Guerrero, S., Walker, N., & Dugdale, S. (2004). Technology in Support of Middle Grade Mathematics: What Have We Learned?. *Journal of Computers in Mathematics and Science Teaching 23*(1), 5-20.

HighBeam Research

Title: Technology in support of middle grade mathematics: what have we learned?(Third International Mathematics and Science Study)(National Council of Teachers of Mathematics)

Date: 3/22/2004; **Publication**: Journal of Computers in Mathematics and Science Teaching; **Author**: Dugdale, Sharon

Use of technology in middle grade mathematics is controversial. Major policy documents have teachers torn between enthusiasm for technology-facilitated mathematical investigation and cautions about undermining students' computational skills. This article examines research concerning use of computers and calculators in mathematics at the middle grade level. The research reviewed relates to teachers' technology experience, teacher and student attitudes, technology implementation trends, and effects of technology on students' skills and conceptual understanding. When technology is used well in middle grade mathematics, it can have positive effects on students' attitudes toward learning, confidence in their abilities to do mathematics, engagement with the subject matter, and mathematical achievement and conceptual understanding. The extent to which this potential is realized depends on the teacher's skill in integrating technology into the mathematics curriculum according to sound pedagogical principles. Careful attention to teacher preparation and development, as well as curriculum revision, are needed to support effective use of technology in middle grade mathematics.

****

The past two decades have seen dramatic growth in the use of technology in mathematics classrooms, diverse and appealing explorations of potential roles for that technology, and sometimes intense debates about the pros and cons of technology in teaching and learning mathematics. The NCTM Curriculum and Evaluation Standards for School Mathematics (NCTM, 1989), with its rather bold statement, "Appropriate calculators should be available to all students at all times" (p. 8), exemplified the high enthusiasm of the late 1980's for the potential of technology to support and enhance the teaching and learning of mathematics.

In contrast, some other prominent policy-setting documents have reflected a more cautious stance. For example, roughly a decade after the publication of the Standards (NCTM, 1989), the Mathematics Framework for California Public Schools (California

Department of Education, 2000) was among the more conservative voices in its assertion that, "Along with the potential of such a powerful tool for doing good, the possibility also exists for doing immense, perhaps incalculable harm" (p. 222). The concerns cited to support this cautionary assertion include anecdotal accounts of poor uses of technology, as well as findings from the Third International Mathematics and Science Study (TIMSS), which suggested that students from top-scoring nations used calculators less than students from countries whose TIMSS scores fell below the international average (Tarr, Uekawa, Mittag, & Lennex, 2000).

Almost concurrently with the release of the technologically-cautious California Mathematics Framework, the NCTM Principles and Standards for School Mathematics (NCTM, 2000) acknowledged the need for careful consideration of how technology is used, but maintained a positive enthusiasm consistent with the earlier NCTM Standards (NCTM, 1989). Indeed, the Principles and Standards document proclaimed that,

> Electronic technologies--calculators and computers--are essential tools for teaching, learning, and doing mathematics. They furnish visual images of mathematical ideas, they facilitate organizing and analyzing data, and they compute efficiently and accurately ... When technological tools are available, students can focus on decision making, reflection, reasoning, and problem solving. (p. 24)

When, as in California, the State-established guidelines for school instruction take a relatively conservative view of the use of technology, teachers can become torn between the cautionary message of their own state guidelines and the more technology-supportive message of the national professional organization with which they identify. In our work with the California Mathematics Education Technology Site (CMETS) (1), we have found middle grade teachers particularly hard hit by these seemingly contradictory messages. They see compelling uses of technology at the high school level, and they understand high school teachers' expectation that students should arrive at the high school level with some preparation and facility with calculators and computers to be ready to engage in explorations that make good use of these tools.

At the same time, middle grade teachers take seriously the cautionary messages about use of computers and calculators at the pre-high school level before all students are facile with computational skills. Further, despite the cautions about using technology "too soon," some teachers believe that middle grade mathematics is especially able to benefit from inclusion of technology. As expressed by one technology-experienced teacher leader,

> The middle school curriculum has the flexibility of being more open-ended. We are not as stuck on following the book. We have fewer restrictions than high school teachers. Many students haven't succeeded with traditional means, and an alternative method is sometimes more effective. I've found that technology can help focus

their attention and build understanding, and that they feel like they are learning something new, even if the work is just fractions.

It is in this context of mixed messages and teachers' concerns that we set out to examine the literature concerning technology use in mathematics specifically at the middle grade level.

REVIEW OF THE LITERATURE

The studies presented in this review were carefully selected from a long list of articles and research on technology in the middle grades. The process used to determine inclusion of various studies was based on an analysis of each study's date of publication, record of peer review, and relevance to mathematics education and technology at the middle grades level. The majority of articles selected for this review were published later than 1990. The few studies included that predate 1990 were thought to be especially substantial as sources of useful data and historical context. It was also decided that only research published in peer-reviewed journals would be analyzed for purposes of this summary; thus, no conference proceedings, dissertations, or other unrefereed articles were used. Finally, an effort was made to include articles that represented a variety of research methodologies and technology-related topics. Articles cited include both qualitative and quantitative studies, project summaries and perspectives, and international comparisons. Studies analyzed for this summary involve the implementation, application and analysis of both computers and calculators.

The use of calculators and computers in teaching mathematics involves a number of issues centered around teaching and learning. Although a large part of the research presented here relates to teacher preparation, teacher and student attitudes, and technology implementation trends within the classroom, we also present findings from a number of studies that address student skills and conceptual understanding. Finally, this synopsis concludes with an international comparison of student technology use and achievement based on data gathered as part of the TIMSS investigation.

Teachers' Technology Experience and Access

Throughout the history of technology usage in education, two elemental concerns have routinely surfaced and served as limitations to implementation of technology in the classroom. Schmidt (1999), in her two-year analysis of teacher beliefs about calculator use in the middle grades, echoed findings from other researchers that the two reasons most commonly cited by teachers for not using technology in their classrooms are (a) lack of experience using technology as part of instruction and (b) lack of availability of calculators and computers. Schmidt and Callahan (1992), in their survey of teachers' and principals' beliefs regarding calculators in the elementary grades, found that although they typically have an open mind about using technology, teachers feel they do not have experience with or understanding of how to use technology as an instructional tool. Technology use is further hindered by the fact that many teachers do not have regular access to technology (Bright & Prokosch, 1995A). Many teachers would like to use technology as part of their mathematics instruction, but lack the practical experience or resources to do so. Limited exposure and insufficient pedagogical knowledge severely limit the usage of technology in mathematics instruction.

Those teachers who have been exposed to technology typically report having very little experience with up-to-date technology. Bright & Prokosch (1995A, 1995B), reported on their two-year middle grades instructional technology inservice training project and noted that teachers' limited experiences encompass outdated technologies, including four-function calculators or computers in drill-and-practice mode as the extent of their knowledge. Inadequate understanding of effective instructional usage of technology further exacerbates the effects of restricted exposure to technology. In his survey of classroom usage of graphing calculators, Milou (1999) concluded that algebra teachers are unsure of how to use the graphing calculator as part of instruction. Evidence suggests that many teachers are willing to use calculators as part of instruction but they need to know and better understand how calculators fit into a mathematics curriculum (Schmidt & Callahan, 1992).

The implication for teacher education, both inservice and preservice, is that there exists an indisputable need for increased teacher training in pedagogical use of technology in the classroom (Bitter & Hatfield, 1993; Schmidt, 1999). As part of their two-year study on the effect of long-term professional development on the teaching and learning of middle school mathematics, Bitter and Hatfield (1993) hypothesized and confirmed that learning to use new technologies involves time, effort, and a rethinking of instructional approaches. Teachers report that lack of time is often a factor making technology use difficult to learn and implement in the classroom (Schmidt & Callahan, 1992). Because it is a time- and energy-intensive undertaking, classroom and administrative support systems and a commitment of resources are necessary elements in the technology-related learning and integration process (Bitter & Hatfield, 1993; Bright & Prokosch, 1995A). Furthermore, teacher training on uses of technology needs to be contextualized. In her study of two different technology integration models, Halpin (1999) concluded that integrating technology instruction with methods courses, rather than learning technology skills in an isolated manner, increases the likelihood that teachers transfer their computer skills into classroom instruction.

Attitudes toward Technology

Teacher and student attitudes toward technology constitute a popular area of educational research. Whereas middle grade teachers express concerns regarding technology use, student attitudes are largely positive and enthusiastic.

Teacher attitudes. Although the use of technology has been widely accepted by high school teachers, there is much debate about whether or not technology is appropriate for middle school mathematics classrooms. Teachers in the middle grades express a variety of fears and concerns about proper usage of technology during mathematics instruction. Many teachers fear that using technology will somehow negatively impact their students' understanding and learning of mathematics (Schmidt & Callahan, 1992). Despite statements such as the one made by the NCTM in 1989 that, "contrary to the fears of many, the availability of calculators and computers has expanded students' capability of performing calculations," (p. 8) teachers continue to be concerned about students' understanding of and competence with basic mathematical skills and processes. Teachers' fears about students not knowing their number facts if technology is used in the classroom remain a primary concern (Schmidt, 1999). Similarly, many teachers fear that students may become too dependent on technology to carry out their mathematical manipulations (Bitter & Hatfield, 1993; Milou, 1999).

Schmidt and Callahan's (1992) survey of elementary school teachers and principals found that, especially in the lower grades, teachers feel little outside pressure from parents or administration to use technology as part of mathematics instruction. Widespread acceptance of technology is further hampered by the fact that teachers question its effectiveness as an instructional tool. Many feel that technology is not as effective in teaching students mathematics as other instructional techniques. Huinker (1996), in her survey of elementary teachers, noted that teachers identified using calculators in instruction as a weakness. If teachers are to decide to integrate technology into their instruction, they must be sufficiently convinced of its utility (Bitter & Hatfield, 1993).

The findings from many of these studies suggest that more teacher preparation and development are needed to make teachers better aware of the potential benefits of technology use during instruction (Huang & Waxman, 1996). Unfortunately, the effects of teacher training programs on teacher attitudes are somewhat mixed. Bright and Prokosch (1995A, 1995B), reported on their calculator and computer inservice training program, and concluded that training appears to have a positive effect on teacher attitudes toward using technology as a part of instruction. Prior to training, these same teachers believed that use of technology was not as effective as other teaching methods in developing student conceptual understanding. In contrast, Schmidt (1999) concluded, based on her calculator inservice project, that there was little change in teacher attitude toward technology use and standards-like instruction once an inservice training project ended.

The difficulty associated with producing and sustaining changes in classroom instruction is a well-documented theme in educational research (e.g., Cohen, 1990; Spillane & Zeuli, 1999). It is not surprising to find similar results in the area of teacher attitude as it relates to instructional change through the use of technology.

Student attitudes. The attitudes of students toward technology use as part of their mathematical learning are far more conclusive and positive than those of teachers. Research indicates that students form their opinions about technology early in their school career and tend to view technology use as a positive experience. However, the manner in which computers and calculators are implemented as part of instruction and learning affects the way in which students view technology as either an instructional or a procedural tool.

Ruthven (1995), in his work with primary school students' representations and views of number work and calculators, concluded that early experiences with calculators in primary school appear to play an important role in the development of students' attitudes toward calculator use. Furthermore, since calculators are the computational devices available to most students, especially in their early years, they are likely to have a large influence on the development of student attitudes toward technology (Ruthven, 1995). While this may appear to contradict findings from other researchers (e.g., Huinker, 1996; Lehman, 1994) about the prevalence of computer, rather than calculator, use as part of instruction during the elementary grades, the distinction here is that children have widespread access to calculators as computational devices in their daily lives outside of school.

Based on their meta-analysis of computer-based instructional studies, Schacter and Fagnano (1999) concluded that students' attitudes toward learning improve when computers are used for instruction. Furthermore, students' confidence in their abilities to do mathematics increases if they are allowed to use a calculator to solve problems and perform some mathematical operations (Bitter & Hatfield, 1993). Some teachers also report that students are more motivated to do mathematics when it involves technology such as graphing calculators (Milou, 1999).

Perhaps the most instructive findings relating technology and student attitudes toward mathematics are how students view technology as part of their own learning process. Students tend to view calculators as procedural tools rather than learning aids (Ruthven, 1995). This prevalent student view, however, can be altered by changes in classroom instructional and learning practices. Students' attitudes toward calculators as instructional tools improve with standards-based instruction (Bitter & Hatfield, 1993). As students engage in more mathematical exploration and problem-solving oriented instruction, they begin to see the calculator as a tool that can enhance their learning and understanding rather than as simply a computational device.

The inference here is the importance of using technology according to sound pedagogical principles. Again, we see a direct implication for teacher training in effective implementation of technology in mathematics instruction. Schmidt (1999) concluded that, following teacher training, teachers showed a change toward problem solving application and away from calculation and drill-and-practice activities. Through training, changes in how teachers apply technology in mathematics instruction can lead to changes in opportunities for students to experience technology as a powerful instructional tool in their learning process.

Implementation Trends

Purpose of technology use. Computer use in educational settings has evolved throughout the last two decades. Becker (1993), reporting results from three national surveys and the 1989 IEA Computers-in-Education survey, concluded that there has been a shift since the early 1980s away from computer programming and toward word processing and database uses among middle and high school teachers. Becker also noted that, among math teachers, drill-and-practice programs, programming languages, and tutorials were the most frequently reported uses during the late 1980s and early 1990s. Similarly, Dickey and Kherlopian (1987), in their survey of over 550 mathematics and 220 science teachers teaching in grades 5 through 9, found that during the mid to late 1980s teachers reported using computers largely for drill-and-practice, educational games, and tutorials. Lehman (1994), in a survey of 80 elementary school principals, found comparable results. Problem solving, demonstration, simulation, graphing, and programming uses were also reported, but with much lower frequencies (Dickey & Kherlopian, 1987; Lehman, 1994). Although types of computer usage evolved throughout the 1980s to include more nonroutine instructional elements, there remained a reliance on computers to provide support for development of rote skills.

By the late 1990s, reported applications of computers during mathematics instruction evidenced less focus on routine skills practice. For example, Berg, Benz, Lasley, and Raisch (1998), in their survey of district-identified exemplary technology-using elementary school teachers, found that the most frequently reported uses of computers in instruction were for instructional planning, student research, and student writing. Less frequently reported, though still identified as important types of application, were Internet applications, problem-solving exercises, basic skills practice, and student use of multi-media authoring software. Of course, these exemplary teachers may have been more sophisticated than average in their implementations of technology.

Trends are also apparent for calculator implementation in mathematics instruction. In their joint project with a major graphing calculator producer, Bitter and Hatfield (1993) surveyed 580 seventh and eighth grade mathematics students. They concluded that students were using graphing calculators extensively for teacher-directed activities, self-directed activities, and understanding of mathematical topics. Over half of students surveyed reported using a calculator for mathematical investigations, when new concepts were introduced, and to practice previously learned skills. Less frequently reported uses included computing grades and checking paper-and-pencil computations. Over three quarters of students surveyed reported using a graphing calculator to do math assignments at home and to work on mathematics in the classroom.

Extent of technology use. Research suggests that computers are used more frequently than calculators across all primary grade levels. For example, in her survey of over 220 elementary teachers, Huinker (1996) found that teachers reported using computers more often than calculators in the elementary grades. Lehman (1994) concluded that as students progress from kindergarten to sixth grade, computer usage, as reported by school principals, steadily increases by almost 40%. Calculator usage also increases significantly, but in contrast to the steady increase of computer use, calculator use increases more dramatically as students approach middle school (Lehman, 1994).

Huang and Waxman (1996) conducted observations of over 1,300 students in 220 sixth, seventh, and eighth grade mathematics classrooms and found contrasting results. They found that within the middle schools in their sample, computers were seldom used and calculators were used only about 25% of the time. The pattern of calculator usage showed that seventh grade mathematics students used calculators significantly more often than their sixth or eighth grade counterparts. The researchers noted that differences between their data and that of other studies may be due to their data being obtained through observations rather than self-reporting. Furthermore, the seventh grade curriculum in the school district used for this study contained many mathematical topics especially well suited to calculator explorations.

Calculators, especially graphing calculators, have emerged in recent years as powerful instructional tools. Although potentially more accessible than computers, due to lower cost and greater portability, calculators are not as widely used in mathematics instruction as one might think. Milou (1999), in his survey of over 140 secondary mathematics teachers, found that only 74% of respondents reported having used graphing calculators as part of their mathematics instruction at any time. Of those who reported using graphing calculators, 60% reported using graphing calculators several times a week, 24% reported using calculators once a week, and 16% reported using calculators hardly at all. Despite the reports of limited calculator usage, 83% of respondents agreed or strongly agreed that students should be introduced to graphing calculators at the Algebra I level. Sixty two percent agreed or strongly agreed that graphing calculators allow algebra classes to cover additional material. Reasons for the differences between teachers' reported use of calculators and their stated support for calculator use are unclear. However, the issues of access and training noted earlier could well account for such discrepancies.

Student Skills and Conceptual Understanding

Many of the studies reviewed address questions regarding the effects of technology on students' mathematical skills and conceptual understanding. Results of these studies are mixed. In their meta-analysis of six studies centered on computer-based instruction at both the elementary and secondary levels, Schacter and Fagnano (1999) concluded that although all of these studies showed positive relationships, none of the results were highly significant. In another study, Childress (1996) attempted to measure the effect of integration of technology on the problem solving skills of 33 eighth graders. He concluded that both the control and experimental groups improved in mathematical understanding following participation in a technology, science, and mathematics integration project, but there was not a significant difference between the two groups.

Some studies have found significant positive relationships between student achievement and technology use in the classroom, but only under certain circumstances or at particular grade levels. Based on their analysis of TIMSS data, Tarr, Uekawa, Mittag, and Lennex (2000) concluded that, depending on how teachers used technology in their mathematics instruction, student achievement varied. TIMSS data obtained from U.S. middle school students showed that when teachers used technology in nonroutine ways (e.g., exploring number concepts and solving complex problems) there was a positive effect on student achievement in mathematics. TIMSS data from middle school Japanese students, however, showed that when teachers used technology in routine ways (e.g., computing values), there was no effect on student achievement. Similarly, Wenglinsky (1998), in his analysis of NAEP (National Assessment of Educational Progress) data from 1996, found that eighth graders who used computers for applications rather than for drill and practice showed significant gains in their average test scores. These studies suggest that when technology is used for nonroutine mathematical applications, it can foster student understanding and intuition and deepen students' mathematical learning.

Some research has suggested that the grade level at which teachers use technology also contributes to dissimilar levels of student achievement. Consistent with previous findings, Middleton and Murray (1999), in their examination of technology use and student performance on standardized tests in grades four and five, found that technology use increased with grade level. Results of their analysis also revealed that technology use was related to significant differences in math scores among fifth graders. However, no significant difference was found among fourth graders.

Other studies have found increased use of technology to be associated with enhanced learning environments and elevated student engagement patterns. Technology can affect a mathematical learning environment by changing a teacher's instructional techniques. Teachers using technology as an integral part of their mathematics instruction have been shown to foster a more constructivist-based learning environment (Waxman & Huang, 1996; Hess & McGarvey, 1987).

Because of their participation in a more engaging learning environment, students become more motivated and engaged with their mathematical learning. Scandura, Lowerre, Veneski, and Scandura (1976) conducted a series of comparative mini-experiments on students in Kindergarten through fourth grade. They concluded that the use of calculators leads to a general increase in student motivation and time on task. Students also showed significant gains in their mathematical skills. Waxman and Huang (1996) found similar results during their observations of over 2100 moderate, slight, and infrequent technology using students. Students in the moderate group were on task significantly more often than students in the other groups. One prerequisite to student success with technology use, however, is instruction on how to use the particular technology. This is especially true for younger students (Scandura, et al., 1976).

Although the results of studies on the effects of technology on student mathematical skills and conceptual understanding are mixed, there is nothing in the research to suggest that the use of technology harms students' social or cognitive development (Hess & McGarvey, 1987). Many of the studies examined report mixed results and insignificantly positive relationships between technology use and student achievement, but none of them report negative effects. In sum, technology has shown potential for positive effects on student engagement and achievement, on teaching techniques, and on the learning environment overall. The extent to which this potential is realized relates to how the technology is used within the mathematics curriculum.

Curricular Development

One challenge in effective technology implementation is a lack of curriculum development that truly realizes the potential of technology in subject matter courses (Becker, 1993; Milou, 1999). Coupled with the need for teacher training in pedagogically sound applications of technology is a need for revised mathematics curricula (Dugdale, Thompson, Harvey, Demana, Waits, Kieran, McConnell, & Christmas, 1995). Often, new technologies get translated into isolated sets of specific skills when introduced to the mathematics curriculum and classroom (Becker, 1993). Typical current technological applications in mathematics classrooms provide basic, but not advanced, mathematical and technological skills (Becker, 1993). With the possibilities of changing emphasis on mathematical topics as a result of technology use in instruction, serious attention needs to be given to questions of what mathematics needs to be taught, the ways in which it should be taught, and how student understanding should be assessed.

International Comparisons

Although several international comparisons were reviewed as part of this summary, only one was deemed especially relevant to the present discussion. Tarr, et al. (2000), examined data from the Third International Mathematics and Science Study (TIMSS) looking for relationships between amount and type of calculator use and student achievement among middle grade students in the United States, Portugal, and Japan. Data from student and teacher surveys indicate that calculator use in the middle grades, and effects on student achievement, vary substantially across nations.

A clear majority of U.S. and Portuguese students and teachers reported high rates of calculator usage. These results suggest that most students have access to calculator technology during instruction and testing situations. Teachers reported using calculators in a variety of ways, including checking answers, tests and exams, performing routine computations, solving complex problems, and exploring number concepts. U.S. data showed significant results relating ways in which calculators were used and student performance in mathematics. When U.S. students used calculators in nonroutine ways like solving complex problems and exploring number concepts, higher order thinking skills, conceptual understanding, and student achievement increased. In contrast, Japanese students and teachers reported a virtual absence of calculators during instruction in mathematics classrooms. When Japanese students did use calculators, they were used for more practical activities such as checking answers and performing routine computations. The Japanese data showed only one significant relationship: a negative relationship between student performance and calculator use on tests or exams. No significant relationships between types of calculator use and mathematical performance were detected for Portuguese students.

Analysis determined that the relationship between frequency of student calculator use and achievement also varied across nations. The relationship between frequency of calculator usage and student test scores was positive but insignificant for students in the United States and negative but insignificant for students in Portugal. For students in Japan, however, the relationship between calculator frequency of use and test scores was negative and significant. That is, the more frequently students reported using calculators the worse they performed on the TIMSS achievement test. Despite these variations in correlation, Japanese students still outperformed U.S. students in all cases.

CONCLUSION

When technology is used well in middle grade mathematics, it can have positive effects on students' attitudes toward learning, on students' confidence in their abilities to do mathematics, and on their engagement patterns, including motivation and time on task. Further, technology use can have a positive impact on students' learning, with significant gains in mathematical achievement and conceptual understanding.

The extent to which this potential is realized depends on how the technology is used within the mathematics curriculum. Research suggests that use of technology for nonroutine applications, such as solving complex problems and exploring number concepts, leads to increased conceptual understanding and higher achievement, whereas use of technology for routine calculations does not.

There is also evidence that teachers who use technology as an integral part of their mathematics instruction tend to foster a more constructivist learning environment. Although it is common for students to perceive calculators as simply computational tools, engagement in mathematical exploration and problem solving with calculators can lead students to broaden their perspective and to see calculators as tools that can enhance their learning and understanding of mathematics.

A clear implication is the importance of the teacher's role in making effective use of technology. If technology is to be implemented productively in middle grades mathematics, substantial teacher training and support are needed. Many teachers would like to use technology as part of their mathematics instruction, but lack the practical experience or resources to do so. Others question the effectiveness of technology as an instructional tool and fear that students may become too dependent on technology to carry out mathematical manipulation.

Teacher preparation and development are needed to educate teachers on how to integrate technology effectively and efficiently into their instruction. Technology experience cast in the context of curriculum and pedagogy, as in a mathematics methods course, is more effective than technology training alone. Teachers need to be aware of the potential benefits of technology in the classroom when used in accordance with sound pedagogical and instructional theories.

Learning to use new technologies involves time, effort, and a rethinking of instructional approaches. Beyond the need for teacher training in pedagogically sound applications of technology, there is a need for revised mathematics curricula that fully exploit the potential of technology. Attention is particularly needed in the middle grades, where the mixed messages of policy documents have teachers torn between the enthusiasm for technology-facilitated mathematical investigation and the cautions about undermining students' computational skills. Technological training and support for teachers, especially in the middle grades, calls for long-term commitments from districts, schools, and the mathematics education community overall.

Notes

(1) The California Mathematics Education Technology Site (CMETS) is a three-year initiative of the California Mathematics Project. Its goal is to assist teachers in making effective use of technology in support of standards-based instruction in mathematics.

REFERENCES

Becker, H.J. (1993). Teaching with and about computers in secondary school. Communications of the ACM, 36, 69-72.

Berg, S., Benz, C.R., Lasley II, T.J., & Raisch, C.D. (1998). Exemplary technology use in elementary classrooms. Journal of Research on Computing in Education, 31, 110-122.

Bitter, G.G., & Hatfield, M.M. (1991). Integration of the Math Explorer[TM] calculator into the mathematics curriculum: The calculator report project. Journal of Computers in Mathematics and Science Teaching, 12, 59-81.

Bright, G.W., & Prokosch, N.E. (1995A). Middle school mathematics teachers learning to teach with calculators and computers. Part I: Background and classroom observations. School Science and Mathematics, 95, 295-301.

Bright, G.W., & Prokosch, N.E. (1995B). Middle school mathematics teachers learning to teach with calculators and computers. Part II: Teacher change. School Science and Mathematics, 95, 338-344.

California Department of Education. (2000). Mathematics Framework for California Public Schools. (Revised Edition) Sacramento, CA: Author.

Childress, V.W. (1996). Does integrating technology, science, and mathematics improve technological problem solving? A quasi-experiment. Journal of Technology Education, 8, 16-26.

Cohen, D.K. (1990). A revolution in one classroom: The case of Mrs. Oublier. Educational Evaluation and Policy Analysis, 12, 311-329.

Dickey, E., & Kherlopian, R. (1987). A survey of teachers of mathematics, science, and computers on the uses of computers in grades 5 - 9 classrooms. Educational Technology (June), 10-14.

Dugdale, S., Thompson, P., Harvey, W., Demana, F., Waits, B., Kieran, C., McConnell, J., & Christmas, P. (1995). Technology and algebra curriculum reform: Current issues, potential directions, and research questions. Journal of Computers in Mathematics and Science Teaching, 14, 325-357.

Halpin, R. (1999). A model of constructivist learning in practice: Computer literacy integrated into elementary mathematics and science teacher education. Journal of Research on Computing in Education, 32, 128-139.

Hess, R.D., & McGarvey, L.J. (1987). School-relevant effects of educational uses of microcomputers in kindergarten classrooms and homes. Journal of Educational Computing Research, 3, 269-287.

Huang, S.L., & Waxman, H.C. (1996). Classroom observations of middle school students' technology use in mathematics. School Science and Mathematics, 96, 28-43.

Huinker, D. (1996). Teaching mathematics and science in urban elementary schools. School Science and Mathematics, 96, 340-349.

Lehman, J.R. (1994). Technology use in the teaching of mathematics and science in elementary schools. School Science and Mathematics, 94, 194-202.

Middleton, B.M., & Murray, R.K. (1999). The impact of instructional technology on student academic achievement in reading and mathematics. International Journal of Instructional Media, 26, 109-119.

Milou, E. (1999). The graphing calculator: A survey of classroom usage. School Science and Mathematics, 99, 133-139.

National Council of Teachers of Mathematics. (1989). Curriculum and evaluation standards for school mathematics. Reston, VA: Author.

National Council of Teachers of Mathematics. (2000). Principles and standards for school mathematics. Reston, VA: Author.

Ruthven, K. (1995). Pupil's view of number work and calculators. Educational Research, 37, 229-237.

Scandura, A.M., Lowerre, G.F., Veneski, J., & Scandura, J.M. (1976). Using electronic calculators with elementary school children. Educational Technology (August), 14-18.

Schacter, J., & Fagnano, C. (1999). Does computer technology improve student learning and achievement? How, when, and under what conditions? Journal of Educational Computing Research, 20, 329-343.

Schmidt, M.E. (1999). Middle grades teachers' beliefs about calculator use: Pre-project and two years later. Focus on Learning Mathematics, 21, 18-34.

Schmidt, M.E., & Callahan, L.G. (1992). Teachers' and principals' beliefs regarding calculators in elementary mathematics. Focus on Learning Problems in Mathematics, 14, 17-29.

Spillane, J.P., & Zeuli, J.S. (1999). Reform and teaching: Exploring patterns of practice in the context of national and state mathematics reforms. Educational Evaluation and Policy Analysis, 21, 1-27.

Tarr, J.E., Uekawa, K., Mittag, K.C., & Lennex, L. (2000). A comparison of calculator use in eighth-grade mathematics classrooms in the United States, Japan, and Portugal: Results from the Third International Mathematics and Science Study. School Science and Mathematics, 100, 139-150.

Waxman, H.C., & Huang, S.L. (1996). Classroom instruction differences by level of technology use in middle school mathematics. Journal of Educational Computing Research, 14, 157-169.

Wenglinsky, H. (1998). Does it compute? The relationship between educational technology and student achievement in mathematics. (ERIC No. ED425191).

SHANNON GUERRERO

University of California, Davis

USA

smguerrero@ucdavis.edu

NORMAN WALKER

Sacramento City College

USA

walker@scc.losrios.edu

SHARON DUGDALE

University of California, Davis

USA

ssdugdale@ucdavis.edu