meetings are used to align the district curriculum with the TEKS.	13%	38%	25%	25%		8
	Our teachers meet weekly to design grouping strategies for struggling students.	13%	63%	13%	13%		8
	Regular and tutoring (CATS) teachers plan content together.	38%	38%	13%	13%		8

3. Please respond to the following statements about assessment by circling your level of agreement or disagreement.

		Disagree Percent	Uncertain Percent	Agree Percent	Strongly Agree Percent	Total Count
Lake Highlands	Our unit benchmarks for assessing student growth are aligned to the district curriculum and the TEKS.	29%		71%		7
	Our unit diagnostics are aligned to the district curriculum and the TEKS.	29%	14%	57%		7
	Our unit diagnostics help me tailor instruction to meet student needs.		29%	57%	14%	7
	Students in my class know the learning goals for each unit of study.	13%		63%	25%	8
	My students' parents know what is expected of their child during the school year.		13%	25%	63%	8
	The increased number of benchmarks has helped me improve instruction.		29%	57%	14%	7
	The more immediate availability of benchmark data has helped me improve instruction.			86%	14%	7
	I feel confident my students will do well on the district TEKS checks assessments.	13%	13%	63%	13%	8
	I feel confident that my students will master grade level content, measured by the TAKS, by the end of the school year.		25%	50%	25%	8
	Students in this school are held accountable for mathematics instruction.	38%		25%	38%	8

4. Please respond to the statements below concerning parent involvement by circling your level of agreement or disagreement.

		Disagree Percent	Uncertain Percent	Agree Percent	Strongly Agree Percent	Total Count
Lake Highlands	I frequently communicate learning expectations to parents.		13%	50%	38%	8
	My students' parents understand the importance of learning math.	13%	13%	13%	63%	8
	My students' parents feel welcome at this school.		25%	38%	38%	8

5. Please respond to the below about use of technology in teaching by circling your level of agreement or disagreement.

		Strongly Disagree Percent	Disagree Percent	Uncertain Percent	Agree Percent	Strongly Agree Percent	Total Count
Lake Highlands	I use the TI Navigator to collect student data.				38%	63%	8
	I use the TI-73 graphing calculator to help students understand mathematics content.				43%	57%	7
	I am able to modify instructional strategies for individual students based on real time data collected through the TI Navigator.				38%	63%	8
	I have found that student motivation has increased with the use of the TI technology.				38%	63%	8
	I have found that fewer students are sent to the office for to behavioral problems when I use technology in my classroom.		25%		13%	63%	8
	It is clear to me that the use of technology has enhanced our district curriculum.		13%		50%	38%	8

6. Please respond to the statements below about the 100 minute power block for teaching math.

		Strongly Disagree Percent	Uncertain Percent	Agree Percent	Strongly Agree Percent	Total Count
Lake Highlands	The daily warm-up is helping students solve problems more effectively.			43%	57%	7
	The additional time spent on problem solving has made a real difference in how students approach solutions to difficult problems.			50%	50%	8
	Additional class time has increased my students' self esteem in mathematics.		14%	29%	57%	7

Texas Instrument Project
Regular Math Class Student's Math TAKS Results
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Introduction

One Texas school district has implemented a novel program to improve mathematical skills for some 7th and 8th graders. With the help of new technology and innovative assessments students are able to communicate their mathematical thinking and then receive immediate feedback regarding their mathematical knowledge.

Earlier pilot results indicate several components of the intervention are crucial to the success of the intervention. These key components include: extended learning time, use of technology to motivate and enhance learning opportunities, provision of common, aligned assessments, increased teacher content knowledge, and development of high expectations for all students.

Students participate in a 100-minute mathematics class that focuses on enhancing mathematical understanding through the use of graphing technology, in-classroom networks and daily problem solving. Students participate in daily lessons where they must communicate solutions, apply content, and connect mathematical models to abstract concepts.

This analysis is follow up to the previous preliminary examination of math Texas Assessment of Knowledge and Skills TAKS scores. The analyses reported changes in math TAKS (Texas Assessment of Knowledge and Skills) percent items correct in study students receiving the intervention from the academic school year 2004-05 to academic school year 2005-06. This follow up report presents a re-analysis of student scores through OLS regression (as before), but this time using the math Normal Curve Equivalent (NCE) TAKS scores. This was performed because, the TAKS test is not a vertically scaled assessment, therefore scaled scores were transformed into NCE scores to more accurately compare TAKS tests across years.

Current analyses includes the use of descriptive and OLS regression techniques. In this preliminary analysis the outcome variable examined is Math TAKS NCE. Future analyses will include examinations of district Benchmark assessments will be analyzed and compared with TAKS performance. Future analyses will also include the use of descriptive, OLS regression, and *regression discontinuity* techniques of investigation.

Methodology

Data provided by the district includes indicators for student ethnicity and whether student is classified as economically disadvantaged. There were no other indicators such as classification as Limited English Proficient (LEP) or participation in Gifted and Talented classes. Students included in the analyses were required to have both a 2005 and 2006 math TAKS score (so change could be assessed). This means that highly mobile students tend to be excluded from the analysis. Students were both 7th and 8th graders in the 2005-06 school year in regular math classes.

Normal Curve Equivalent scores (NCE) were used to compare TAKS tests across years. NCEs are represented on a scale of 1 – 99. The NCE scale corresponds with a percentile rank scale at 1, 50, and 99. Unlike percentile rank scores, the interval between scores is equal. This allows researchers to manipulate the test data algebraically, e.g., comparing across tests across years and subjects.

In these analyses, a value-added Ordinary Least Squares (OLS) regression models were constructed by using each student's previous-year TAKS score or Benchmark score as a proxy for each student's academic level. Using a previous score allowed for a value-added analysis from a baseline test (TAKS) to the following assessment.

A total of four groups of students were compared across analyses. The *study group* received the TI implemented intervention in three 7th grade classrooms and four 8th grade classrooms. Among the intervention group, 79 students had both a 2005 and 2006 math TAKS score. The study students were placed in the classrooms receiving the intervention based on their 2005 math TAKS score. All the students in the study group had a *below* passing score on the math TAKS. Due to the high district mobility rates, many students receiving the intervention (as well as comparison students) were not included in the study because a prior TAKS score was not available.

A second group was located at the same campus. These students were not selected for treatment based on their TAKS scores, these students were the *control group*. A third group, called *comparison students*, was created from another school in the same district with similar demographics (recommended by project director). The comparison student group included 234 7th and 8th graders enrolled in regular math classes (students in Pre-AP math courses were excluded). The final comparison group was all *other 7th and 8th grade students* (N = 1876) in the district that were enrolled in regular math classes (students in Pre-AP math courses were excluded) and had a 2005 and 2006 math TAKS score.

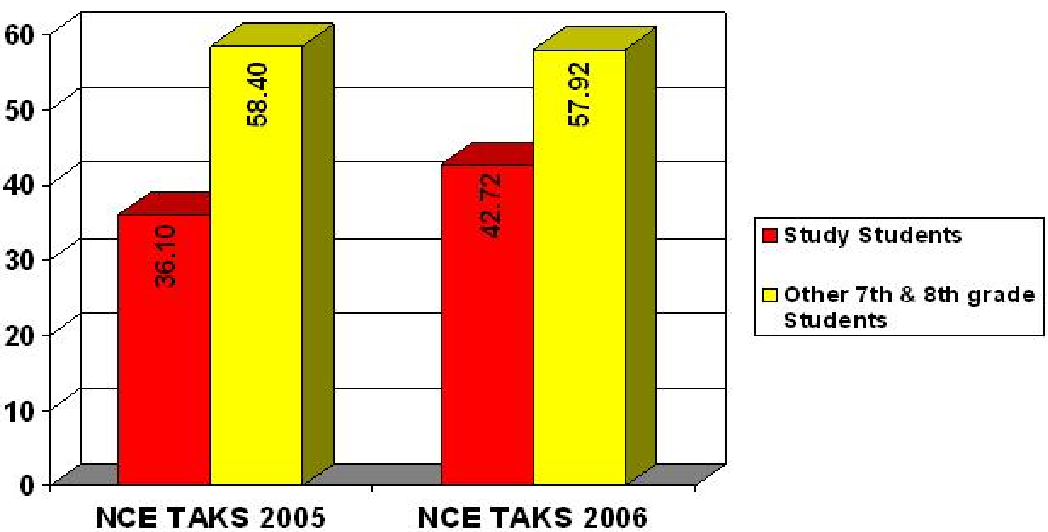
Table 1: Comparison of *study group* students, *control group* students, *comparison students*, and *other 7th and 8th grade students* in the district.

Percents	% Econ. Disad	% White	% African American	% Hispanic	% Other	% Below Pass 2005	% Below Pass 2006	TAKS 2005 NCE	TAKS 2006 NCE
Study Students[1] N=79	47.2	35.9	40.1	22.9	1.0	100	67.1	36.10	42.72
Control Students at Study Campus[1,2] N=102	46.8	25.5	49.0	23.5	2.0	0	35.3	62.06	58.58
Comparison Students[1] N=234	59.3	23.9	50.4	21.0	4.7	41.9	53.0	49.36	47.83
Other District Students[1]N=2119	53.0	31.0	28.4	34.0	6.6	28.2	29.2	58.40	57.92

[1] Students in Regular Math with a 2005 *and* 2006 math TAKS score
[2] Control Students all scored *above* passing (2100)

The most striking change noted in Table 1 is the increase NCE mean score of the study students' math TAKS scores from 36.10 in 2005 to 42.72 in 2006. This is particularly noteworthy due to the fact that all three comparison groups had NCE scores decreased from 2005 to 2006. The NCE scores for 2005 and 2006 are illustrated in the bar graph in Figure 1 for each of the four groups of students that were compared across analyses.

Figure 1: NCE scores of Math TAKS for Regular Math Students



The bars help illustrate that the study student's TAKS NCE score increased from the TAKS 2005 to TAKS 2006 more than the other regular math students in the district.

Statistical results

The statistical technique of multiple regression was used to analyze the data. The indicator variables that were used to help control for the types of students taking the exam were if a student was a minority or is a student was classified as economically disadvantaged. For this analysis, the most important variable to examine was the study student variable. Three models were created using the different groups as comparisons.

All assumptions for model validity of regression were examined. The Durban-Watson statistic was used to measure the correlation among the errors to test the independence assumption. A value less than about 1.4 or greater than about 2.6 indicates a possible violation of the independence assumption. A formal test of the assumption of equal variance was made that indicated that the outputs from the final model outputs did not present a statistically significant departure from equal variance.

The two models presented examined TAKS growth from the 2005 to 2006 administration. Due to the low numbers (particularly for the study students) the 7^{th} and 8^{th} grade students were combined to form one group.

The dependent variable is the 2006 math TAKS NCE for each student. A previous 2005 math TAKS NCE score for each student is included as an independent variable. This is included as a *proxy* for previous learning and allows for a value-added analysis from a baseline year to assess growth (change) in student scores. In general student test scores of economically disadvantaged and minority students tend to be significantly less than those of non-economically disadvantaged and non-minority students. The variables used as controls for economically disadvantaged and minority status are applied to help take into account the effect these individual characteristics tend to have on test scores.

The major findings for Model 1 (Table 2), indicate that study students, on average, tend to have a significantly higher growth in percent items correct than the comparison students F(295, 4) = 82.25, p< .001, R^2 = .53. These results include controlling for economically disadvantaged status and minority status (See Table 2). Study student's estimated NCE score tends to be 5 NCE points greater in gains than comparison students. Although, not statistically significant, minority students tend to have a lower math TAKS gain than non-minority comparison students.

Table 2: Regression Results-TAKS Math — study and comparison students (2005-06)

Variables[1]	Unstandardized coefficients		Standardized coefficients		
	B	Std. error	Beta	*t*	Sig.
TAKS 2005 NCE	0.734	0.042	0.758	17.363	0.000**
Students in study campus	5.022	1.720	0.127	2.919	0.004*
Minority	-2.094	2.562	-0.034	-0.817	0.414
Econ. disadvantaged	0.175	1.625	0.005	0.107	0.915

[1] Dependent variable: TAKS 2006 NCE
Note. R^2 = .532, Durbin-Watson = 2.024, Cohen's *d* effect size = -0.93, N = 295
*p<.05. **p<.001.

The major findings for Model 2 (see Table 3), indicate that study students, on average, tend to have a slightly higher growth (although not significant) in NCE than the other 7^{th} and 8^{th} grade students in regular math in the district while controlling for the comparison students F(2070, 4) = 612.425, p< .001, R^2 = .54. These results include controlling for economically disadvantage status and minority status (See Table 3). Study students' estimated NCE score increase tends to be almost 1 NCE point higher the other 7^{th} and 8^{th} grade students in the district, but is not significant. Minority students tended to have significantly less gains in math TAKS than the non-minority 7th and 8th grade district students.

Table 3: Regression Results-TAKS Math — study students compared to rest of 7th and 8th graders in the district (including comparison campus) (2005-06)

Variables[1]	Unstandardized coefficients		Standardized coefficients		
	B	Std. error	Beta	*t*	Sig.
TAKS 2004 NCE	0.674	0.016	0.685	43.155	0.000**
Students in study campus	0.971	1.764	0.008	0.550	0.582
Minority	-4.680	0.621	-0.133	-7.533	0.000**
Econ. disadvantaged	-0.389	0.594	-0.011	-0.654	0.513

[1] Dependent variable: TAKS 2006 NCE
Note. R^2 = .54, Durbin-Watson = 0.429, Cohen's *d* effect size = -0.89, N = 2070
*p<.05. **p<.001.

Summary

This report describes an analysis of an intervention with the goal of enhancing mathematical understanding through the use of graphing technology, in-classroom networks and daily problem solving. The intervention has been implemented in several 7th and 8th grade math classes in a Texas school district. This analysis examined changes in TAKS math scores of student receiving the intervention compared to students not receiving the intervention in the academic school year 2005-06.

These results indicate that being included in the study group tends to predict an increase in the math TAKS assessment. The first model indicated that the estimated math TAKS NCE score tends to be about 5 NCE points greater in gains than comparison students. However, in the second model, the study group change was not statistically significant, although the coefficient was positive, indicating that scores for the study students increased slightly compared to other 7th and 8th grade students in the district.

Extra Bar-Graph