Identifying Evidence-Based, Promising and Emerging Practices That Use Screen-Based and Calculator Technology to Teach Mathematics in Grades K-12: A Research Synthesis

Fiona K. Innes Helsel, Ph.D., John H. Hitchcock. Ph.D., Grant Miller, M. A.,
Andrew Malinow, Ph.D., Elizabeth Murray, Sc.D.
Center for Implementing Technology in Education (CITEd)

AERA 2006 Meeting
San Francisco

CITEd Center for Implementing Technology in Education
www.citeducation.org

American Institutes for Research®

Identifying Evidence-Based, Promising and Emerging Practices That Use Screen-Based and Calculator Technology to Teach Mathematics in Grades K-12:
A Research Synthesis

A paper prepared for the annual meeting of the American Educational Research Association, San Francisco, California, April 7–11, 2006

Fiona K. Innes Helsel, Ph.D., John H. Hitchcock. Ph.D., Grant Miller, M. A., Andrew Malinow, Ph.D., Elizabeth Murray, Sc.D.
Center for Implementing Technology in Education (CITEd)

Author Notes

The Center for Implementing Technology in Education (CITEd) is funded by the United States Department of Education, Office of Special Education Programs; Contract Number: H327M040004. Fiona K. Innes Helsel, American Institutes for Research; John H. Hitchcock, American Institutes for Research; Grant Miller, Center for Applied Special Technology; Andrew Malinow, formerly of the Center for Applied Special Technology; Elizabeth Murray, Center for Applied Special Technology.

Correspondence concerning this paper should be addressed to John Hitchcock, American Institutes for Research, 1000 Thomas Jefferson Street, NW, Washington, DC 20007-3835. Electronic mail may be sent to jhitchcock@air.org.

Contents

Identifying Evidence-Based, Promising and Emerging Practices That Use Screen-Based and Calculator Technology to Teach Mathematics in Grades K-12: A Research Synthesis 1
  Abstract 1
  Introduction 2
  Purpose 3
  General Approach 3
    Initial Content Areas 3
    Framework 4
    Literature Search 4
    Coding Tools and Synthesis Scheme 5
    Document and Disseminate Findings 6
  Conclusions and Discussion 10
  General References 13
  References for K-8 Screen-Based Technologies 16
  References for K-12 Calculator Technologies 20

List of Figures

Figure 1. CITEd Synthesis Scheme 31

List of Tables

Table 1. Defining Educational Technology Practices 25
Table 2. Continuum of Definitions: Emerging, Promising, and Evidence-based Practices 26
Table 3. Search Terms for K-8 Screen-based Technology 27
Table 4. Search Terms for K-12 Calculator Technology 28
Table 5 Evidence Evaluation Captured for Each Study 29
Table 6. Screen-based ETPs and Representative Examples 30
Table 7. Summary of Evidence for Screen-based Technologies by Educational Technology Practice, Mathematics Topic, and Grade Band 32
Table 8. Summary of Evidence for Calculator Use by Calculator Type, Mathematics Topic, and Grade Band 36

List of Exhibits

Exhibit 1. Sample Product for Practitioners 37

Identifying Evidence-Based, Promising and Emerging Practices That Use Screen-Based and Calculator Technology to Teach Mathematics in Grades K-12: A Research Synthesis

Abstract

Technology is becoming increasingly prevalent in mathematics education; however, it is unclear what effects it has on students, particularly those with learning disabilities. The purpose of this paper is to report on research synthesis work conducted by the Center for Implementing Technology in Education (CITEd), an initiative of the Office of Special Education Programs of the U.S. Department of Education. CITEd staff identified, reviewed, and summarized available evidence about educational technology practices (ETPs) for students with diverse learning needs. The synthesis focuses on mathematics instruction in grades K-8 that used screen-based technology and grades K-12 for calculators. To develop the synthesis, CITEd staff designed a framework, coding tools, and synthesis scheme; conducted a literature search; coded studies that met review parameters; summarized practices as evidence-based, promising, or emerging depending on the evidence available to support their use; and, determined how the practices reviewed related to the National Council of Teachers of Mathematics (NCTM) content standards. Sixty-one studies were coded for K-8 screen-based technologies and eight ETPs were identified across three NCTM grade bands (i.e., K-2, 3-5, 6-8). Only two of the ETPs were determined to be evidence-based[1]: computer-assisted instruction with tutoring/cooperative learning in grades 3-5 and computer-assisted instruction with screen-based manipulatives in grades 6-8. Sixty-five studies were coded for K-12 calculator technologies and four calculator types were identified across the four NCTM grade bands. One ETP was identified as evidence-based: the use of graphing calculators in grades 6-8. CITEd's synthesis work in the areas of K-8 screen-based technologies and K-12 calculators indicates that there are relatively few studies that reflect evidence-based practices and that relatively few research studies exist to test the effects of any particular ETP. Synthesis findings are discussed in terms of needed research for ETPs.

---

[1] CITEd uses the term "evidence-based" to mean proven effective (i.e., demonstrating that an intervention works), which may differ from a more mainstream definition of evidence-based (i.e., basic research is used to construct an intervention that should but does not always have an impact). The terminology itself is also emerging so the reader should note that our definition may differ from that of others.

Introduction

The use of technology in education is becoming more prevalent; however, it is unclear what effects it has on students, particularly those with learning disabilities. Furthermore, across the education community it is not widely known which technology-based educational practices are supported by research (U.S. Department of Education, National Center for Education Statistics [NCES], 2002). Although progress has been made toward integrating students with disabilities into the general education curriculum, these students continue to be at high risk for academic failure and underperformance in general (Blackorby, Wagner, Cameto, Davies, Levine, Newman, Marder, & Sumi, 2004; Frieden, 2004) and in math in particular (Allsopp, Lovin, Green, & Savage-Davis, 2003; Woodward & Montague, 2002). In the most recent National Assessment for Educational Progress (NAEP), 43% of 4th grade students with disabilities scored below basic level in math. By the time students have completed 8th grade, this number increases to 68% (NCES, 2005). Given the fundamental importance of math to students' success and livelihood inside and outside of school, such achievement gaps have serious consequences. A number of educators suggest that mathematics instruction can be enhanced by incorporating technology into pedagogy (e.g., Clements, 2000; Hall, 2000; Ruthven & Hennessy, 2002), and although there are a number of publications that synthesize technology use in education (e.g., Burrill, Allison, Breaux, Kastberg, Leatham, & Sanchez, 2002; Ellington, 2003; The McKenzie Group, 2002), it appears that little effort has been made to examine the quality of the research evidence available for any given ETP. To better understand how technology can be used to enhance teaching practices and impact mathematics instruction, it is helpful to identify and synthesize research that addresses the effectiveness of ETPs and to determine how those practices are related to the NCTM content standards.

Another pressing need identified by NCTM is the issue of linking research to practice and practice to research (NCTM Research Committee: Heid, Middleton, Larson, Gutstein, Fey, King, Strutchens, & Tunis, 2006). Researchers need to learn from practitioners and accessible research syntheses need to be developed to "inform instructional leaders and policymakers about research perspectives on critical issues of practice" (p. 76) and to help teachers respond to the pressure to "change practice based on research" (p. 83).

To address these concerns, CITEd supports state and local education agencies with developing systems that effectively integrate instructional technology so that all students achieve high educational standards. CITEd provides this support through professional development, technical assistance, promoting communities of practice, and offering web-based resources (see: http://www.citeducation.org). Another service is disseminating information about technology-based teaching practices to the education community. A first step toward providing this service is to identify technology-based teaching approaches that have been subject to empirical investigation (or at least described in the literature), summarize this information in the form of a research synthesis, and distribute information to practitioners. The purpose of this paper is to report on a research synthesis that covers screen- and calculator-based technologies developed to help teachers of mathematics in K-12 settings.[2]

Research syntheses on these topics are not novel ideas. In terms of previous synthesis work on screen-based technology, a 1997 review of the educational technology literature (excluding calculators) was conducted by Woodward and Reith and that work contextualized some of the findings described below. Despite the existence of previous work in this area, we recognized the need for a newer synthesis, due in part to the quickly changing nature of educational technology.

---

[2] A review of screen-based technologies in grades 9-12 is not ready as of this writing.

Indeed, popular hardware and software quickly become obsolete as the ability to develop more innovative technologies continues to evolve. This review updates the earlier review.

In terms of previous synthesis work on calculators, Ellington (2003) conducted a meta-analysis of 54 studies published between 1983 and 2002. Additional meta-analyses on the topic have also been published by Hembree and Dessart (1986; 1992). Ellington's work is up to date and CITEd did not repeat that effort. What is missing, however, is descriptive information about the lesson plans that can demonstrate to a teacher how to replicate the effects; that is, specific information on how to best integrate calculators into instruction. This review provides more context to the earlier review.

Purpose

In sum, this paper endeavors two distinct but interrelated directions:

1. A synthesis of K-8 screen-based technology. Synthesis work on the broad field of educational screen-based technology is nearly a decade old as of this writing. Meanwhile, the types of technology covered by Woodward and Reith (1997) have evolved, at least compared to calculators. This portion of the synthesis involves a review of the screen-based literature to identify ETPs that are evidence-based, promising, or emerging and relate these practices to the NCTM content standards.
2. A synthesis of K-12 calculator-based technology. As stated above, the information on calculators and their effects in educational settings has been documented via a recent meta-analysis, but there was limited descriptive information available to teachers that might show them how best to implement calculators in lessons. Our general strategy for this work was to identify new empirical studies that might update the findings of the meta-analysis; to identify calculator practices that are evidence-based, promising, and emerging; and to identify descriptive articles that exemplify the identified practices, again capturing these practices according to the NCTM content standards.

General Approach

Our general approach to the synthesis work included:

1. Identification of initial content areas
2. Development of a framework and literature search guide that included parameters for the review, key words, and search strategies
3. Development of a set of coding tools to screen and evaluate the research and a synthesis scheme to evaluate the level of evidence for the ETPs
4. Documentation of findings in practitioner-friendly language and dissemination of resulting products to key consumers (e.g., teachers). Related objectives are to encourage educators to apply technology by giving them concrete examples of how to use it
5. Learn about the status of research in educational technology and identify areas in need of further investigation.

Initial Content Areas

CITEd chose to focus on K-12 mathematics because students with disabilities have underachieved in mathematics (as demonstrated by the NAEP results reported earlier in this paper). This is problematic because mathematics achievement is predictive of later success. In addition, focusing on mathematics aligns well with work that other centers are conducting (e.g., K-8 Access Center and National Center for Technology Innovation). Given the disparities between the literature on calculators and that of broader types of educational technology, this review is divided into two sections—K-8 screen-based mathematics and K-12 calculator research[3].

Framework

During the initial stages of the project, CITEd developed a framework that outlined the overall approach, definitions, parameters for the literature review, and literature search processes. One of the initial steps was to define technology, which is easier said than done. A broad definition of technology is "the application of scientific knowledge, or the methods and materials of applied science" (Webster's Dictionary, 1996, p. 691). It is reasonable to consider some resources that are ubiquitous in U.S. schools, such as chalkboards or textbooks, as forms of technology. We remained interested in technologies that might be thought of as novel and likely to transform pedagogical approaches. This work therefore focused on screen-based (i.e., computer-based) instructional technologies and calculators. Given that CITEd's mission is to inform pedagogical approaches, we focused on what we thought of as *educational technology practices* (ETPs; see Table 1). The most important information to glean from this table is that the review did not focus on technology or educational practices isolated from each other, but rather an interface between the two where the combination is generative (technology transforming practice and practice transforming technology). Finally, CITEd focused on instructional technology (as opposed to assistive technology) because it can be used by all students in the classroom to enhance their educational outcomes. Assistive technology typically benefits only the user of the assistive device (i.e., eyeglasses). Instructional and assistive technologies are not always mutually exclusive however, so the latter was reviewed to the extent that they are necessary to access the instructional technologies.

In addition to specifying a definition for technology, there is the matter of defining "evidence-based," "promising," and "emerging" practices. Other technical assistance centers have grappled with these definitions (e.g., K-8 Access Center; http://www.k8accesscenter.org) as well as research organizations that have been focused on efforts to figure out how to categorize levels of evidence (e.g., Council for Exceptional Children, 2004). Our definitions, outlined in Table 2, were driven by the availability of original data and the research design used to collect those data.

Other parameters outlined in the framework included: (1) eligible publication years (1985 was the initial cutoff date but was changed to 1999 for the calculator work because earlier technology had become obsolete), (2) grades (K-12), (3) student population (students with or without disabilities), (4) location (various instructional environments including regular education classrooms, classrooms that included special education students, special education classrooms), and (5) outcome type (academic or behavioral). Academic outcomes include constructs such as scores on standardized tests and curriculum-based measures, and behavioral outcomes include constructs such as motivation and engagement. CITEd also considered teacher outcomes if these were reported in a study, although such information is more ancillary for the purposes of this review.

Literature Search

The literature on educational technology varies widely in purpose, design, and quality. There are also relatively few studies of the effects of screen-based technologies in a mathematics setting and even fewer that utilize quantitative analyses. These factors precluded the use of a traditional

---

[3] A review of screen-based technologies in grades 9-12 is not ready as of this writing.

meta-analysis. Furthermore, because technology evolves quickly and new approaches may be worth noting even if researchers have not yet been able to investigate their effects, it falls within the mission of CITEd to identify these approaches with a caveat that they have not yet been fully evaluated.

The search started via consultation with experts in educational technology, to identify key words, journals, intervention names, and practices. The keywords identified for K-8 screen-based technologies are located in Table 3 and were used to search EBSCO, ERIC, JSTOR, PsycInfo, PsycArticles, and the AACE digital library. We also reviewed reference sections from meta-analyses and literature reviews that were uncovered as we progressed through the literature search. We were most interested in recent articles (1999 was a cutoff date); however, for screen-based literature we reviewed older articles and we included articles older than 1999 if: (1) they had compelling findings; (2) the technology was still being used; or (3) the studies are not dependent on the version of the technology (e.g., studies about motivation or engagement).

For the calculator search (see Table 4 for a list of search terms) CITEd staff modified the process for two reasons: (1) a recent meta-analysis of calculator work had been completed by Ellington in 2003 and replication of that work was unnecessary; and, (2) we also wanted to try to provide a richer description of practices that might be considered in conjunction with Ellington's meta-analysis. Thus, CITEd limited the calculator search to (a) empirical studies that could update the meta-analysis and (b) practitioner-oriented pieces that describe practices that were covered in that work. In addition to pursuing research in electronic databases, we searched the *Journal for Research in Mathematics Education, School Science in Mathematics,* and *Educational Studies in Mathematics* because these were journals that Ellington focused on for her meta-analysis.

Coding Tools and Synthesis Scheme

CITEd developed a coding tool to evaluate the rigor of the research reviewed. The coding tool for screen-based technologies was developed based on efforts by the What Works Clearinghouse (see: http://www.whatworks.ed.gov/) and the Council for Exceptional Children's indicators of quality research (see: Odom, Brantlinger, Gersten, Horner, Thompson, & Harris, 2004) and it focused on elements such as study design, data collection methods, characteristics of the participants, research goals, and initial determination of whether the practice studied in the article is evidence-based, promising, or emerging. The indicators developed by CEC were both broad enough for our purposes and relatively easy to translate into a coding scheme.

Studies were coded individually by CITEd staff who have extensive research and methodology backgrounds and every fifth article (as well as all articles that were especially complex) was double-coded for quality control purposes. Coders also participated in initial training to ensure that they had a consistent understanding of CITEd's procedures and terminology. Coders identified articles as level 1 evidence (either for students with or without disabilities), level 2 evidence, or level 3 evidence (see Table 5). Level 1 studies offer original data from rigorous research designs with no design flaws; level 2 studies are based on less rigorous research designs, designs with flaws, or are based on theory; and level 3 studies are not based on research or theory or do not have original data, but do offer professional wisdom or anecdotal evidence. Level 1 studies with positive findings contribute to calling a practice "evidence-based," level 1 studies with mixed findings and level 2 studies contribute to calling a practice "promising," and level 1 studies with negative findings and level 3 studies contribute to calling a practice "emerging."[4] For the calculator research that we reviewed, our coding tool was streamlined to reflect CITEd's focus on more descriptive articles. Again, we wanted to delineate information on practices being used in the field and much of the quantitative synthesis work on calculators had already been captured in the work of Ellington (2003).

To synthesize coding results so that statements could be made about the evidence base for ETPs, CITEd developed a scheme (see Figure 1) that synthesized the level of evidence of individual studies (screen-based and calculator) into a rating of the evidence available for any given ETP (i.e., evidence-based, promising, or emerging). Note that there are no definitive rules for classifying a practice as evidence-based (Gersten, Fuchs, Compton, Coyne, Greenwood, & Innocenti, 2005). An exception might be a quantitative synthesis of a series of randomized controlled trials that yield an overall, positive effect size with confidence intervals that do not include zero, and satisfy topic-specific criteria for meeting practical significance. On the other side of the coin, no single study on its own can be used to conclude that a practice is evidence-based. Even a high quality, randomized controlled trial will yield an analysis with a possible type 1 error. Complicating matters was the necessity to consider qualitative work and single-case designs. The synthesis scheme presented here allows for the incorporation of these types of designs and our coding utilized CEC's quality indicators (Odom et al., 2004) to enable us to determine their quality and how to incorporate them into our synthesis of ETPs.

Document and Disseminate Findings

CITEd's most recent products have focused on developing a synthesis of evidence-based, promising, and emerging K-8 screen-based and K-12 calculator technologies. The results of this synthesis work are captured next.

K-8 screen-based technology: Synthesis of practices

As noted earlier, our focus for screen-based technologies was on studies published in 1985 or later for students enrolled in grades K-8. A total of 61 articles qualified based on our initial screening criteria and of these 61 articles, 34 were empirical, 7 were descriptive, 7 were literature reviews, 2 were meta-analyses, and 11 were not coded for a variety of reasons (e.g., a deeper read of the article demonstrated that it did not focus on an ETP). The results presented in this section demonstrate the level of evidence (emerging, promising, or evidence-based) for any particular ETP, and present this information by content standard and grade levels as defined by the NCTM (see: http://standards.nctm.org/).

The review yielded eight screen-based ETP categories. Table 6 provides representative examples of each of these ETPs and they are listed below:

- Computer-assisted instruction (CAI) that used hypermedia
- CAI that used games and drill and practice/reinforcement

---

[4] Although some readers may find this a questionable approach, we made the assumption that developers may be revising the intervention in light of the negative findings. The practice would be emerging until either (a) rigorous research with positive findings has been done at which point it could be called evidence-based or (b) more studies are conducted that show negative findings at which point the practice is deemed not effective.

- Enhanced anchored instruction[5]
- CAI that was more general or unspecified (e.g., did not fit in other defined CAI ETPs)
- CAI combined with tutoring and/or cooperative learning
- CAI that utilized screen-based manipulatives
- CAI with feedback
- Web-based activities

Table 7 provides an overview of the findings for K-8 screen-based ETPs. This table categorizes the coded studies across NCTM standards by NCTM grade bands. It also summarizes the level of evidence available, based on our literature review, for the categories of ETPs outlined in table 6. Topic area categories should be considered general and in many cases studies had content that crossed topic areas—when an article specified that it dealt with multiple content areas, we noted that. A quick review of Table 7 shows that the majority of articles focused on number and operations and that there were more studies available about ETPs for the higher grade bands.

Table 7 reveals that for grades K-2, three of the ETPs are promising and two are emerging. For grades 3-5, one of the ETPs has a level of evidence sufficient to categorize it as evidence-based, two are on the border between evidence-based and promising, two are promising, and two are emerging. Finally, for grades 6-8, one of the ETPs was categorized as evidence-based, two are on the border between evidence-based and promising, three are promising, and two are emerging. A discussion of the evidence-based practices is provided next.

For grades 3-5, a single evidence-based practice—CAI tutoring/cooperative learning—was identified. Supporting this practice were one randomized controlled trial and one quasi-experimental study. The randomized controlled trial (Xin, 1996) studied computer-assisted instruction using cooperative or whole-class learning to examine impacts on 3rd and 4th grade students' (both with and without disabilities) math achievement, attitude, and social relationships. Results showed that 3rd graders who participated in cooperative learning using CAI had higher achievement scores than 3rd graders who participated in the whole-class learning using CAI classrooms. It is important to note that in this RCT, both groups used computer-assisted instruction, so this study demonstrates that CAI plus cooperative learning has an effect; it does not demonstrate that CAI has an effect regardless of the classroom instruction. The quasi-experimental study (Butzin, 2001) compared schools implementing Project CHILD (Computers Helping Instruction and Learning Development; a transformed learning environment where children work in cross-grade clusters and rotate between clusters to receive instruction; Florida State University, 1988) to traditional classrooms. Second through fifth grade regular education students participated for one hour per day over a three-year period and results showed significantly higher academic achievement outcomes (e.g., standardized tests in math) for Project CHILD participants than those in the traditional classes. This study demonstrates that CAI combined with cooperative learning is more effective than a more traditional classroom approach.

For grades 6-8, one practice was identified as evidence-based: CAI screen-based manipulatives. Supporting this practice were two randomized controlled trials conducted by Moreno and her

---

[5] Enhanced anchored instruction, as described by Bottge and his colleagues, is a way of anchoring the learning of students in problems that seem authentic and meaningful to them, which motivates them and increases their understanding of math. The "anchors" are video clips and the "enhancement" is the hands-on project (e.g., building skateboard ramps) that applies the learning.

colleagues (Moreno & Mayer, 1999; Moreno & Duran, 2004). In the 1999 study, experiment 1, 60 6th graders used a computer-based multimedia program using a number line to help build connections between conceptual and procedural knowledge. Students were taught about adding and subtracting signed numbers using either a symbolic form or using a symbolic, visual, and verbal form over a two-week period to examine the effect of these two teaching styles using a computer-based multimedia game on adding and subtracting signed numbers. Results showed that the multiple representation group outperformed the other group on all dependent variables. In the 2004 study, the same computer-based multimedia program was used with 61 5th and 6th grade students who were taught about adding and subtracting signed integers in either a verbal guidance group or a no verbal guidance group. Posttest scores were significantly higher for students in the guidance group and children with more computer experiences in the guidance group scored better than all other students. As noted for Xin (1996) above, however, both of these studies' treatment and comparison conditions participated in CAI, but what varied was the form in which the CAI was presented. Additionally, only one type of CAI screen-based manipulative was reviewed so it is possible that we are seeing the impact of this practice rather than the impact of this category of practices.

Although other level 1 studies were identified for a number of the ETPs across grade bands (see Table 7) they did not contribute to identifying the practice as evidence-based because their findings were either mixed or there were no effects (thereby contributing to identifying a practice as promising) or negative (thereby contributing to identifying a practice as emerging). Level 1 studies that fall into these categories are footnoted in Table 7.

K-12 calculator technology: Synthesis of practices

Recall that the focus for the calculator search and syntheses took a different focus than the screen-based effort. The primary reason for this is the 2003 Ellington meta-analysis found that use of calculators in testing and instruction were associated with enhanced operational and problem-solving skills. Furthermore, the analysis found that students tend to have better attitudes toward mathematics when they have access to calculators. Rather than attempt to replicate that work, CITEd chose to focus the current synthesis on delineating more specific information that practitioners can use. Hence, work presented here provides information about the level of evidence (i.e., emerging, promising, or evidenced-based) available to support the use of calculator types, for specific subtopics within mathematics, by grade levels.

The review identified four broad calculator types: (1) basic, (2) scientific, (3) graphing, and (4) other, which is consistent with Ellington's (2003) work. Basic calculators are common and tend to perform basic operations, tend to have small memory, and usually have an LCD screen. Scientific calculators are equipped to perform more complex functions and have larger memory stores. Graphing calculators tend to be the most advanced and can handle complex formulae, tend to have large screens to display graphs, and have more advanced capacities for memory. Other calculators might include ones that are specialized in financial and accounting fields or are not easily represented in the typology scheme.

The mathematics content areas and grade bands are based on NCTM standards. In many cases, studies have outcomes that apply to multiple areas (e.g., algebra, geometry). An effort was therefore made to classify a study by what appeared to be the primary focus (e.g., algebra). When a study specified it dealt with multiple content areas, CITEd categorized it as such.

Table 8 provides an overview of findings. A total of 65 studies were coded (empirical articles post Ellington, 2003 and descriptive articles), yielding seven broad categories of calculator use (see rows). No studies focused on measurement concepts, although several did deal with this topic in a more ancillary manner. The majority of studies were classified as level 3 evidence (which makes sense given our focus on identifying descriptive information for practitioners), and there was almost no information about the use of scientific calculators. Studies that did consider such calculators used them in comparison conditions (e.g., effects of a graphing calculator versus scientific ones). Because we did not replicate work of a previous review, it is important to recall the evidence generated by Ellington (2003). She conducted a meta-analysis of 54 studies, published between 1983 and 2002. Of these, 81% used random assignment and sample sizes ranged from 14 to 48,081; four studies had sample sizes greater than 4,000 (p. 441). Most effect sizes were positive, moderate (in the .40 ranges) and in only a few cases did their confidence intervals include zero. As with any meta-analysis, many findings were generated from this work and they are not covered here. The overall finding was that calculators had positive effects on operational and problem-solving skills when they were part of both instruction and later testing. In short, calculators appear to have positive effects on mathematics achievement, so long as they are used in instruction and testing. We reviewed some of the works in the meta-analysis (e.g., Graham & Thomas, 2000; Pennington, 1998) and our conclusions were consistent. To provide some descriptive information, we discuss below some of the studies Ellington reviewed.

A single evidence-based practice, graphing calculators for algebra in grades 6-8, was found. Supporting this practice are three randomized controlled trials. One of these, Graham and Thomas (2000), studied a curriculum designed to promote students' ability to understand what a variable is by using the "store" function of a graphing calculator. The sample included 189 students (ages 13 and 14) of mixed ability; participants in the treatment group did significantly better from pre-post-testing than those in the control group. This study demonstrated that using graphing calculators rather than not using calculators helps students understand what a variable is. In another randomized controlled trial, Owens (1995) compared multi-line, multi-operation calculators (classified here as a type of graphing calculator) to Last-Entry-or-Result calculators (scientific) to see if the former would improve algebra and pre-algebra students' understanding of basic order of operation problems. Four 8th grade classes participated, of which two were pre-algebra (lower ability) and two were algebra (higher ability). Sixty-one students were used in the analysis. Overall, there was a significant difference on algebra performance, favoring the treatment group. This demonstrated that graphing calculators are better than scientific calculators in helping students understand order of operations.

One other level 1 study was identified. To investigate the effects of calculator use in testing on students academic outcomes, Pennington (1998) randomly assigned 89 seventh and eighth grade students to three groups: (1) no calculator used during pre- and posttests (control), (2) calculators used only on posttest without instructions, and (3) calculator used only on posttests with instructions on how to use them. Students who received instruction had scores that were higher than those who did not receive instruction or use calculators. Students who used calculators (but did not receive instruction) did score higher than those who did not use calculators; however, their scores were not statistically significantly higher. This study demonstrates that using calculators during assessments improves students' academic outcomes, and that instruction in how to use the calculators further improves these skills.

It is noteworthy that another randomized controlled trial was found, McNamara (1995), which compared two approaches to teaching multiplication facts to 28 second–grade students in a public school. All of the children were just beginning to learn multiplication; none of them had received any previous classroom instruction in this topic. There was, however, no control group available to compare these students' testing results with those who did not use calculators at all, and no significant differences were found between each treatment. Given the lack of clear findings, this study was not rated as level 1.

K-12 calculator technology: Products for practitioners

CITEd is in the process of developing a number of products for practitioners to be placed on our website (http://www.citeducation.org). The purpose of these products is to describe ETPs so that practitioners can make informed decisions about what particular practices work for what mathematical area in what grade. An example of a practitioner product that has been developed, but not yet disseminated, is located in Exhibit 1. This particular product focuses on the use of calculators for students in grades K-2. It is important to note that these products will not just be developed for practices that are evidence-based.

Conclusions and Discussion

CITEd's synthesis work in the areas of K-8 screen-based technologies and K-12 calculators indicates that there are relatively few studies that reflect evidence-based practices and that relatively few research studies exist to test the effects of any particular ETP. Furthermore, studies that use rigorous designs to test the effectiveness of ETPs are scarce. Research designs often lack suitable control groups, they use researcher-designed prototypes that are not publicly available that makes replication impossible, and they utilize small sample sizes—a problem that has been salient in studies that have focused on students with disabilities. Instead there is a preponderance of less rigorous methodologies, such as quasi-experimental, case study, and single group pre-post test designs. In addition, while the internal validity problems that are inherent to these designs is considerable, more demanding randomized controlled trials can often times be impractical. There are many descriptive pieces and qualitative work that has been done to examine ETPs; this work was considered and is being used to help CITEd develop the practitioner products described above. In addition to delineating the evidence-based practices captured by our synthesis work, CITEd will provide information about promising and emerging practices to practitioners, but will make it clear that those practices are not as strong. CITEd's work is a first step in the direction of helping educational researchers and educators understand why and how ETPs work.

As mentioned above, CITEd's task for this project is to also provide practitioner-friendly summaries of suggested practices. Such documents can help teachers adapt their curriculum and instruction to make them accessible to all students. The need for evidence-based research in this area is equally important, yet this review of the literature reveals that there is a lack of current research concerning students with special needs and their uses of technology in the area of mathematics. For instance, there is not an extensive body of current research that illustrates practices that assist struggling learners with word problems, representations of mathematical concepts, and applying appropriate problem-solving strategies. Though a majority of the literature reviewed above does not specifically address these issues, CITEd is beginning to take steps towards synthesizing these articles through a special needs lens. An early step in this process was revisiting Woodward and Reith's (1997) literature review for the purposes of comparing their conclusions of this body of research to those studies reviewed for this current synthesis.

Woodward and Reith (1997) examined studies published between 1980 and 1997 that focused on the uses of technology for students with special needs. Their task was to reveal how teachers used technology in naturalistic settings for the purposes of instruction and assessment. This emphasis, they argue, was a shift from previous reviews of the literature that overemphasized the medium of technology by sacrificing a focus on the embedded pedagogy. The problem with this focus was that previous meta-analyses too often failed to recognize that the pedagogical approach utilized in a computer program often has more of an impact on student learning than the use of technology itself. Second, Woodward and Reith argue that a majority of the studies highlighted in previous literature reviews and meta-analyses were interventions that took place over a very short period of time. This approach is problematic “because students with disabilities can be expected to learn at slower rates, have longer histories of academic failure, and need more intensive instruction than their non-disabled peers, short-term interventions hardly can be expected to produce significant changes” (Okolo et al, 1993, p. 4; quoted in Woodward & Reith, 1997, p. 505). Finally, they point out prior emphases on short-term interventions are also problematic when the focus is on gains in student achievement. Rarely do these studies find that there is a statistically significant change in these students’ achievement levels because progression in their learning is often irregular. Short intervention units and research designs simply are not able to capture positive change.

Using these precautions, Woodward and Reith (1997) reviewed studies that emphasized the uses of technology for instruction, assessment, and naturalistic settings for students with special needs. An overall trend that they noticed was the concerted shift from using technology for skill and drill practices to more conceptual approaches to learning. They do, however, point out a few concerns in the design, availability, and uses of technology for students with special needs.

First, the most important problem Woodward and Reith (1997) found was that the technology researched rarely aligned with the specific needs of special needs students: “These studies examine the effects of specific instruction design rather than how these design variables, in conjunction with categorical variables (e.g., average ability, learning disabled, mentally retarded), might suggest one type of technology-based instruction is best suited for students in a particular disability category” (p. 524). From its current review of studies published since 1997, CITEd has found that for the most part these concerns persist. Of the 24 screen-based technology studies reviewed in grades K-8 since 1997, only half included students with special needs in their classroom, and none isolated the specific needs of the individuals in the sample. More often, studies such as Bottge et al. (2003) would mention that the sample included students from “low” and “average” ability. Other studies that did focus on students with special needs (c.f., Wisniewski & Smith, 2002) only pointed out that these students received additional instruction support in a resource room or had Individual Education Plans (IEPs). Though Bottge et al. (2002) used a rigorous research design that included a control group, they were not able to make any specific conclusions about the technology’s effectiveness in addressing an individual’s learning needs because effects for students with special needs were not isolated. Of the calculator articles reviewed, the same challenge persists—strategies are either mentioned or researched with a control group, but students with special needs are still lumped together as one group.

The second concern Woodward and Reith (1997) point out is the availability of the technology being researched. Too often, they claim, a majority of the technologies examined were prototypes: “While they were robust enough to use in experimental studies, either they were not marketed commercially or they did not achieve sufficient visibility because of the narrowness of the special education commercial market” (Woodward & Reith, 1997, p. 525). Of the sixty-one screen-based studies published since 1985 examined for this synthesis, only ten appear to be available. For instance, a lot of the video-based instruction Bottge and colleagues (e.g., 2001; 2002; 2003) examined are available online. Reimer and Moyer’s (2005) digital manipulatives are also available online. They found the use of this tool effective for students with and without special needs, though they did exclude data from the four autistic students also present in this classroom. It appears that the increased use of the internet is one way researches are making the programs they research accessible for wider audiences; however, many programs remain unavailable as prototypes.

Whereas a majority of the research concerning screen-based technologies CITEd reviewed were prototypes, studies examining the use of calculator models such as the TI-82 or programs such as

CABRI are more readily available to teachers. The challenge is finding calculator studies that focus on the academic effects these tools have on students with special needs. In her meta-analysis of the uses of calculators in K-12 classrooms, Ellington (2003) was unable to isolate the impact calculators had on achievement for "low ability students" (p. 456). CITEd, too, was limited by this dearth of research concerning students with special needs using calculators. Of the 65 calculator articles reviewed, none focused specifically on how calculators can support student with special needs. Though twelve of these articles did include samples of mixed-ability students, only two of these studies (Hanson, 2001; Pennington, 1998) used a rigorous evidence-based research design and yielded unambiguous effects.

Third, Woodward and Reith (1997) concluded that the research reveals that special education teachers tend to use technology more for motivational than academic purposes. Instead of focusing on technology as a diagnostic tool to facilitate decisions about students' IEPs, special educators were more prone to use computers to get students excited about various academic tasks. The K-8 screen-based articles that CITEd reviewed seem to indicate a shift from this emphasis. That is, those studies in which students with special needs were included as participants focused on academic tasks rather than behavioral (or motivational) outcomes (c.f., Bottge et al., 2001; Fuchs et al., 2002). Two studies published since 1997 that included students with special needs did focus on motivational and academic outcomes, but in these cases the motivational emphasis was either on how "low ability" students worked with their "average ability" peers during cooperative learning activities supported by video learning (Bottge et al., 2004) or compared students' attitudes towards the use of digital manipulatives to how well this tool increased academic achievement (Reimer & Moyer, 2005).

Woodward and Reith's (1997) final concern about the literature up to 1997 was that special education teachers tend to focus too much on the acquisition of basic skills. The articles CITEd has reviewed since then appear to differ. This possible shift towards using technology to facilitate higher-order thinking may be the result of new technologies that promote conceptual learning. Yet, despite this shift, the research is not specific on the benefits for students with special needs.

Another approach is to focus on documented areas of difficulty in learning mathematics for students with special needs and suggest how these new technologies could be of benefit to them. While difficulty with computation and retrieving basic facts has been well researched (Cawley, Parmar, Yan, & Miller, 1998; Cumming & Elkins, 1999; Geary, 2004; Geary, Hoard, Byrd-Craven, & DeSoto, 2004; Janssen, De Boeck, Viaene, & Vallaeys, 1999; Jordan & Hanich, 2003), research also indicates that many students struggle with mathematics due to a variety of problems, including limited ability to create and interpret visual representations of mathematical concepts (Booth & Thomas, 2000; Brown & Presmeg, 1993; Geary, 1993; Geary, Hamson, & Hoard, 2000; Hegarty & Kozhevnikov, 1999; van Garderen & Montague, 2003), poor reading, language, and communication skills (Baxter, Woodward, & Olson, 2001; Cawley, Parmar, Foley, Salmon, & Roy, 2001; Fuchs & Fuchs, 2002; Hanich, Jordan, Kaplan, & Dick, 2001; Hegerty, Mayer, & Monk, 1995; Verschaffel, De Corte, & Vierstraete, 1999), and poor problem solving strategies (Lucangeli, Coi, & Bosco, 1997; Ostad, 1998; Pape & Wang, 2003; Xin, Jitendra, & Deatline-Buchman, 2005). It is from this point that CITEd is developing practitioner-friendly documents that outline these evidence-based, promising, and emerging teaching practices that utilize technology as a means for promoting an in-depth understanding of mathematical concepts. Exhibit 1 provides an example of how these documents 1) describe the teaching practice, 2) outline the research that supports this practice, 3) align the practice to an NCTM content standard, and 4) illustrate how the practice aligns with strategies also proven to support academic achievement for struggling learners.

General References

Allsopp, D., Lovin, L., Green, G., & Savage-Davis, E. (2003). Why students with special needs have difficulty learning mathematics and what teachers can do to help. *Mathematics Teaching in the Middle School, 8*(6), 308-314.

Baxter, J. A., Woodward, J., & Olson, D. (2001). Effects of reform-based mathematics instruction in five third grade classrooms. *Elementary School Journal, 101*(5), 529-548.

Booth, R. D. L., & Thomas, M. O. J. (2000). Visualization in mathematics learning: Arithmetic problem-solving and student difficulties. *Journal of Mathematical Behavior, 18*(2), 169-190.

Brown, D. L., & Presmeg, N. C. (1993). *Types of imagery used by elementary and secondary school students in mathematical reasoning.* Paper presented at the Proceedings of the 17th Annual Meeting of the International Group for the Psychology of Mathematics Education, Tsukuba, Japan.

Burrill, G., Allison, J., Breaux, G., Kastberg, S., Leatham, K., & Sanchez, W. (2002). *Handheld graphing technology in secondary mathematics: Research findings and implications for classroom practice*. Dallas, TX: Texas Instruments, Inc.

Cawley, J., Parmar, R., Foley, T. E., Salmon, S., & Roy, S. (2001). Arithmetic performance of students: Implications for standards and programming. *Exceptional Children, 67*(3), 311-328.

Cawley, J., Parmar, R., Yan, W., & Miller, J. H. (1998). Arithmetic computation performance of students with learning disabilities: Implications for curriculum. *Learning Disabilities Research & Practice, 13*(2), 68-74.

Clements, D. H. (2000). From exercises and tasks to problems and projects: Unique contributions of computers to innovative mathematics education. *Journal of Mathematical Behavior, 19,* 9-47.

Cumming, J. J., & Elkins, J. (1999). Lack of automaticity in the basic addition facts as a characteristic of arithmetic learning problems and instructional needs. *Mathematical Cognition, 5*(2), 149-180.

Ellington, A. J. (2003). A meta-analysis of the effects of calculators on students' achievement and attitude levels in precollege mathematics classes. *Journal for Research in Mathematics Education, 34(5),* 433-463.

Fuchs, L. S., & Fuchs, D. (2002). Mathematical problem-solving profiles of students with mathematics disabilities with and without comorbid reading disabilities. *Journal of Learning Disabilities, 35*(6), 564-574.

Geary, D. C. (1993). Mathematical disabilities: Cognitive, neuropsychological, and genetic components. *Psychological Bulletin, 114*(2), 345-362.

Geary, D. C. (2004). Mathematics and learning disabilities. *Journal of Learning Disabilities, 37*(1), 4-15.

Geary, D. C., Hamson, C. O., & Hoard, M. K. (2000). Numerical and arithmetical cognition: A longitudinal study of process and concept deficits in children with learning disability. *Journal of Experimental Child Psychology, 77*, 236-263.

Geary, D. C., Hoard, M. K., Byrd-Craven, J., & DeSoto, M. C. (2004). Strategy choices in simple and complex addition: Contributions of working memory and counting knowledge for children with mathematical disability. *Journal of Experimental Child Psychology, 88*, 121-151.

Gersten, R., Fuchs, L. S., Compton, D., Coyne, M., Greenwood, C., Innocenti, M. S. (2005). Quality indicators for group experimental and quasi-experimental research in special education. *Exceptional Children, 71*(2), 149-164. Available: http://www.cec.sped.org/

Hall, D. T. (2000). Technology and versatile thinking in mathematical development. In M. O. J. Thomas (Ed.), *Proceedings of TIME 2000*, pp. 33-50. Auckland, New Zealand.

Hanich, L. B., Jordan, N. C., Kaplan, D., & Dick, J. (2001). Performance across different areas of mathematical cognition in children with learning difficulties. *Journal of Educational Psychology*, *93*(3), 615-626.

Hegarty, M., & Kozhevnikov, M. (1999). Types of visual-spatial representations and mathematical problem solving. *Journal of Educational Psychology, 91*(4), 684-689.

Hegerty, M., Mayer, R. E., & Monk, C. A. (1995). Comprehension of arithmetic word problems: A comparison of successful and unsuccessful problem solvers. *Journal of Educational Psychology, 87*(1), 18-32.

Heid, M. K., Middleton, J. A., Larson, M., Gutstein, E., Fey, J. T., King, K., Strutchens, M. E., & Tunis, H. (2006). The challenge of linking research and practice. *Journal for Research in Mathematics Education, 37*(2), 76-86.

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

Hembree, R., & Dessart, D. J. (1992). Research on calculators in mathematics education. In J. T. Fey (Ed.), *Calculators in mathematics education* (pp. 23-32). Reston, VA: National Council of Teachers of Mathematics.

Janssen, R., De Boeck, P., Viaene, M., & Vallaeys, L. (1999). Simple mental addition in children with and without mild mental retardation. *Journal of Experimental Child Psychology, 74*, 261-281.

Jordan, N. C., & Hanich, L. B. (2003). Characteristics of children with moderate mathematics deficiencies: A longitudinal perspective. *Learning Disabilities Research & Practice, 18*(4), 231-221.

Lucangeli, D., Coi, G., & Bosco, P. (1997). Metacognitive awareness in good and poor math problem solvers. *Learning Disabilities Research & Practice, 12*(4), 209-212.

Odom, S. L., Brantlinger, E., Gersten, R., Horner, R. D., Thompson, B., & Harris, K. (2004). *Quality indicators for research in special education and guidelines for evidenced-based practice: Executive summary*. Division for Research: Council for Exceptional Children. Available: http://www.cec.sped.org/

Ostad, S. A. (1998). Developmental differences in solving simple arithmetic word problems and simple number-fact problems: a comparison of mathematically normal and mathematically disabled children. *Mathematical Cognition, 4*(1), 1-20.

Pape, S. J., & Wang, C. (2003). Middle school children's strategic behavior: Classification and relation to academic achievement an mathematical problem solving. *Instructional Science, 31*, 419-449.

Ruthven, K., & Hennessy, S. (2002). A practitioner model of the use of computer-based tools and resources to support mathematics teaching and learning. *Educational Studies in Mathematics*, *49*, 47-88.

The McKenzie Group (2002). *Handheld technology and student achievement: A collection of publications.* An independent study conducted for Texas Instruments Incorporated, Austin, TX: Author.

U.S. Department of Education, National Center for Education Statistics (2002). *Technology in Schools: Suggestions, Tools,* and *Guidelines for Assessing Technology in Elementary and Secondary Education*, National Forum on Education Statistics. Washington, DC: 2002.

van Garderen, D., & Montague, M. (2003). Visual-spatial representation, mathematical problem solving and students of varying abilities. *Learning Disabilities Research & Practice, 18*(4), 246-254.

Verschaffel, L., De Corte, E., & Vierstraete, H. (1999). Upper elementary school pupils' difficulties in modeling and solving nonstandard additive word problems involving ordinal numbers. *Journal for Research in Mathematics Education, 30*(3), 265-285.

Woodward, J., & Montague, M. (2002). Meeting the challenge of mathematics reform for students with LD. *Journal of Special Education, 36*(2), 89-101.

Woodward, J., & Reith, J. (1997). A historical review of technology research in special education. *Review of Educational Research*, 67(4), 503-536.

Xin, Y. P., Jitendra, A. K., & Deatline-Buchman, A. (2005). Effects of mathematical word problem-solving instruction on middle school students with learning problems. *Journal of Special Education, 39*(3), 181-192.

References for K-8 Screen-Based Technologies

Axelrod, S., McGregor, G., Sherman, J. & Hamlet, C. (1987). Effects of video games as reinforcers for computerized addition performance. *Journal of Special Education Technology, 9*(1), 1-8.

Babbitt, B., & Miller, S. (1996). Using hypermedia to improve the mathematics problem-solving skills of students with disabilities. *Journal of Learning Disabilities, 29*(4), 391-401.

Bahr, C. M. & Reith, H. J. (1989). The effects of instructional computer games and drill and practice software on learning disabled students' mathematical achievement. *Computers in the School, 6*(3/4), 87-101.

Bottge, B. (1999). Effects of contextualized math instruction on problem solving of average and below-average achieving students. *The Journal of Special Education, 33*(2), 81-92.

Bottge, B. (2001). Building ramps and hovercrafts—and improving math skills. *Teaching Exceptional Children, 34*(1), 16-23.

Bottge, B., & Hasselbring, T. (1993). A comparison of two approaches for teaching complex, authentic mathematics problems to adolescents in remedial math classes. *Exceptional Children, 59*(6), 556-566.

Bottge, B., Heinrichs, M., Chan, S., & Serlin, R. (2001). Anchoring adolescents' understanding of math concepts in rich problem-solving environments. *Remedial and Special Education, 22*, 299-314.

Bottge, B., Heinrichs, M., Chan, S., Mehta, Z. D., & Watson, E. (2003). Effects of video-based and applied problems on the procedural math skills of average and low-achieving adolescents. *Journal of Special Education Technology, 18*(2), 5-22.

Bottge, B., Heinrichs, M., Mehta, Z. D. & Hung, Y-H. (2002). Weighing the benefits of anchored math instruction for students with disabilities in general education classes. *The Journal of Special Education, 35*(4), 186-200.

Bottge, B., Heinrichs, M., Mehta, Z. D., Rueda, E., Hung, Y-H., & Danneker, J. (2004). Teaching mathematical problem solving to middle school students in math, technology education, and special education classrooms. *Research in Middle Level Education Online, 27*(1), 43-69. Retrieved July 5, 2005, from http://www.nmsa.org/research/rmle/winter_03/27_1_article_1.htm

Burch, M. (2002). *Effects of computer-based test accommodations on the math problem-solving performance of students with and without disabilities*. Unpublished doctoral dissertation.

Butzin, S. (2001). Using instructional technology in transformed learning environments: An evaluation of project CHILD. *Journal of Research on Computing in Education, 33*(4), 367-373.

Carrier, C., Post, T. & Heck, W. (1985). Using microcomputers with fourth-grade students to reinforce arithmetic skills. *Journal for Research in Mathematics Education, 16*(1), 45-51.

Chiang, B. (1986). Initial learning and transfer effects of microcomputer drills on LD students' multiplication skills. *Learning Disability Quarterly, 9*(2), 118-123.

Christensen, C., & Gerber, M. (1990). Effectiveness of computerized drill and practice games in teaching basic math facts. *Exceptionality*, *1*(3), 149-165.

Clements, D., & Sarama, J. (1997). Computers support algebraic thinking. *Teaching Children Mathematics*, *3*, 320-325.

Clements, D. H. & Sarama, J. (2000). Predicting pattern blocks on and off the computer. *Teaching Children Mathematics*, March, 458-461.

Cosden, M. A., Gerber, M. M., Semmel, D. S., Goldman, S. R., & Semmel, M. I. (1987). Microcomputer use within micro- educational environments. *Exceptional Children, 53*(5), 399-409

Emihovich, C., & Miller, G. (1988). Effects of logo and CAI on black first graders' achievement, reflectivity, and self-esteem. *The Elementary School Journal, 88*(5), 472-487.

Flener, F. (2000). Use of interactive video technology to teach middle school mathematics in Chicago Schools, September-November 2000. *Final Evaluation Report*. Northeastern University, Chicago, IL. (ERIC Document Reproduction Service No. ED451055)

Fuchs, L. S., & Fuchs, D. (2001). Principles for the prevention and intervention of mathematics difficulties. *Learning Disabilities Research & Practice*, *16*(2), 85-96.

Fuchs, L. S., Fuchs, D., Hamlett, C. L., & Appleton, A. C. (2002). Explicitly teaching for transfer: Effects on the mathematical problem-solving performance of students with mathematics disabilities. *Learning Disabilities Research & Practice*, *17*(2), 90-107.

Fuchs, L. S., & Fuchs, D. (2005). Enhancing mathematical problem solving for students with disabilities. *Journal of Special Education*, *39*(1), 45-58.

Fuson, K., & Brinko, K. (1985). The comparative effectiveness of microcomputers and flash cards in the drill and practice of basic mathematics facts. *Journal for Research in Mathematics Education*, *16*(3), 225-232.

Garofolo, J., & Sharp, B. D. (2003). Teaching fractions using a simulated sharing activity. *Learning & Leading with Technology, 30*(7), 36-39.

Gerber, M. M., Semmel, D. S., & Semmel, M. I. (1994). Computer-based dynamic assessment of multidigit multiplications. *Exceptional Children, 61*(2), 114-128.

Gleason, M. M. (1985). *A comparison of two CAI approaches in teaching math word problems to handicapped learners*. Unpublished doctoral dissertation, University of Oregon.

Goetzfried, L., & Hannafin, M. (1985). The effect of the locus of CAI control strategies on the learning of mathematical rules. *American Educational Research Journal, 22*(2), 273-278.

Goldman, S., & Hasselbring, T. (1997). Achieving meaningul mathematics literacy for students with learning disabilities. *Journal of Learning Disabilities*, *30*(2), 198-208.

Hannafin, R. (2004). Achievement differences in structured versus unstructured instructional geometry programs. *Educational Technology Research and Development*, *52*(1), 19-32.

Hasselbring, T. S., Goin, L., & Bransford, J. D. (1988). Developing math automaticity in learning handicapped children: The role of computerized drill and practice. *Focus on Exceptional Children, 20,* 1-7.

Hasselbring, T. S., Goin, L., & Sherwood, R. D. (1986). *The effects of computer based drill-and-practice on automaticity*. (Technical Report). Nashville, TN: Vanderbuilt University, Learning Technology Center.

Hativa, N. (1988). Computer-based drill and practice in arithmetic: Widening the gap between high-and low-achieving students. *American Educational Research Journal*, *25*(3), 366-397.

Howell, R., Sidorenko, E., & Jurica, J. (1987). The effects of computer use on the acquisition of multiplication facts by a student with learning disabilities. *Journal of Learning Disabilities, 3,* 131-161.

Johnson, R., Johnson, D., & Stanne, M. (1986). Comparison of computer-assisted cooperative, competitive, and individualistic learning. *American Educational Research Journal*, *23*(3), 382-392.

King, W. (2001). The wall. *Micromath, 17*(1), 12-13.

Kramarski, B. (1999). Study of graphs by computers: Is easier better? *Educational Media International, 36*(3), 203-09.

Kulik, C., & Kulik, J. (1991). Effectiveness of computer based instruction: An updated analysis. *Computers in Human Behavior*, *7*(1-2), 75-94.

Lawrence (2001). Evaluation of a spreadsheet: Data Handling. *Micromath, 17*(1), 14-17.

Malinow, A., & Black, J. Integrating a multiple-linked representational program into a middle-school learning disabled classroom. Proceedings from the 2003 International Conference on Computing in Education sponsored by the Asia-Pacific Chapter of the Association for the Advancement of Computing in Education (AACE): Hong Kong.

McDermott, P., & Watkins, M. (1983). Computerized vs. conventional remedial instruction for learning disabled pupils. *The Journal of Special Education*, *17*(1), 81-88.

Miller, S. P., Butler, F. M., & Lee, K. (1998). Validated practices for teaching mathematics to students with learning disabilities: A review of literature. *Focus on Exceptional Children, 31*(1), 1-24.

Moreno, R., & Mayer, R. E. (1999). Multimedia-supported metaphors for meaning making in mathematics. *Cognition and Instruction, 17*(3), 215-248.

Moreno, R., & Duran, R. (2004). Do multiple representations need explanations? The role of verbal guidance and individual differences in multimedia mathematics learning. *Journal of Educational Psychology, 96*(3), 492-503.

Moore, L., & Carnine, D. (1989). Evaluating curriculum design in the context of active teaching. *Remedial and Special Education, 10*(1), 28-37.

Morgan, P., & Ritter, S. (2002). *An experimental study of the effects of cognitive tutor algebra I on student knowledge and attitude*. Pittsburgh, PA: Carnegie Learning, Inc.

No stated author (2002). Strengthening the third "R." Helping students with disabilities achieve in mathematics. Research Connections in Special Education, *11*, 1-10. (ERIC Document No. ED 471811)

Okolo, C. (1992). The effects of computer-assisted instruction format and initial attitude on the arithmetic facts proficiency and continuing motivation of students with learning disabilities. *Exceptionality, 3*, 195-211.

Okolo, C. (1992). The effects of computer-based attribution retraining on the attributions, persistence, and mathematics computation of students with learning disabilities*. Journal of Learning Disabilities*, *25*(5), 327-334.

Pellegrino, J. W., & Goldman, S. R. (1987). Information processing and elementary mathematics. *Journal of Learning Disabilities, 20*, 23-32, 57.

Podell, D. M., Tournaki-Rein, N., & Lin, A. (1992). Automatization of mathematics skills via computer-assisted instruction among students with mild mental handicaps. *Education and Training in Mental Retardation, 27*(3), 200-206.

Reimer, K., & Moyer, P (2005). Third-graders learn about fractions using virtual manipulative: A classroom study. *Journal of Computers in Mathematics and Science Teaching*, *24*(1), 5-25.

Sarama, J., & Clements, D. (2004). Building blocks for early childhood mathematics. *Early Childhood Research Quarterly*, *19*, 181-189.

Shiah, R., Mastropieri, M., Scruggs, T., & Fulk, B. (1994). The effects of computer-assisted instruction on the mathematical problem solving of students with learning disabilities. *Exceptionality*, *5*(3), 131-161.

Shield, M. (2000). Virtual "real life" mathematics. *Australian Mathematics Teacher, 56*(3), 25-28.

Tzur, R. (1999). An integrated study of children's construction of improper fractions and the teacher's role in promoting that learning. *Journal for Research in Mathematics Education, 30*(4), 390-416.

Wilson, M. (1999). Student-generated multimedia presentations: Tools to help build and communicate mathematical understanding. *Journal of Computers in Mathematics and Science Teaching*, *18*(2), 145-156.

Wilson, R., & Majsterek, D. (1996). The effects of computer-assisted versus teacher directed instruction on the multiplication performance of elementary students with learning disabilities. *Journal of Learning Disabilities*, *29*(4), 382.

Wisniewski, Z., & Smith, D. (2002). *How effective is touch math for improving students with special needs academic achievement on math addition mad minute timed tests?* Indiana University South Bend. (ERIC Document Reproduction Service No. ED469445)

Xin, F. (1996). *The effects of computer-assisted cooperative learning in mathematics in integrated classrooms for students with and without disabilities.* Rowan College of New Jersey, Special Education Department. (ERIC Document Reproduction Service No. ED412696)

Zimmerman, S. (1988). Problem-solving tasks on the microcomputer: A look at the performance of students with learning disabilities. *Journal of Learning Disabilities, 21*(10), 637-641.

References for K-12 Calculator Technologies

Abramovich, S., & Norton, A. (2000). Technology-enabled pedagogy as an informal link between finite and infinite concepts in secondary mathematics. *Mathematics Educator, 10*(2), 36-41.

Arnold, S., & Taylor, J. (1996). New technology. *Australian Mathematics Teacher, 52*(4), 36-39.

Austin, J. D. (1996). Mathematizing string art. *Mathematics and Computer Education, 30*(3), 272-277.

Bardini, C., Pierce, R. U., & Stacey, K. (2004). Teaching linear functions in context with graphics calculators: Students' responses and the impact of the approach on their use of algebraic symbols. *International Journal of Science and Mathematics Education, 2,* 353-376.

Barker, S. K., & Mahoney, J. (2005). *Calculator demonstrations of bell curve convergence using polynomial algebra*. National Council of Teachers of Mathematics: Reston, VA.

Barnes, S. (1996). Perimeters, patterns, and pi. *Mathematics Teacher, 89*(4), 284-288.

Barrett, G. B. (1999). Investigating distributions of sample means on the graphing calculator. *Mathematics Teacher, 92*(8), 744-747.

Bates, P., Greiner, E., Hampshire, J., Jolly, S., Keel, E., Lancaster, E., Leake, C., Locum, J., Moore, V., Morton, S., Moser, S., Peterson, B., Simmons, J., & Stewart, R. (1998). *Graphing calculators in mathematics grades 7-12: A resource guide for the classroom and for preservice/inservice training*. Washington, DC: Office of Educational Research and Improvement.

Berthgold, T. (2004/2005). Curve stitching: Linking linear and quadratic functions. *Mathematics Teacher, 98*(5), 348-353.

Beigie, D. (2002). Investigating limits in number patterns. *Mathematics Teaching in the Middle School, 7*(8), 438-443.

Brown, A. R. (1999). Geometry's giant leap. *Mathematics Teacher, 92*(9), 816-819.

Cedillo, T. E. (2001). Toward an algebra acquisition support system: A study based on using graphic calculators in the classroom. *Mathematical Thinking and Learning, 3*(4), 221-259.

Child, D. (2001). The symbolic math guide and the laws of exponents. *Micromath, 17*(2), 32-35.

Choate, J., & Picciotto, H. (1997). Iterating linear functions: An introduction to dynamical systems. *Mathematics Teacher, 90*(2), 122-126, 132-136.

Choi-Koh, S. S. (2000). Effect of a graphing calculator on a 10th grade student's study of trigonometry. *The Journal of Educational Research, 96*(6), 359-369.

Cuoco, A., & Manes, M. (2001). When memory fails. *Mathematics Teacher, 94*(6), 389-493.

Cyrus, V. F., & Flora, B. V. (2000). Don't teach technology, teach with technology. *Mathematics Teacher, 93*(7), 564-567.

DiCarlucci, J. A. (1995). Dynamic polygons and the graphing calculator. *School Science and Mathematics*, *95*(3), 147-153.

Doerr, H. M., & Zangor, R. (2000). Creating meaning for and with the graphing calculator. *Educational Studies in Mathematics, 41*(2), 143-163.

Edwards, T. G. (2000). Pythagorean triples served for dessert. *Mathematics Teaching in the Middle School, 5*(7), 420-423.

Eisen, A. P. (1999). Exploring factor sets with a graphing calculator. *Mathematics Teaching in the Middle School, 5*(2), 78-82.

Eisner, M. P. (1997). A simple formula for quantiles on the TI-82/83 calculator. *Mathematics and Computer Education, 31*(3), 237-240.

Embse, C. V., & Engebretsen, A. (1996). A mathematical look at a free throw using technology. *Mathematics Teacher, 89*(9), 774-779.

Embse, C. V., & Yoder, V. W. (1998). Multiple representations and connections using technology. *Mathematics Teacher, 91*(1), 62-67.

Farrell, A. M. (1995). Matrices draw connections for precalculus students. *Ohio Journal of School Mathematics, 30*, 11-18.

Felsager, B. (2001). Mapping stars with TI-83. *Micromath, 17*(2), 26-31.

Forbes, I. (2001). The circle of understanding: Optimisation with the TI-92. *Micromath, 17*(3), 15-18.

Forster, P. A., & Taylor, P.C. (2000). A multiple-perspective analysis of learning in the presence of technology. *Educational Studies in Mathematics, 42*(1), 35-59.

Fox, T. B. (2005). Transformations on data sets and their effects on descriptive statistics. *Mathematics Teacher*, *99*(3), 208-213.

Gilliland, K. (2002). Calculators in the classroom. *Mathematics Teaching in the Middle School, 8*(3), 150-151.

Goos, M., Galbraith P., Renshaw, P., Geiger, V. (2003). Perspectives on technology mediated learning in secondary school mathematics classroom. *Journal of Mathematical Behavior, 22*, 73-89.

Graham, T., Headlam, C., Honey, S., Sharp, J., Smith, A. (2003). The use of graphics calculators by students in an examination: What do they really do? *International Journal of Mathematical Education in Science and Technology, 34*(3), 319-334.

Graham, T., & Smith, P. (2004). An investigation into the use of graphics calculators with pupils in key stage 2. *International Journal of Mathematical Education in Science and Technology, 35*(2), 227-237.

Graham, A. T., & Thomas, M. O .J. (2000). Building a versatile understanding of algebraic variables with a graphic calculator. *Educational Studies in Mathematics, 41*(3), 265-282.

Hand, R. (2000). *Covering the Bases: A Teacher Introduces a Math Concept with Help from Mickey Mouse, Mr. Ed and a Tribe of Polydactylites.* <www.teachingK-8.com> 48-49.

Hanson, K., Brown, B., Levine, R., & Garcia, T. (2001). Should standard calculators be provided in testing situations? An investigation of performance and preference differences. *Applied Measurement in Education, 14*(1), 59-72.

Helfgott, M., & Simonsen, L. M. (1998). Using technology (instead of calculus) to derive the law of reflection for parabolic mirrors from Fermat's principle of least time. *Mathematics and Computer Education, 32*(1), 62-73.

Holliday, B. W., & Duff, L.R. (2004). Using graphing calculators to model real world data. *Mathematics Teacher, 97*(5), 328-331.

Hubbard, D. (1998). Improving Student Knowledge of the Graphing Calculator's Capabilities. An Action Research Project submitted to the Graduate Faculty of the Saint Xavier University School of Education. Unpublished masters thesis, Saint Xavier University.

Huinker, D. (2002). Calculators as learning tools for young children's explorations of number. *Teaching Children Mathematics, 8*(6), 316-321.

Hurwitz, M. (1997). Visualizing the proof of the mean-value theorem for derivatives. *Mathematics Teacher, 90*(1), 16-18.

Johnson, I. D. (2000). Mission possible! Can you walk your talk? *Mathematics Teaching in the Middle School, 6*(2), 132-134.

Judson, E., & Sawada, D. (2000). Examining the effects of a reformed junior high school science class on students' math achievement. *School Science and Mathematics, 100*(8), 419-425.

Kissane, B. (2001). Algebra and personal technology. *Australian Mathematics Teacher, 57*(1) 38-44.

Kwon, O. N. (2002). The effect of calculator-based ranger activities on students' graphing ability. *School Science and Mathematics, 102*(2), 57-67.

Lagrange, J. (1999). Techniques and concepts in pre-calculus using CAS: A two year classroom experiment with the TI-92. *International Journal of Computer Algebra in Mathematics Education, 6*(2), 143-165.

Marty, J. F. (1997). Centers of triangles exploration on the TI-92. *Wisconsin Teacher of Mathematics, 48*(2), 30-33.

McNamara, D. S. (1995). Effects of prior knowledge on the generation advantage: Calculators versus calculation to learn simple multiplication. *Journal of Educational Psychology, 87*(2), 307-318.

Merriweather, M., & Tharp, M. L. (1999). The effect of instruction with graphing calculators on how general mathematics students naturalistically solve algebraic problems. *Journal of Computers in Mathematics and Science Teaching, 18*(1) 7-22.

Mok, I. A. C. (1999, December). Learning opportunities with graphing calculators: The case of asymptotes. Paper presented at the Asian Technology Conference in Mathematics. Guangzhou, China.

Oldknow, A. (1996). Micromaths: Tea cups, T cubed, discharge and the elimination of drips. *Teaching Mathematics and Its Applications*, *15*(4), 179-185.

Orton-Flynn, S., & Richards, C.J. (2000). The design and evaluation of an interactive calculator for children. *Digital Creativity, 11*(4), 205-217.

Owens, J. (1995, October). *The day the calculator changed: Visual calculators in pre-algebra and algebra*. Paper presented at the Annual Meeting of the North American Chapter of the International Group for the Psychology of Mathematics Education, Columbus, OH.

Pennington, R. (1998). *A study to determine the effect of instruction in effective use of a calculator on test scores of middle school students*. Unpublished Master’s Thesis, Salem-Teikyo University.

Ratliff, M. I., & Martinez-Cruz, A. M. (2002). A stochastic tip-off: Simulating the NBA playoffs with a graphing calculator. *Mathematics and Computer Education, 36*(3), 261-270.

Scheuneman, J. D., Camara, W. J., Cascaller, A. S., Wendler, C., & Lawrence, I. (2002). Calculator access, use, and type in relation to performance on the SAT I: Reasoning Test in Mathematics. *Applied Measurement in Education, 15*(1), 95-112.

St. John, D., & Lapp D. A. (2000). Developing numbers and operations with affordable handheld technology. *Teaching Children Mathematics, 7*(3), 162-164.

Swingle, D. A., & Pachnowski, L. M. (2003). Filling in the gaps: Modelling incomplete CBL data using a graphing calculator. *International Journal of Mathematical Education in Science and Technology, 34*(3) 361-370.

Teppo, A. R., & Hodgson, T. (2001). Dinosaurs, dinosaur eggs, and probability. *Mathematics Teacher, 94*(2), 86-92.

Torres-Skooumal, M. (2001). Alternative assessment models: Assessing through group work and the use of CAS as a self-assessment tool. *The International Journal of Computer Algebra in Mathematics Education, 8*(1), 61-83.

Whitney, M. C. (2001). Exploring the birthday paradox using a monte carlo simulation and graphing calculators. *Mathematics Teacher*, *94*(4), 258-262.

Widmer, C., & Sheffield, L. (1998). Modeling mathematics concepts: Using physical, calculator, and computer models to teach area and perimeter. *Learning and Leading with Technology, 25*(5), 32-35.

Wilson, J., & Brown, R. (1998). Using motion detectors in junior secondary mathematics. *Australian Mathematics Teacher, 54*(3), 14-16.

Wilson, W. S., & Naiman, D. Q. (2004). K-12 calculator usage and college grades. *Educational Studies in Mathematics*, *56*, 119-122.

Windsor, N. J. (1998). Simulating a sampling problem using a TI-83 graphics calculator. *Australian Senior Mathematics Journal*, *12*(2), 32-37.

Table 1. Defining Educational Technology Practices

Curriculum/Subject Area: The general area in which objectives belong.	**Objective:** That which one is trying to teach or influence.	**Educational Practice:** Pedagogical technique believed to promote student learning.	**Technology:** A tool (e.g., pencil, calculator, visual representation software).[6]	**Educational Technology Practice (ETP):**[7] Educational practice combined with technology--synergistic effect on learning.	**Student Outcomes: The measured impact associated with the use of the educational technology practice.**		**Teacher Outcomes/Other Outcomes of Interest**[8]
					Academic	**Behavioral**	
Math	Addition	Drill and Practice	Calculator	Use of a calculator in drill & practice format to help student learn addition	Academic achievement test; teacher grades	Self report of student motivation; observation of on-task behavior	Teacher report of student progress

---

[6] In an educational context, these tools can be used for instructional or assistive purposes. For the purposes of this review, we will focus on instructional technology but will list assistive applications when we present findings (this effort will be separate from the review phase). Technology is a vastly broad concept but can be classified into various types (e.g., screen-based applications, calculators, etc.), and generally only one given type will be focused on for any single review.

[7] Objective + Educational Practice + Technology = ETP; denotes an interface between education and technology. ETP's, and not technology types, will be the focus of all reviews. If a report describes a technology outside the context of an educational practice, it will not be included in a CITEd review.

[8] CITEd will primarily focus on student-outcomes with reported psychometric properties or that have a 1 to 1 correspondence with the construct of interest (e.g., student grades in math). We will consider other outcomes; for example, we may use the quality of outcome measure as a criterion for classifying a study as a promising, emerging, or evidence-based ETP. To the extent possible, CITEd will also gather other information such as cost, required professional development, type of support available from the developer, etc.

Table 2. Continuum of Definitions: Emerging, Promising, and Evidence-based Practices

Emerging Practices	Promising Practices	Evidence-Based Practices
Includes practices that are not based on research or theory and on which original data have not been collected, but for which anecdotal evidence and professional wisdom exists. These include practices that practitioners have tried and claimed effectiveness. Emerging practices also include new technologies that have not yet been researched.	Includes practices that were developed based on theory or research, but for which an insufficient amount of original data have been collected to determine the effectiveness of the practice. If a study uses a weak design (e.g., one-group pretest posttest) resulting evidence will be categorized as promising. The original data can be for students with or without disabilities. If original data have been collected and a strong design has been used but the study only uses a general education sample, we will note this, but the practice may be considered promising or evidence-based depending on the quality of the research.	Includes practices for which original data have been collected to determine the effectiveness of the practice for students with disabilities. The research utilizes scientifically-based rigorous research designs (i.e., randomized controlled trials, regression discontinuity designs, quasi-experiments, single subject, and qualitative research). Other less rigorous research designs may be categorized here depending on how they compare to CEC quality indicators. Subcategories within this category as well as promising practices may be subdivided later, depending on the type of information found. Evidence-based practices will be divided into two types: practices for students w/ disabilities and practices for students without disabilities that may be used with students w/ disabilities.

Table 3. Search Terms for K-8 Screen-based Technology

Mathematics and K-8 paired with:		
Operations	Functions	Virtual manipulatives
Numerical	Venn diagrams	Interactive tools
Measurement	NCTM standards terminology	Concept instruction
Problem-solving	Visual representation software	Math keys
Manipulations	Graphing drawing programs	CampOS
Algebra	Geometry tools	Tenth planet series
Visualization	Geometry software	Cruncher
Simulation	Dynamic geometry software	CABRI
Set theory	Blocks and tiles	Three dimensional objects
Perceptual software		

Table 4. Search Terms for K-12 Calculator Technology

Calculators	Mathematics	Arithmetic
Mathematics achievement	Math computation	TI-83
TI-84	TI-92	Linear functions
Calculator-based ranger	Geometry	Algebra
Graphs	Plots	TI-Instructional Tools

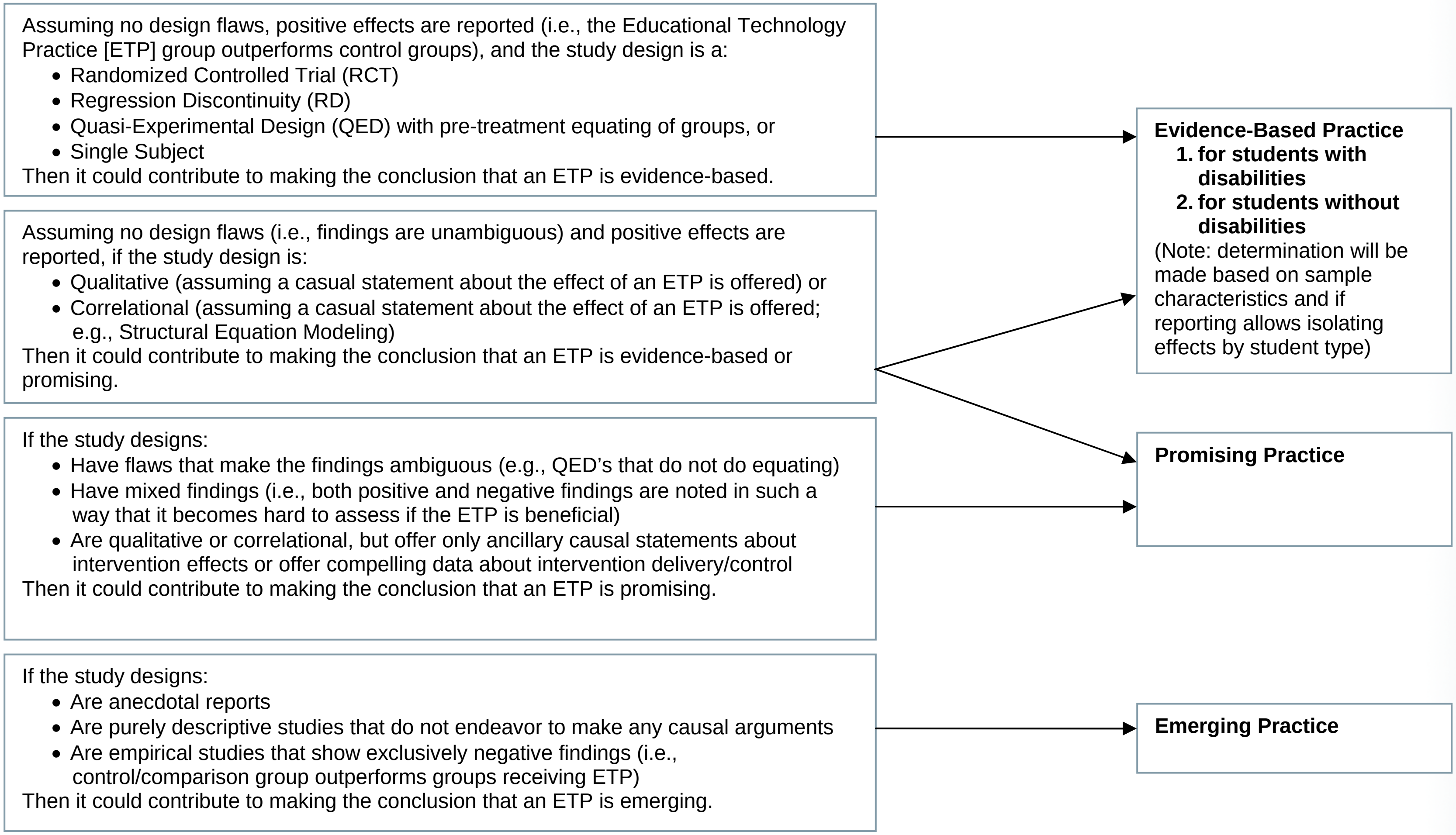
Table 5. Evidence Evaluation Captured for Each Study

This study could potentially be categorized as:	
Level 1 evidence (unambiguous findings) for students with disabilities	Includes practices for which original data have been collected to determine the effectiveness of the practice for students with disabilities. The research utilizes scientifically-based rigorous research designs (i.e., randomized controlled trials, regression discontinuity designs and quasi-experiments). If given this rating determine if: • Findings consistently support the ETP for children with disabilities suggesting this is an evidence-based practice • Findings are mixed, suggesting the practice is promising • Findings consistently do not support the ETP, suggesting the practice is emerging
Level 1 evidence (unambiguous findings) for students without disabilities	Includes practices for which original data have been collected to determine the effectiveness of the practice for students without disabilities. The research utilizes scientifically-based rigorous research designs (i.e., randomized controlled trials, regression discontinuity designs and quasi-experiments). If given this rating determine if: • Findings consistently support the ETP for children without disabilities suggesting this is an evidence-based practice • Findings are mixed, suggesting the practice is promising • Findings consistently do not support the ETP, suggesting the practice is emerging
Level 2 evidence (ambiguous findings)	Includes practices that were developed based on theory, less rigorous research designs (e.g., one-group pretest posttest), or designs with serious flaws (e.g., contamination). • Note if the study was descriptive in nature and causal inferences regarding the ETP's effects cannot be made
Level 3 evidence (anecdotal/descriptive)	Includes practices that are not based on research or theory and on which original data have not been collected, but for which anecdotal evidence and professional wisdom exists. These include practices that practitioners have tried and claimed effectiveness. Emerging practices also include new technologies that have not yet been researched.

Table 6. Screen-based ETPs and Representative Examples

ETP	Example
CAI Hypermedia	Students use computer programs and are given screen-based feedback such as screen prompts to read the question carefully to improve problem solving
CAI Games and Drill and Practice/Reinforcement	Students use computerized games like Alien Addition that have embedded drill and practice to improve math achievement
Enhanced Anchored Instruction	Students used the Adventures of Jasper Woodbury Series developed at Vanderbilt University to enhance their problem-solving performance
CAI General or Unspecified	Students are taught on the computer using an unnamed program to determine if their basic mathematics skills can become automatized
CAI Tutoring and/or Cooperative Learning	Students used computer programs in cooperative settings versus competitive and individual learning settings to enhance their mathematics performance
CAI Screen-based Manipulatives	Students are taught on the computer using virtual manipulatives to determine if their procedural and conceptual knowledge can be enhanced
CAI and Feedback	Students are taught using computer-assisted instruction and receive either attributional or neutral feedback to see if type of feedback affects math outcomes
Web-based Activities	Students use online, real-world activities (e.g., banking, house planning) to improve their conceptual mathematical knowledge

Figure 1. CITEd Synthesis Scheme



Assuming no design flaws, positive effects are reported (i.e., the Educational Technology Practice [ETP] group outperforms control groups), and the study design is a:

- Randomized Controlled Trial (RCT)
- Regression Discontinuity (RD)
- Quasi-Experimental Design (QED) with pre-treatment equating of groups, or
- Single Subject

Then it could contribute to making the conclusion that an ETP is evidence-based.

Assuming no design flaws (i.e., findings are unambiguous) and positive effects are reported, if the study design is:

- Qualitative (assuming a casual statement about the effect of an ETP is offered) or
- Correlational (assuming a casual statement about the effect of an ETP is offered; e.g., Structural Equation Modeling)

Then it could contribute to making the conclusion that an ETP is evidence-based or promising.

If the study designs:

- Have flaws that make the findings ambiguous (e.g., QED's that do not do equating)
- Have mixed findings (i.e., both positive and negative findings are noted in such a way that it becomes hard to assess if the ETP is beneficial)
- Are qualitative or correlational, but offer only ancillary causal statements about intervention effects or offer compelling data about intervention delivery/control

Then it could contribute to making the conclusion that an ETP is promising.

If the study designs:

- Are anecdotal reports
- Are purely descriptive studies that do not endeavor to make any causal arguments
- Are empirical studies that show exclusively negative findings (i.e., control/comparison group outperforms groups receiving ETP)

Then it could contribute to making the conclusion that an ETP is emerging.

Evidence-Based Practice

1. **for students with disabilities**
2. **for students without disabilities**

(Note: determination will be made based on sample characteristics and if reporting allows isolating effects by student type)

Promising Practice

Emerging Practice

CITEd will attempt to make summary statements about whether a practice is evidenced-based, promising or emerging. What will determine this ranking is the number of available studies using various designs, as well as whether their findings support the ETP under investigation. The arrows in the above scheme show that, should a study with no design flaws yield positive findings, it will be suggestive the EPT is evidence-based. If the study has design flaws or yields mixed findings, this would suggest the study is promising, and so on. CITEd will consider virtually any study during synthesis work, making it difficult to establish a priori synthesis rules. CITEd will acknowledge the suggestions CEC recently offered for identifying if there is enough evidence to call a practice evidence-based, and will use meta-analysis techniques should the opportunity to arise. Finally, CITEd will carefully examine qualitative and correlational designs studies that endeavor to make causal statements.

Table 7. Summary of Evidence for Screen-based Technologies by Educational Technology Practice, Mathematics Topic, and Grade Band

Educational Technology Practice[9]	Evidence Synthesis	Number and Operations	Algebra	Geometry	Measurement	Data Analysis & Probability	Multiple Topics
Grades K-2							
CAI Hypermedia	Emerging	Level 1=0 Level 2=0 Level 3=1	Level 1=0 Level 2=0 Level 3=1				Same study addressed two content standards
CAI Games/Drill and Practice/Reinforcement	Promising	Level 1=2[10] Level 2=1 Level 3=4					
CAI General/Unspecified	Promising	Level 1=2[11] Level 2=1 Level 3=0					
CAI Tutoring/Cooperative Learning	Promising	Level 1=1[12] Level 2=0 Level 3=0					
Web-based activities	Emerging	Level 1=0 Level 2=0 Level 3=1					

---

[9] ETPs not listed in the table did not contain any reviewed studies

[10] Findings for one study were mixed and positive and for the other study there were no effects which downgrades the studies to contributing to a promising practice

[11] Findings were mixed and positive which downgrades the studies to contributing to a promising practice

[12] Findings were positive but one study is not sufficient to call a practice evidence-based

Educational Technology Practice[13]	Evidence Synthesis	Number and Operations	Algebra	Geometry	Measurement	Data Analysis & Probability	Multiple Topics
Grades 3-5							
CAI Hypermedia	Emerging	Level 1=0 Level 2=0 Level 3=1	Level 1=0 Level 2=0 Level 3=1				Same study addressed two content standards
CAI Games/Drill and Practice/Reinforcement	Evidence-based/promising	Level 1=5[14] Level 2=0 Level 3=2					
Enhanced Anchored Instruction	Promising	Level 1=0 Level 2=1 Level 3=0					
CAI General/Unspecified	Promising	Level 1=5[15] Level 2=2 Level 3=0	Level 1=1 Level 2=0 Level 3=0				One level 1 study addressed two content standards
CAI Tutoring/Cooperative Learning	Evidence-based	Level 1=2 Level 2=0 Level 3=0					
CAI Screen-based manipulatives	Evidence-based/promising	Level 1=1[16] Level 2=1 Level 3=2					
Web-based activities	Emerging	Level 1=0 Level 2=0 Level 3=1					

---

[13] ETPs not listed in the table did not contain any reviewed studies

[14] Findings for one study were mixed, for another there were no effects, and for a third both groups showed an increase in performance which downgrades the studies to contributing to a promising practice

[15] Findings from two studies were mixed and positive, findings from another study were mixed, findings from a 4th study showed increases in both groups, and findings from a 5th study showed no effects which downgrades the studies to contributing to a promising practice

[16] Findings were positive but one study is not sufficient to call a practice evidence-based

Educational Technology Practice[17]	Evidence Synthesis	Number and Operations	Algebra	Geometry	Measurement	Data Analysis & Probability	Multiple Topics
Grades 6-8							
CAI Hypermedia	Emerging	Level 1=0 Level 2=0 Level 3=1	Level 1=0 Level 2=0 Level 3=1				Same study addressed two content standards
CAI Games/Drill and Practice/Reinforcement	Evidence-based/promising	Level 1=2[18] Level 2=2 Level 3=1	Level 1=0 Level 2=1 Level 3=0	Level 1=1[19] Level 2=0 Level 3=0			One level 2 study addressed two content standards
Enhanced Anchored Instruction	Evidence-based/promising	Level 1=3[20] Level 2=2 Level 3=0	Level 1=3 Level 2=1 Level 3=0		Level 1=2 Level 2=1 Level 3=0		Two level 1 studies counted in two content standards; one level 1 study counted in three content standards
CAI General/Unspecified	Promising	Level 1=3[21] Level 2=1 Level 3=0	Level 1=0 Level 2=1 Level 3=0				
CAI Tutoring/Cooperative Learning	Promising	Level 1=1[22] Level 2=0 Level 3=1	Level 1=0 Level 2=0 Level 3=1	Level 1=0 Level 2=0 Level 3=1	Level 1=0 Level 2=0 Level 3=1	Level 1=0 Level 2=0 Level 3=1	One level 3 study counted in all content standards
CAI Screen-based manipulatives	Evidence-based	Level 1=2 Level 2=0 Level 3=0					

---

[17] ETPs not listed in the table did not contain any reviewed studies

[18] Findings were positive for one of the studies but one study is not sufficient to call a practice evidence-based

[19] There were no effects for this study which downgrades it to contributing to a promising practice

[20] The four level 1 studies represented across content standards all showed mixed and positive findings which downgrades these studies to contributing to a promising practice

[21] No effects for two studies and mixed effects for a 3rd study which downgrades these studies to contributing to a promising practice

[22] Findings were positive but one study is not sufficient to call a practice evidence-based

Educational Technology Practice[17]	Evidence Synthesis	Number and Operations	Algebra	Geometry	Measurement	Data Analysis & Probability	Multiple Topics
Grades 6-8 (cont'd)							
CAI + Feedback	Promising	Level 1=1[23] Level 2=0 Level 3=0					
Web-based activities	Emerging	Level 1=0 Level 2=0 Level 3=1					

---

[23] No effects for this study which downgrades it to contributing to a promising practice

Table 8. Summary of Evidence for Calculator Use by Calculator Type, Mathematics Topic, and Grade Band

Calculator Type	Evidence Synthesis	Number and Operations	Algebra	Geometry	Measurement	Data Analysis & Probability	Testing	Multiple Topics
Grades K-2								
Basic	Promising	Level 1=0 Level 2=1 Level 3=2						
Grades 3-5								
Graphing	Promising	Level 1 = 0 Level 2 = 2 Level 3 = 1[a]						
Grades 6-8								
Basic	Promising						Level 1 = 0 Level 2 = 1 Level 3 = 0	
Graphing	Evidenced-Based		Level 1 = 2 Level 2 = 3 Level 3 = 5				Level 1 = 1 Level 2 = 0 Level 3 = 0	
Graphing	Promising							Level 1 = 0 Level 2 = 1[b] Level 3 = 4
Grades 9-12								
Graphing	Promising		Level 1 = 0 Level 2 = 5 Level 3 = 14	Level 1 = 0 Level 2 = 2 Level 3 = 10		Level 1 = 0 Level 2 = 1 Level 3 = 8		
Graphing	Emerging	Level 1 = 0 Level 2 = 0 Level 3 = 2						

a = Study uses basic and graphing calculators

b = Study addresses geometry and number and operations

Exhibit 1. Sample Product for Practitioners

Using Calculators for Students in Grades K-2

Are your students familiar with calculators? Do they know, at the most basic level, what calculators are used for (addition, subtraction, multiplication, division)? Following are examples of how teachers in three classrooms have incorporated calculator use into their mathematic lessons, from teaching K-2 students how to count to presenting them with basic algebraic concepts.

Before describing these works, a quick caveat is needed. Only one of these studies (Huinker, 2002) used a research design that can potentially show unambiguous evidence that calculators led to better student achievement. But this particular study still did not have clear outcomes, possibly because both the treatment and comparison groups used calculators (things may have been more clear if there was a group that did not use calculators at all). Despite the limited evidence, it's important to let teachers know about what types of calculator practices are available, and judge for themselves if any of these fit with their style and specific classroom needs. If you have bigger questions about whether calculators are beneficial and when, please click here <hyperlink>. Now to those studies…

In one class[1], two teachers worked with kindergarteners and first graders to use a calculator to explore numbers. The students entered different numbers into the calculator, like their age and the number of legs that a spider has. They also added numbers together, anticipating the correct outcome; and talked about number magnitude (i.e., understanding that 1 is smaller than 100, and that it takes longer to count to bigger numbers). The students were also able to look at number relationships (i.e., "one more than," "one less than," and "ten more than") on the calculator. We classified these activities as pedagogical in nature (as opposed to functional), meaning they infused the calculator in teaching concepts rather than simply using it to do computation and drill & practice. The authors also stated that this might help children connect number "words" with the quantities they represent; an NCTM content standard (Number and Operations).

Although the teachers kept track of both their own and their students' experiences with calculators in written journal entries, they did not communicate whether such use led to better student outcomes in math. However, the students in these classes demonstrated increased familiarity with calculators and their functions, a skill that would serve them well in the upper grades.

A teacher in another classroom[2] also used calculators to help her students learn about numbers. In this case, a two-line calculator was used. These calculators can be helpful by allowing students to see a whole formula or equation because there are two lines of text visible in the window. It is possible that this feature might be especially helpful to students with short-term memory deficits.

A final example[3] of using calculators in early grades looks at two approaches to teaching multiplication facts to 28 second-grade students in a public school. All of the children were just beginning to learn multiplication; none of them had received any previous classroom instruction in this topic.

One approach required the students to figure out their own answers to multiplication problems, before checking their work on a calculator. A second group of students entered a problem into the calculator and wrote that answer down on their paper. The two groups of students were assigned by lottery to each of the experimental groups. The goal of this exercise was to determine how students can best learn new multiplication facts. The students were tested individually on 34 problems in two tests that were taken two weeks apart.

Children in both groups increased both their testing time and the number of problems solved during the training. The students who figured out their own answers before checking them on a calculator proved to be ultimately more efficient at the calculations. It would seem that using calculators leads to improved scores in multiplication, whether the students were in the first or the second testing group.

References

[1] Huinker, D. (2002). Calculators as learning tools for young children's explorations of numbers. *Teaching Children Mathematics*, *8*(6) 316-321.

[2] St. John, D., & Lapp, D.A. (2000). Developing numbers and operations with affordable handheld technology. *Teaching Children Mathematics*, November, 162-164.

[3] McNamara, D.S. (1995). Effects of prior knowledge on the generation advantage: Calculators versus calculation to learn simple multiplication. *Journal of Educational Psychology*, *87*(2) 307-318.