Using Handheld Graphing Technology in Secondary Mathematics:
What Scientifically Based Research Has to Say

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Executive Summary

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TEXAS INSTRUMENTS

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As a leader in developing graphing handhelds, Texas Instruments has a keen interest in scientifically based research on the effects of using such graphing devices in classrooms.

This paper presents the results of the most credible, scientifically based research available related to the use of handheld graphing devices in secondary mathematics instruction. It also describes how products and services available from Texas Instruments match with instructional practices whose effectiveness has been demonstrated in scientifically based research.

Procedure

In 2002, Texas Instruments commissioned a survey of research on handheld graphing technology in secondary mathematics (Burrill, Allison, Breaux, Kastberg, Leatham, & Sanchez, 2002). From a field of over 180 research reports, the research team for this project identified 43 studies that met criteria related to publication, relevance, inclusion of evidence, rigor, and scientific design.

Working from this set of 43 studies, Texas Instruments commissioned a further review based on the criteria for scientifically based research as described in the No Child Left Behind Act. Researchers found six studies that focused on the effectiveness of an instructional program or method that included graphing handheld devices, used an experimental or quasi-experimental design, and were of sufficient quality for inclusion in this report. One of the studies focused on college-level calculus. The other five studies are described in this paper.

Summary of Selected Studies

All five of the studies reviewed in this paper focus on use of handheld graphing devices in advanced algebra instruction.

Research results from these studies fall into two main categories: general algebra performance, and understanding of functions. In both of these areas, use of handheld graphing devices was demonstrated to have positive impacts on student learning.

Results from each of the studies are summarized below.

Using Graphing Handhelds as an Integrated Part of an Algebra 2 Reform Curriculum

Thompson and Senk (2001) compared matched pairs of Algebra 2 classes within the same school. One class in each pair used an exploratory, problem-solving-based reform curriculum; the other class used a traditional curriculum. At one of the schools included in this study, only students in the two reform classes had access to graphing handhelds; the two corresponding comparison classes did not have access to graphing technology.[1]

At the end of the school year, the researchers administered a posttest focusing on core curriculum content. To correct for differences in content coverage within each pair of classes, only items identified by both teachers as reflecting the content they had covered were counted toward a “fair test” version of the posttest results. **Students in the two reform classes who used the graphing handhelds significantly outperformed students in their matched comparison classes who did not have access to graphing technology.**

Incorporating Graphing Handhelds into Existing Curriculum in a Precalculus-Level Course

Harskamp, Suhre, and Van Streun (2000) conducted research on secondary students in a precalculus-level course in Holland. The comparison group used the existing textbook without alteration. The first experimental group incorporated use of graphing handhelds with all four topics to explore functions. The second experimental group incorporated use of the handhelds for only one topic. For both experimental groups, textbook sections were altered to incorporate use of graphing devices.

[1] The other three schools reported in the study were not included in the white paper because students in the comparison classes had broad access to graphing handhelds.

Researchers found that **among students who scored low on a pretest of content covered during the previous year, members of the graphing technology-using groups scored significantly higher on a posttest of topics covered in the course**. This advantage was greater in classes where the graphing handhelds were used for an entire year. Students in the experimental groups also used many more graphical solution strategies involving plotting or drawing (based on an analysis of problems where they had to show their work), which contributed to improved performance for students in the first experimental group (Van Streun, Harskamp, and Suhre, 2000). Harskamp et al. (2000) also found that teachers in the experimental groups spent much more time using graphs and tables and conducting problem-solving activities than teachers in the comparison group.

Undirected Addition of Graphing Handhelds in Precalculus-Level Classes

Ruthven (1990) compared the performance of students in matched classes in an advanced-level, academic upper secondary (precalculus-level) course at four English secondary schools. Teachers in the experimental classes were provided with access to graphing handhelds for their students, while the comparison classes had no access to graphing technology. Teachers were given no guidance on how to use the handhelds and had no previous experience with them.

Near the end of the school year, students were tested on their comprehension of two types of problems related to algebraic functions: *symbolization* items, which require students to write the equation that matches a given graph; and *interpretation* items, which require students to extract information from and answer questions about a given graph. There was no significant difference in performance on the interpretation items. However, **students who used graphing handhelds achieved significantly higher results on items involving symbolization—more than a standard deviation**. Further analysis of both answers and reasoning reported by students showed that experimental group members did better at both *recognition* (correct identification of the type of function) and *refinement* (finding the precise equation for the graph).

Using Graphing Handhelds in an Investigation-Based Algebra 2-Level Course on Functions

Schwarz and Hershkowitz (1999) compared two different but related curricula, one incorporating use of handheld graphing technology, the other not, in a one-year grade nine course on functions in Israel. The curriculum using graphing calculators was also more exploratory, open-ended, and student-directed in focus. The research focused on three separate dimensions of function understanding: *prototypicality* (student use of key examples and models to understand functions), *part-whole reasoning* (correctly matching parts of a graph with other parts of the same graph), and *attribute understanding* (identifying graphs that match a given equation or vice versa, or that match a set of specific numerical values for the function).

On a functions test at the beginning of the next school year, researchers found that **students using the graphing technology performed significantly better on items related to prototypicality, leading to significantly better overall performance**. Analysis of students' justifications for their answers showed that these students included significantly more *idea units* (idea elements or parts) for items related to prototypicality and attribute understanding, and that the number of idea units correlated to correct answers in these areas. Qualitative analysis also showed more sophisticated use of prototypical examples by students who had used the graphing technology.

Integrating Graphing Handhelds into Intermediate College Algebra (Equivalent to High School Algebra 2 Level)

Hollar and Norwood (1999) compared performance of college students enrolled in two versions of an intermediate algebra course (roughly equivalent to high school Algebra 2), one incorporating handheld graphing technology, the other not.

At the end of the course, the researchers found no significant differences between the two groups on the standardized departmental final exam. However, **on a more specialized test designed to assess conceptual knowledge of functions, they found that students in the group using graphing technology performed significantly better on the test as a whole and on each of its four components**: modeling, interpreting, translating, and reifying (i.e., shifting from viewing functions as rules to seeing them as objects on which operations are performed).

Summary of Findings

Research cited in this paper shows that handheld graphing technology can have a positive impact on student learning in a range of settings and using a variety of instructional approaches. In particular, the research shows that use of graphing handhelds can have a positive impact both on general skill and understanding of algebra concepts and, more specifically, on student comprehension of functions.

Specific findings of the research cited here can be summarized as follows:

- Use of an Algebra 2 reform curriculum incorporating graphing handhelds can result in significant improvement in overall student performance. (Thompson & Senk, 2001)
- Incorporation of graphing handhelds as an integrated part of an existing precalculus-level curriculum can lead to higher achievement among low-performing students; increased student use of graphical solution strategies (a trait linked to improved performance); improved understanding of functions; and increased teacher time spent on presentation and explanation of graphs and tables, and on problem solving activities. (Harskamp, Suhre, & Van Streun, 2000; Van Streun, Harskamp, & Suhre, 2000)
- Student use of handheld graphing technology can improve students' skill in creating algebra descriptions of Cartesian graphs (symbolization), even when teachers are inexperienced in the use of graphing handhelds and there is no specified structure for integrating use of graphing handhelds into the curriculum. (Ruthven, 1990)
- An investigation-based approach utilizing graphing handhelds can improve student knowledge of functions by promoting appropriate use of prototype examples. Such an approach can also lead students to include significantly more ideas in their justifications of answers, a trait that correlates in turn to correct student responses. (Schwarz & Hershkowitz, 1999)
- Integrated use of graphing handhelds as part of a course covering standard Algebra 2 content can improve student understanding of functions without diminishing performance on computations performed without use of the handhelds. (Hollar & Norwood, 1999)

Since each of these findings is based on a single study, they should be taken as preliminary conclusions.

Research Findings and TI Products and Services

A variety of specific uses of handheld graphing technology were modeled in the studies described here, including creating graphs of functions from algebraic representations of the functions; manipulating graphs of functions by zooming and changing scales; using graphs to find solutions to equations; making tables from algebraic representations of functions, and using the handheld's features to explore the tables; and checking answers found algebraically. All of these represent features of graphing technology that are available with the Texas Instruments TI-8X handheld series, and in particular with the TI-83 Plus.

General implementation strategies modeled in these studies include use of written materials specifically prompting and/or modeling use of graphing technology; organization of students in small collaborative groups for problem solving; and ongoing interaction among teachers to share strategies for using graphing handhelds.

Specific identifiable instructional strategies modeled in the studies include estimation and checking of algebraic solutions using a graphing handheld; investigations in which students are prompted to make connections and discover patterns related to functions and their various representations; introduction of new types of functions through modeling with graphing handhelds; investigations in which students explore the effects of transforming algebraic representations of functions; and exploration of a representative variety of functions in problem contexts that highlight key aspects of functions.

These general implementation strategies and more specific instructional strategies for using graphing handhelds are supported in the Texas Instruments T^3 professional development offerings for Algebra 1, Algebra 2, Connecting Math and Physics, and PreCalculus.

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