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ABSTRACT

This report reviews the mathematics program of Miami-Dade public schools in grades 5 through 8 and provides recommendations about how technology might be used to improve learning opportunities for students. The main conclusion of the study and the conceptual foundation for all the conclusions and recommendations is that technology use must be undertaken as part of and within the context of systemic reform. The paper is divided into four sections. The first section reviews the literature to discern what research and best practices suggest are important factors in high-quality mathematics programs. The second section of the paper is concerned with how well Miami-Dade schools are meeting the middle school mathematical goals they have set for themselves. The third section examines technology research, with an emphasis on summarizing very recent studies focused on the use of technology to increase student learning. In the fourth section, recommendations are made that might help Miami-Dade Public Schools incorporate cost-effective interventions. (Contains an annotated list of Internet resources and 68 references.) (MM)

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Middle School Mathematics in Miami-Dade Public Schools: Reform and Technology Considerations

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Introduction

The North Central Regional Educational Laboratory (NCREL) and the Milken Exchange on Education Technology Foundation are pleased to have this opportunity to review the mathematics program in Grades 5 through 8 and provide recommendations about how technology might be used to improve learning opportunities for students. We hope that this review will help the Mathematics and Technology Divisions make research-based decisions that offer the greatest potential for benefiting student learning in the most cost-effective manner. The most significant conclusion of this study and the conceptual foundation for all the conclusions and recommendations is that technology use must be undertaken as part of and within the context of systemic reform. Technology in isolation cannot solve educational problems in Miami-Dade Public Schools or anywhere else.

This paper is divided into four sections. The first section reviews the literature to discern what research and best practices suggest are important factors in high-quality mathematics programs. This first section also draws on a 1999 NCREL study conducted for the state of Indiana, entitled *A Study of the Differences Between High- and Low-Performing Indiana Schools in Reading and Mathematics* and authored by Mary Foertsch and Kim Hufferd-Ackles.

The second section of the paper is concerned with how well (from our perception) Miami-Dade schools are meeting the middle school mathematical goals they have set for themselves. Our evaluation is based on a review of publicly available programs and assessment data. In this section, we also review and report on how Miami-Dade schools compared in relation to international, national, and Florida benchmarks.

The third section examines technology research, with an emphasis on summarizing very recent studies focused on the use of technology to increase student learning. Various research sources were used. However, full reporting of all the research would require hundreds of pages and probably bring confusion instead of clarity. Original research also would require extensive peer review, with timelines much longer than possible for this study. NCREL recently completed three major documents focused on planners, teachers, and policymakers. The major conclusions of those documents, which were extensively reviewed by external experts, are the main sources of this section. (If Miami-Dade Public Schools is interested, NCREL offers it permission—at no cost—to duplicate and distribute those documents as desired, with proper citation and credit to NCREL.) To the extent possible, the technology research we examined is focused on the means for addressing strengths and needs specific to Miami-Dade Public Schools.

In the fourth section, we make a few recommendations that might help Miami-Dade Public Schools incorporate cost-effective interventions. Special emphasis is given to those recommendations that might have considerable potential for positive and cost-effective results in the next three years. Some of the recommendations incorporate technology use; others do not.

Section I. Effective Mathematics Instruction: What Does Research and Best Practice Tell Us?

This section focuses on what current research says about effective mathematics instruction. In particular, we look at two major studies: the Third International Mathematics and Science Study (TIMSS) and the National Assessment of Educational Progress (NAEP).

Any research analysis on middle school students requires that we consider their developmental characteristics. Gary Tsuruda (1998) stated that "the developmental characteristics of students in the middle school age group demand the kind of curriculum advocated by the National Council of Teachers of Mathematics Standards" (p. 3). Traditional content-centered curriculum, dominated by skills, he noted, "is very difficult to sell to students who are intensely curious, egocentric, social, and active. Telling middle school students how to perform a particular procedure without giving it a personal context and then requiring them to sit quietly by themselves to practice the procedure goes against their very nature. More than any other age group, middle school students need a curriculum that challenges them to think, discuss, and solve problems related to their lives" (p. 3).

Tsuruda also noted that "the traditional content-centered curriculum evolved because there was a need for students to know how to perform certain procedural skills. The pretechnological workplace demanded these skills so the schools taught them.... Textbooks supported this model by providing lessons that covered isolated skills algorithmically. Unfortunately, this traditional approach has been ineffective as illustrated by the results of the National Assessment of Educational Progress and the Third International Math and Science Study. Both of those assessments have shown that the traditional curriculum offered in the United States produces students who cannot compute and cannot compete internationally" (p. 4).

The two studies referenced by Tsuruda offer important data on the status of American education.

Third International Mathematics and Science Study (TIMSS)

A very important resource for determining the condition of math and science in the United States is the data derived from the Third International Mathematics and Science Study. TIMSS examined student performance in 41 nations and gave us reliable information on how United States students were performing compared with their international peers.

TIMSS results show that U.S. fourth-grade students are among the very best in the world in science and about average in math. Unfortunately, the longer students stay in U.S. schools, the more their scores drop in comparison to other countries. In fact by the time U.S. students are seniors, they have moved from favorable to among the worst performers in international comparisons of math and science achievement (U.S. Department of Education, 1998, pp. vi, vii, ix).

Researchers have concluded that math and science curriculum in the United States lacks focus, rigor, and coherence. TIMSS shows that middle school students are doing elementary math and science while their international counterparts are doing algebra, geometry, physics, and chemistry. When U. S. high school students do take those courses, the courses fail to offer the necessary conceptual and content understanding needed to apply them in other contexts and settings.

High-scoring countries, researchers determined, study a smaller number of critical concepts and do so to high levels of understanding. Researchers indicated that United States offerings provided superficial exposure to a lot of concepts, which led to a lack of mastering of important content. Even when students are able to solve problems they often do so through procedural routines without conceptual understanding. These conclusions led to a characterization of American curriculum as being a mile wide and an inch deep.

One of the most powerful contributions that TIMSS provided was documenting how differently mathematics is taught in Germany, Japan, and the United States. After analyzing hundreds of videotapes, researchers concluded that United States teachers were primarily concerned with teaching formulas and procedures instead of conceptual understanding and application strategies for solving problems more effectively. Readers are highly encouraged to look at the *Teaching Gap* by James Stigler and James Hiebert (1999) for a more detailed review of the conclusions reached after careful review of those videotapes.

There is no Florida or Miami-Dade data presently available so direct comparisons are not possible. It is our belief, however, that both Florida and Miami-Dade will have difficulty scoring well on the TIMSS-R given performance by other districts with similar profiles.

National Assessment of Educational Progress (NAEP)

A recent study released by the Council of Chief State School Officers, entitled *State Indicators of Science and Mathematics Education* (1999), reported that in 1996, nationally at the eighth-grade level, 23 percent of students scored at or above proficient level in mathematics on the National Assessment of Educational Progress. Florida had 17 percent of its students scoring at or above proficient level. This figure did represent an improvement of 5 percent from 1990, but given that the average gain was 8 percent, this increase put Florida further behind. The actual scores show Florida with an average proficiency of 264 compared to an average national proficiency of 271, from a high of 284 in Minnesota and North Dakota to a low of 233 in the District of Columbia (Figures 1 and 2, pp. 2-3).

At the fourth-grade level, Florida was below the mean but not as far below as in the eighth-grade level. Florida scored 216 as compared to 222 nationally and 232 in Connecticut, Minnesota, and Wisconsin (Figures 3 and 4, pp. 4-5).

The scores of eighth-grade minorities were especially low in Florida when compared to their white peers. Florida was tied for second place for states having the greatest disparity between white and minority students scoring at or above the basic level. While 72 percent of white students in Florida scored at or above the basic level in 1996, only 21 percent of African-American students reached basic proficiency. The national average proficiency for African-Americans was 27 percent.

Thirty-nine percent of Hispanic students reached proficiency in Florida as compared to the national average Hispanic score of 37 percent. The scores in Florida for Hispanic students were close to scores in other states with large Hispanic populations. For example, California had 32 percent proficiency; Arizona, 35 percent; New Mexico, 38 percent; and Texas, 42 percent (Table 4, p. 8).

Examination of instructional practices showed that Florida was not significantly different enough to document attribution to any one practice for either higher or lower achievement. There was no significant difference in reported time spent on mathematics and science in the fourth grade. Florida was close to average in regard to the number of mathematics teachers with majors in assigned fields. This was not true in science, where the state had a huge deficit as compared to the nation. Florida did score higher than average in professional development of teachers in mathematics.

Research Review of Studies on Mathematics

Educators and business people generally agree that mathematics education in the United States is not adequate for contemporary needs (e.g., National Council of Teachers of Mathematics, 1989, 1991, 1998; Shifter & Fosnot, 1993). The recommended shift in mathematics education is to teaching practices that allow and encourage learners to actively explore mathematical concepts in the context of meaningful problems in order to build structures of understanding. In this type of learning scenario, students are given opportunities to comprehend the conceptual underpinnings of mathematical concepts, a "principled approach." This is very different from instructional practices where teachers convey to students how to do mathematical tasks through a procedural or algorithmic approach and focus only on eliciting "right" answers from students (Greeno, Riley, & Gelman, 1984). The National Council of Teachers of Mathematics (NCTM) (1998) asserts that mathematics classrooms should be places where students learn to think about and value mathematics, become confident in their own abilities, become mathematical problem solvers, learn to communicate mathematically, and learn to reason mathematically.

The Colorado Statewide Systemic Initiative for Mathematics and Science (Mid-continent Research for Education and Learning, 1999) determined that there are seven important norms that must be given attention if mathematics and science education is to be improved. They indicated that exemplary teaching of mathematics and science:

- Requires an understanding of the nature of those disciplines and current theory related to their teaching.
- Includes the careful consideration of how content is selected and taught.
- Incorporates an understanding of how learning occurs and uses that knowledge to create opportunities that foster success for all.
- Requires vibrant learning environments that encourage critical thinking and reflection.
- Includes the regular and systemic use of a variety of assessment tools and strategies so that assessment is interwoven with instruction.

- Sustains democratic environments by honoring individuals and cultivating communication in classrooms and schools.

- Includes taking the time to be reflective and making contributions to the profession. (p. 3)

NCREL, in its study commissioned by Indiana (Foertsch & Hufferd-Ackles, 1999), found similar important factors. These are described below.

Effective teaching practices involve finding the balance between learning mathematical content and mathematical processes. Ball (1993b), a third-grade mathematics teacher and researcher, described this as keeping one's ears to the ground, listening to students, while focusing one's eyes on the mathematical horizon. Ball said about her own teaching practices, "My work...aims to create and explore practice that tries to be intellectually honest to both mathematics and the child" (p. 377). Ball's classroom reflects Lampert's (1986, 1990) recommended practice of resting validation for mathematical ideas on students' mathematical arguments and reasoning instead of on the teacher's and the textbook's authority. This approach invites and challenges students to examine assumptions behind traditional algorithms.

NCTM (1998) recommends that the mathematical content teachers cover include tasks that students can access on different levels and that challenge different students in different ways. Mathematical tasks should "fuel students' curiosity and encourage them to talk about mathematics" (p. 31). Effective teachers use a variety of mathematics teaching strategies with a range of student groupings. They also tie together mathematical learning, understanding, and use. All practitioners are encouraged by NCTM to see mathematics as "something to be deeply understood, so that it can be used effectively" (p. 33).

Peterson, Fennema, Carpenter, and Loef (1989) studied a group of mathematics teachers. They identified four tangible constructs that represent fundamental assumptions held by the teachers who were embracing and effectively implementing a meaning-focused approach to teaching mathematics. These are:

- Children construct their own mathematical knowledge.

- Mathematics instruction should be organized to facilitate children's construction of knowledge.

- Children's development of mathematical ideas should provide the basis for sequencing topics for instruction.

- Mathematical skills should be taught in relation to understanding and problem solving. (p. 4).

Stein and Lane (1996) asserted that mathematics instruction that emphasizes meaningful engagement with cognitively demanding tasks supports student math learning. As a result of a study of 23 teachers, Kazemi (1998) added that teachers should press students to think conceptually about mathematics. Kazemi identified four sociomathematical norms that helped create a high press for conceptual thinking:

- Explanations consisted of mathematical arguments, not simply procedural summaries of the steps taken to solve the problem.

- Errors offered opportunities to reconceptualize a problem and explore contradictions and alternative strategies.
- Mathematical thinking involved understanding relations among multiple strategies.
- Collaborative work involved individual accountability and reaching consensus through mathematical argumentation. (p. 411)

Thus, effective mathematics teaching requires teachers to choose mathematics content that makes sense and also to implement effective teaching strategies in order to connect the mathematics with children. Effective teachers recognize when and how to direct discussion and how to balance telling, leading, asking, and summarizing.

Building a math discourse community. The NCTM Professional Teaching Standards (1991) called unprecedented attention to discourse in the mathematics classroom. Three of the six standards for teaching mathematics explained in that document addressed discourse: Teacher's Role in Discourse, Student's Role in Discourse, and Tools for Enhancing Discourse. The term "discourse" is used to describe the ways knowledge is constructed and exchanged in mathematics classrooms. Ball (1991) highlighted the crucial role that teachers play in shaping the classroom discourse because they send signals about what knowledge and ways of thinking about knowledge are valued. An effective teacher shapes an environment where students feel safe sharing their mathematical ideas, students respect one another and themselves, and serious engagement in mathematical thinking is the norm.

The NCTM Standards 2000 document (NCTM, 1998) is built around five standards that describe mathematical content students should learn:

1. Number and operation
2. Patterns, functions, and algebra
3. Geometry and spatial sense
4. Measurement
5. Data analysis, statistics, and probability

There are an equal number of mathematical processes through which students should acquire and use their mathematical knowledge:

1. Problem solving
2. Reasoning and proof
3. Communication
4. Connections
5. Representations

Many elements of the process components require students to communicate verbally or in writing about their mathematical thinking.

By developing a mathematics discourse community in the classroom, teachers and students can help one another meet NCTM goals (see NCTM Standards 2000 for a complete list), which are for all students to:

- Apply a wide variety of strategies to solve problems and adapt the strategies to new situations.
- Monitor and reflect on their mathematical thinking in solving problems.
- Make and investigate mathematical conjectures.

- Develop and evaluate mathematical arguments and proofs.
- Express mathematical ideas coherently and clearly to peers, teachers, and others.
- Extend their mathematical knowledge by considering the thinking and strategies of others.
- Use the language of mathematics as a precise means of mathematical expression.
- Recognize and use connections among different mathematical ideas.
- Create and use representations to organize, record, and communicate mathematical ideas. (pp. 49-50)

The type of teaching and learning environment presented by math reformers is a vastly different classroom situation than most children experience. Research reveals the need for change in classroom math discourse patterns (Cazden, 1988; Goodlad, 1984; Lampert, 1990). After a large study of schooling, encompassing over one thousand classrooms, Goodlad (1984) reported that elementary children spend the majority of their time in school listening to a teacher talk or doing skills practice. Specifically, in elementary math classes, teachers present concepts and algorithms that students practice independently. Teachers rely on rote teaching and depend on textbooks. This type of instruction forces students to be almost totally dependent for learning mathematics on what the teacher says. Because no one else explains their thinking, students and teachers remain unaware that other strategies exist or are feasible. The results of Stodolsky's (1988) study of 21 elementary teachers indicated that teachers provide more possible routes to learning in social studies classes than mathematics classes. As a result, students are left believing that they can "figure it out" in social studies, but not in math. Significantly, even when teachers desire to modify their teaching in response to reform initiatives, they often only implement the large piece of a new reform and they continue with the same traditional routines for producing and sharing knowledge (Leinhardt, 1993; Spillane & Zeuli, 1997). Effective teachers implement new mathematical tasks and change the classroom discourse norms.

Observations in traditional classrooms rarely yield evidence of connected discourse between students and the teacher, or with other students. Furthermore, Goodlad's (1984) study found few classrooms in which individuals cooperate to ensure each other's success in the pursuit of commonly held goals. The prevailing practice of frontal teaching runs counter to Vygotsky's view of teaching as assisted performance, to reformers' call for opportunities for students to learn within a wider community, and to the economic need to help more students succeed in school mathematics. Development of a classroom discourse culture provides everyone with learning opportunities that are not available in a traditional classroom. Gallimore and Tharp (1990) propose that the task of effective schooling is "creating and supporting instructional conversations among students, [and] teachers" (p. 197).

The effective classroom mathematics teacher alters the traditional roles of teachers and students to match those advocated by reformers of mathematics education. Effective teachers develop a discourse community by following up on and engaging in mathematical arguments with students (Cazden, 1988; Lampert, 1990).

This strategy lets them model mathematical tools and conventions by participating in the discussion and by assisting students in making their thinking public. Teachers can also listen to student thinking in order to plan their teaching strategies and for future lessons. The student's role becomes one of finding solutions to problems and then articulating and defending them. The strategies that students use become the material for math discussions. Lampert (1990) asserts, "generating a strategy and arguing for its legitimacy indicates what the student knows about mathematics" (p. 40). This type of math classroom, engendering discourse about the mathematical thinking of its members, operates very differently from a traditional math class in which the teacher "teaches" the book. It has the potential to give students a much broader picture of the discipline, patterns, and connections in the discipline, and a deeper understanding of math concepts.

Equity in mathematics teaching: Mathematics for all. NCTM (1998) states, "Those students who have many opportunities to study well-taught, important mathematics are more likely to gain mathematical proficiency—and the associated educational and employment advantages—than students who have fewer such opportunities" (p. 21). Students' proficiency in mathematics is often used to base decisions about tracking, further schooling, and job opportunities. Unfortunately, there is a pervasive belief that a sector of our student population is not capable of acquiring proficiency in mathematics (Anyon, 1981; Spillane & Jennings, 1996). Ironically, in many of the same educational communities there is the belief that *all* students can read and write in English.

A common argument or deep-seated belief held by many teachers and administrators that effectively blocks change in mathematics education is that students need to attain a basic competency in math skills before they will be able to work with aspects of math that require higher thinking (Peterson, Fennema, Carpenter, & Loef, 1989). Unfortunately, this perspective results in many students never being given opportunities to experience teaching that focuses on the understanding of ideas and concepts rather than rote memorization of facts and algorithms. Teachers often provide students with rote strategies for remembering procedures (Knapp, 1995). The goal held by reformers that *all* students be able to master basic skills and think mathematically may not be attained because many educators believe that their students are lacking basic skills. Teachers respond to their students' needs to learn math by concentrating on basic skills *and* they ignore calls to incorporate more challenging content (Spillane & Jennings, 1996). Or, they are skeptical of the ideas of math reform (Wilson, 1990) and thus hold to the traditional view that students should memorize before they will understand math concepts. In opposition to this perspective, reformers argue, and some studies indicate, that with the appropriate support, all students can engage in higher thinking (Fuson, Smith, & Lo Cicero, 1997; Carpenter, Fennema, Peterson, Chiang, & Loef, 1989).

Effective mathematics instruction and student achievement. Many educators are concerned that students who are in classrooms with teaching and learning as described by NCTM and other reform groups will not achieve as well as students in classrooms with traditional, skills-based teaching practices. Studies led by Knapp and associates (1995), Fennema et al. (1996), and Mayer (1998) address these concerns.

Knapp and associates (1995) studied teaching and learning in 140 high-poverty classrooms. They found that students exposed to meaning-oriented mathematics instruction performed higher than students receiving skills-oriented instruction. In Grades 1, 3, and 5, children performed 6.4 national curve equivalents (NCEs) higher, and in Grades 2, 4, and 6, 1.7 NCEs higher on the Concepts and Applications Test. In addition, children's learning of discrete skills was no worse in the meaning-focused mathematics classes than in classes that were oriented toward discrete skill learning. As a result of this study, Knapp and associates recommend that schools can help all children gain greater understanding of mathematical concepts and reason mathematically by:

- Orienting curriculum and instruction toward conceptual understanding of mathematical ideas and procedures.
- Broadening the range of mathematical content studied. (p. 48)

Fennema et al. (1996) followed, over a four-year period, 21 first-, second-, and third-grade teachers who were participating in cognitively guided instruction, a teacher development program focused on helping teachers understand mathematical thinking. As teachers' roles changed from demonstrating procedures to helping children build on their mathematical thinking by engaging them in problem solving and talking about their mathematical thinking, student achievement improved. Achievement was higher in the areas of concepts and problem solving, with no overall change in computational performance. The concepts and problem-solving tests that were administered included single-digit and multi-digit addition, subtraction, multiplication, division word problems, and items that measured place-value concepts.

In addition, Mayer (1998) used data from 40 teachers, 2,369 students, and 40 schools to demonstrate that middle and high school algebra students' performances on standardized tests were not undermined by teaching practices that were consistent with NCTM recommendations. Furthermore, the NCTM teaching approaches did not hinder low-achieving students.

In conclusion, effective schools incorporate meaning-oriented instruction for all students in safe classroom environments. Students study well-chosen content from coherent curricula and teachers use a range of teaching strategies and approaches. In these schools, teaching and learning builds productively on students' prior knowledge and experience and engages student interest.

Key Differences in Critical Mathematics Program Features in High-Achieving and Low-Achieving Schools in Indiana

In an Indiana study conducted by NCREL (Foertsch & Hufferd-Ackles, 1999), three critical program features were identified as key qualities and characteristics of best practices in mathematics instruction: instructional practices, high expectations for student achievement, and the need for professional development

Instructional Practices

The analyses of instructional practices within classrooms document the fact that, on average, teachers within higher-achieving schools operate their mathematics classrooms differently than do teachers in lower-achieving schools. Our observation instrument looked at mathematics instructional practices in the areas of meaning-focused math teaching, collaboration in a math learning community, pursuing high-level mathematics for all students, and building on traditional instruction. The differences observed in each of these areas are described below.

Meaning-focused math teaching. Teachers in the higher-achieving schools pressed students to make sense of the mathematics they studied. They provided students with activities (often using manipulatives) that allowed them to build meaning around mathematical ideas. The teachers encouraged students to try out strategies rather than use algorithms to memorize a particular procedure. For example, one teacher presented a money lesson in which students practiced with their coins in various ways to come up with total values and figured out methods for counting them. In doing this task, children become comfortable counting by tens and fives, which will later help them make the transition into multiplicative thinking. Doing meaning-oriented activities like this also allows students to consider and examine different strategies. One student said that he made 27 cents using 1 dime and 17 pennies.

As various strategies were presented, students were asked to defend the answers they created. For example, one student explained, "You need 1 dime to make 14 cents because it's 10 cents plus 4 cents."

Teachers in higher-achieving schools linked mathematical language to symbols, notation, and discourse. These teachers seemed to fully understand the mathematical goals in their lessons. They modeled the use of mathematical language by incorporating it throughout their math time. One teacher asked students if they had "less than ten" or "more than ten" pennies as she walked around the room passing them out. Another teacher asked her students to take out a yellow hexagon and a red trapezoid. Then she asked students to cover the hexagon with the trapezoid. The class discussed how much of the hexagon was covered by the trapezoid. Students used the language that had been modeled for them. Rather than focusing on memorizing the terms, this teacher helped her students grow comfortable using them.

Students in higher-achieving schools were confronted with questions from teachers that made them think deeply about the content they were studying: "What number problem will tell the story of this picture?" "Where did that answer come from?" "How did you get that answer?" "What helped you decide on that?" "How do you know which shape is a rectangle and which is a square?" These questions pressed students to think about the mathematical meaning beyond a simple answer.

Teachers in higher-achieving schools also worked to make math meaningful by establishing connections for students within and between mathematics domains. NCTM (1998) states that "students will better acquire and utilize mathematical knowledge from coherent curriculum" (p. 29). Successful Japanese schools build math lessons around one central topic and develop and extend from there. One teacher in a higher-achieving school connected the idea of half of a shape to half-past on the clock. In another class students explored number families by using triangle cards and discussing the numbers' relationships to one another. The class together came up with various related number sentences. Helping students to see the interconnectedness among $11 - 7 = 4$, $11 - 4 = 7$, and $4 + 7 = 11$ will make students' transitions between addition and subtraction more smooth. Also, memorizing one statement gives students the means to find the other two. In general, these teachers reminded their students about past related lessons and helped them to see day-to-day connections. At the beginning of her lesson, one teacher asked, "What do we already know about adding even numbers?" Another teacher asked her students to describe what they had done the day before.

In lower-achieving schools, teachers also used a variety of manipulatives; however, the push for meaning and understanding beyond the tasks was not apparent. For example, in one class the teacher led a lesson on probability. The teacher had students take turns shaking and dropping pennies and reading heads or tails. The teacher kept track of the instances of each on the chalkboard. The ensuing discussion focused on the totals recorded and how to keep track with tally marks. The teacher missed the opportunity to discuss the topic of probability and explorations of applications or extensions of the concept. Another teacher seemed to have the goal of making mathematics meaningful by creating a story of a doubling pot. She used students to act this out as stirrers and as part of the soup. However, the students were unable to understand the connection between the doubling pot and the idea of making doubles by adding two like numbers. In general, teachers in lower-achieving schools used mathematical tasks, but did not press their students to think meaningfully about the mathematical issues they were exploring. The students were more likely to be going through the motions.

The majority of questions teachers asked were answer driven rather than exploratory or they were questions that required justification from the students. It was not as clear that all of the teachers in the lower-achieving schools felt confident with the mathematical goals of their lessons. They did not use the language of the mathematical domain as naturally in conversations with students. One teacher said to the students, "I don't know why they make me say half past 9. Most people say 9:30, but they want me to teach it to you, so I've got to." This teacher missed an opportunity to connect the concept of half and time (the clock) with his students.

Collaboration in a math learning community. Observers noted that in higher-achieving schools, classrooms were inviting learning communities. For example, classroom discourse was described as two-way dialogue, and students were comfortable taking the initiative, trying things out, and expressing their thoughts. The classes were described as student centered rather than teacher centered. The teachers took on the role of learner along with their students. In several of the classes, students made up their own problems, which the whole class would try to solve. In one class, all the students practiced addition facts using flash cards. After the practice, they decided as a group that they needed to focus more on fact practice and working with their flash cards. The teacher did not make this decision for the students. Another class co-constructed the idea of estimation as they sat together on the rug. Another class sat on the rug and co-constructed the definitions of square and triangle that accurately expressed why they are different.

The teachers in the higher-achieving classrooms often embedded the mathematics they studied in the lives of the children to make it meaningful. For example, one teacher had students lie down flat on the ground (like nap time) and then stand up tall with their feet together. This led to a productive discussion of horizontal and vertical. Other teachers talked about gymnastics, going to a candy shop, and having parties to help students contextualize addition and subtraction math problems. In most of the higher-achieving schools, there was evidence of students listening as other students explained their math thinking (another learning community attribute). One class clapped twice if they agreed with a student's explanation. In another class students did a "thumbs up" if they agreed with another student's solution. The classroom climates also seemed to lend themselves to students helping one another as they worked in small groups or when the teacher was unavailable. One teacher told a student to work with his group so he could explain how he did a problem.

The teachers observed in the classrooms of the lower-achieving schools primarily led teacher-centered classes. The principle form of dialogue was one-way, from teacher to student, with the teacher doing all of the explaining of mathematics. One teacher did not allow time for questions or show interest in receiving them. Her focus was on moving along and getting started on individual worksheets. In another class, students did not appear to grasp telling time on the clock or the concept of doublers, although these topics were the focus of their lesson. Students looked on each other's papers to finish their work. Because there was less student-directed dialogue, teachers missed opportunities to assess and support student understanding and to make shifts in practice.

Pursuing high-level mathematics for all students. Teachers in the higher-achieving schools had a philosophy embedded in their teaching that *all* of their students could do the math. They verbalized that belief and their actions reflected it. These teachers made efforts to make sure their students had the prerequisite competencies before moving to more difficult work. They did this by filling in gaps in understanding and by connecting new math material to past material students studied. As mentioned earlier, before starting a new lesson, one teacher asked, "What do we already know about adding even numbers?"

There were high expectations in the classes of higher-achieving schools that all students would participate in the discussions. Teachers were aware of individual progress and geared their instruction to individual needs in their classes. They were able to express indicators they used for student understanding, such as students are using the math language, they can explain their work, and students are able to solve correctly. These teachers expected students to make errors and often created meaningful learning opportunities from them, without diminishing the value of the original idea.

Several teachers in the lower-achieving schools' mathematics classes arranged for struggling students to be supported by classroom aides or pull-out resource staff. Some teachers believed that not all of their students would understand all of the mathematics being covered in their classrooms. Meaning-oriented instruction for all students was pushed aside, in the case of one teacher, due to a belief that the teacher needed to push through content.

Because the classes in the lower-achieving schools tended to be teacher centered, the opportunities for the teacher to assess the students were less varied. Most assessment was done through written work. Students spent more time in class individually completing worksheets than did their counterparts in the higher-achieving schools.

Building on traditional instruction. Important traditional practices are being used effectively in math classes in the higher-achieving schools. Teachers explain and provide students with opportunities to explain. One observer noted, "This class has a great balance of teacher and student explainers." Teachers assist students in learning productive roles in the class so that they might take the initiative in their own learning and continue with productive tasks when the teacher is helping other students. Teachers who were conducting lessons about addition and subtraction conveyed the importance of learning the facts. In addition, they equipped students with strategies to find the facts. As mentioned previously, one class of students set their own goals to practice their facts. Students in the classes of higher-achieving schools also got help when they needed it from their teacher or peers.

Traditional practices were also present in the lower-achieving schools. They were actually present to a greater extent than we would like to see. There was a lot of teacher telling, teacher-directed tasks and activities, and answer-driven questioning present. One observer noted, "No questioning, teacher gives directions." Teachers pushed students through content (some teachers seemed to talk over students' heads) and got them started on worksheet activities. The push through content often circumvented substantive exploratory discussions of mathematics. In one classroom, the observer noted, "She's focused on moving along, getting to the worksheet." As a result, students had less opportunity to explain their mathematical thinking and to hear the mathematical thinking of others. Teachers seemed comfortable with the classroom norm that conversations were teacher led and few opportunities were taken to assist children in learning productive roles such as questioning, explaining, and evaluating. One observer noted that the teacher valued the ability to follow directions and worked on this with students. In the math classes in lower-achieving schools, students often put their work up on the board, but did not explain their mathematical thinking behind the work.

The teaching practices seen in the mathematics classes in the higher-achieving schools exhibited many of the characteristics that research indicates are important for successful mathematics education. Some of the same practices were seen scattered throughout the math classrooms of the lower-achieving schools, but the approaches were not as coherent and connected.

Data analysis has generated six areas in which teachers and mathematics classes varied in the higher- and lower-achieving schools. It is interesting to note that these differences were apparent even in schools implementing the same curriculum. The table on page 14 summarizes these differences.

That such differences exist is not all that surprising. Teachers across the country are being asked to implement teaching practices that support more challenging content learning for all students, and for many teachers this is a difficult task. A number of explanations have been

Higher-Achieving Schools	Lower-Achieving Schools
Teachers and students participate in two-way conversations about mathematical issues.	Conversations tend to be one-way; the teacher tells information to students or looks for answers and moves on.
Classes exhibit the characteristics of learning communities. There are norms in place that students and teachers are learning together.	Few learning community characteristics exist. Individuals are more disconnected.
Teachers push for mathematical meaning behind the students' tasks.	Teachers lead mathematics tasks; however, meaning-oriented discussion is missing.
High expectations exist that all will learn.	Expectation exists that there will be other sources of help that will fill in the gaps for struggling students.
Teachers build continuity in the mathematical domain from day to day.	Little continuity is built in mathematical content from day to day.
Students are comfortable with classroom routines and expectations and take initiative in their progress (e.g., students know where to find enrichment materials when finished with assignments and get started on their own).	Classroom routines are teacher initiated rather than student initiated. Lots of teacher reminding of expectations occurs.

offered for the unsuccessful implementation of these pedagogical reforms (e.g., Cohen, 1990; Spillane, 1995; Wilson, 1990). First, teachers believe that disadvantaged students are not ready for more advanced mathematical challenges and need to be brought up to speed on basic skills before they can do more challenging math thinking (Spillane & Jennings, 1996). Second, teachers often prefer to retain the behavioral and intellectual control of their classrooms to save time and prevent situations of uncertainty for themselves as well as for their students (Anyon, 1981; Good & Brophy, 1987; Pimm, 1987).

Teachers' fears of releasing the intellectual reins in their classes are exacerbated by their lack of mathematical knowledge about the subject matter and its pedagogy. As a result, they fall back on traditional teaching practices where they are the experts and knowledge flows unilaterally from the "expert" teacher to the "novice" students. This is not surprising because most teachers' own experiences with math have not included a conceptual emphasis or support for deeper understanding (Ball, 1993a, 1996). Rather they likely absorbed lessons of how to teach mathematics from their own traditionally oriented classroom teachers (Cohen, 1989; Cuban, 1992).

Additional research (Wood, Cobb, & Yackel, 1991; Fennema et al., 1996) supports the argument that teachers can learn content knowledge *while* implementing teaching for understanding. Wood et al. (1991) affirmed the effectiveness of teacher development for changing mathematics practice in their case study of a second-grade teacher. This teacher learned while implementing changes prescribed by the research team. She learned about her role, the students' role, and the nature of mathematics as she "encountered situations that were in sharp contrast to her previous experiences in teaching math" (p. 588). The teacher learned that students had their own ways of thinking about math. She also learned that her role did not have to be one of transmitting information, but that she could be a guide for students' thinking.

High Expectations for Student Achievement

Students who succeed have teachers who expect them to succeed. At every level in every classroom, the teachers who participated in this study said they focused on student's strengths and weaknesses with appropriate instruction. Teaching and assessing a variety of skills and capabilities also emerged as important characteristics of effective instruction, so that success or failure does not depend upon a few things that only a few students do well. Effective teachers try to find the best instruction by being flexible in their approach to instruction, knowing when students need additional help, organizing cooperative work groups, and meeting with parents to discuss how they can support learning at home. At the same time, teachers and administrators must work in concert to ensure that the necessary resources are available.

When students are interested in what they do and when they understand why a task is worthy of effort, they are capable of significant accomplishments. Students tend to be motivated by—and rise to—the highest expectations.

Need for Professional Development

Curriculum implementation issues are salient in our nation's schools. However, it is important to note in this study that reform-oriented curriculum may be implemented, with teachers still understanding and using the curriculum in traditional or ineffective ways. One teacher can lead a lesson on probability that focuses on rich exploration and another teacher may focus on students' recording their coin flips with tally marks. Curriculum lessons do not stand alone; teachers may need support in implementing them in the ways that they are intended.

NCTM (1998) reminds us, "Those students who have many opportunities to study well-taught, important mathematics are more likely to gain mathematical proficiency—and the associated educational and employment advantages—than students who have fewer such opportunities" (p. 21). In order to facilitate these types of learning opportunities for children, instruction needs to support student engagement with mathematically challenging tasks (Stein & Lane, 1996). Teachers need to be regularly supported by professional development opportunities to accomplish this goal. Professional development, if implemented, has the potential to support teacher learning in the areas of mathematics content and mathematics pedagogy (Cohen & Hill, 1997; Fennema, et al., 1996; Wood, Cobb, & Yackel, 1991). Our observations indicate that this is an area of need for the lower-performing schools.

Section II. Systemic Mathematics Reform in Miami-Dade Public Schools

Miami-Dade Public Schools is to be commended for its exemplary and detailed attention to systemic reform in mathematics. Special commendations need to be given to the work of the Urban Systemic Initiative. As a result of their work:

- New curriculum guides appear to be aligned with the National Council of Teachers of Mathematics Standards and with the Florida Sunshine State Standards.
- District officials have given thoughtful attention to the needs of learners, teachers, parents, and the community and to making them active partners in finding solutions for increasing students' learning.
- There appears to be significant and very positive alignment between the Florida state curriculum standards and assessments and the curriculum guide resources provided by the district.
- There appears to be districtwide commitment to having high standards for all students.

It is important to note that these positive observations are based on examination of the work of the Central Office and not on observations of schools implementing them. The most serious deficit of this study is that sufficient observation of school implementation was not possible. Consequently, this study had an overdependence on documents that were in some cases self-reporting.

In order to judge how well Miami-Dade Public Schools are performing in their mathematics achievement, it is necessary to establish comparison benchmarks. In this analysis we have carefully studied data from the Miami-Dade Urban Systemic Initiative report and the Florida Comprehensive Assessment Test (FCAT) and found it extremely valuable in analyzing minority achievement as noted below.

Miami-Dade Urban Systemic Initiative Data

Student performance in mathematics has improved during the five years that the Miami-Dade Urban Systemic Initiative has been in operation. Median percentile scores increased at each grade level from second through eighth. This increase was true for all ethnic groups, with the most dramatic growth evident for African-American students who demonstrated growth rates of over 50 percent during the five-year period as measured by the Stanford Achievement Test. Hispanic students increased in all grade levels but especially in Grades 5 and 10, and the gap between Hispanic and white students decreased by nine percentile points.

African-American enrollment in Algebra 1 increased 167 percent between 1993 and 1999 and 116 percent in geometry. Hispanic students increased their participation in algebra by 149 percent and in geometry by 91 percent. Given a much larger base of students, it is not surprising that there was a slightly larger percentage of students who did not complete those courses.

Similar positive trends are reported for geometry and Algebra II. Geometry enrollment increased by 84 percent for all students and by 116 percent and 91 percent, respectively, for

African-American and Hispanic students. Algebra II enrollment increased by 59 percent for all students and by 88 percent and 66 percent, respectively, for African-American and Hispanic students. The increase in total number of African-American and Hispanic students who did graduate with the advanced mathematics was extraordinarily dramatic, increasing by 83.7 percent.

Florida Comprehensive Assessment Test (FCAT)

The primary data source used for comparisons of Miami-Dade achievement was the Florida Comprehensive Assessment Test (FCAT). Specifically, we used the mean score of Florida total student population scores as contrasted to those of Miami-Dade students to determine areas of strength and deficits. There is at least one caveat that needs to be expressed in using state scores as the major source for comparisons. The National Assessment of Educational Progress (Blank & Langesen, 1999) revealed that Florida scores were in the middle nationally and that 22 states had a significantly higher percentage of students who were "at or above proficient on NAEP" (p. 2). Traditionally high-scoring states such as Maine, Montana, North Dakota, Wisconsin, Massachusetts, and Minnesota have scores that were 15 percentile points higher than Florida.

On the FCAT, the news is quite positive for Miami-Dade fifth- and tenth-grade students. Grade 5 students achieved a significant increase of 12 points on the math section of the FCAT from an average of 282 to 294 and tenth graders increased from 286 to 296 for a gain of ten points. Eighth-grade students improved their achievement from 282 to 284 but that gain was actually less than that for the state of Florida as a whole. The scores for African-American students in the eighth grade actually declined one point. All the data points out that Grades 5 through 8 need the most specific interventions.

Analysis of student achievement data revealed that Miami-Dade students were scoring 12 to 18 percent below state averages in mathematics by the time they reached fourth grade. Interviews with Miami-Dade staff and research from other urban locations suggested that students likely came to school in kindergarten with about the same level of deficiency noted at the fourth grade. In other words, the school readiness of Miami-Dade students put them behind state averages before they had ever entered schools. It takes considerable effort to overcome those preschool deficits and, for this reason, value-added is the best measure of a school's success and not necessarily the raw score that compares economically advantaged students with poor students.

While those Miami-Dade elementary student deficits must be looked upon as a problem to be solved, there is good news in that the deficits for students did not become greater as they continued in school. Research findings, especially those coming from the Third International Mathematics and Science Study revealed that increasingly larger deficits in achievement occurred as students attended middle and high schools. Compared to the achievement of other students in other countries, United States students lost ground in every grade that they were in school. That didn't happen in Miami-Dade Public Schools. Although they were unable to overcome the original deficits, they were able to prevent those deficits from increasing in relation to Florida benchmarks. And, as evidenced in the report of the Urban Systemic Initiative, they have been reducing those deficits.

An important component of analyzing student achievement is disaggregation of achievement by content subscores. In much of our other work, we have found considerable difference in achievement in the subscores. The general pattern in other settings is that urban (and very rural) students score much worse in the areas of algebraic thinking, data analysis and probability, and especially problem solving when compared to suburban students. It is to Miami-Dade Public Schools' credit that its problem-solving scores are not following that urban trend.

As noted in the previous paragraphs, Miami-Dade scores are lower than the average for Florida when students reached the fourth grade. On the Stanford Achievement Test, Miami shows great gains. However, Miami-Dade schools appear to lose a little ground in comparison to Florida schools on the FCAT in three of the five subareas of mathematics between the fifth and eighth grade. Because the declines were only one unit lower, this decline is not statistically significant. One explanation is that Florida test scores as measured by the FCAT are improving more rapidly than Miami-Dade's scores (see Figures 1 and 2).

The FCAT data for Miami-Dade Public Schools raise concerns about algebraic thinking where there was a two-unit decrease between the fifth and eighth grades. Miami-Dade Public Schools did not lose ground on geometry and spatial sense where the minus six units deficit remained exactly the same in Grade 8 as it was in Grade 5. The subscore differences between the fifth and the eighth grade may be due to statewide improvement in those areas, thereby raising the comparison mean (see Figure 3).

Figure 1
Grade 5, 1999 Subscores

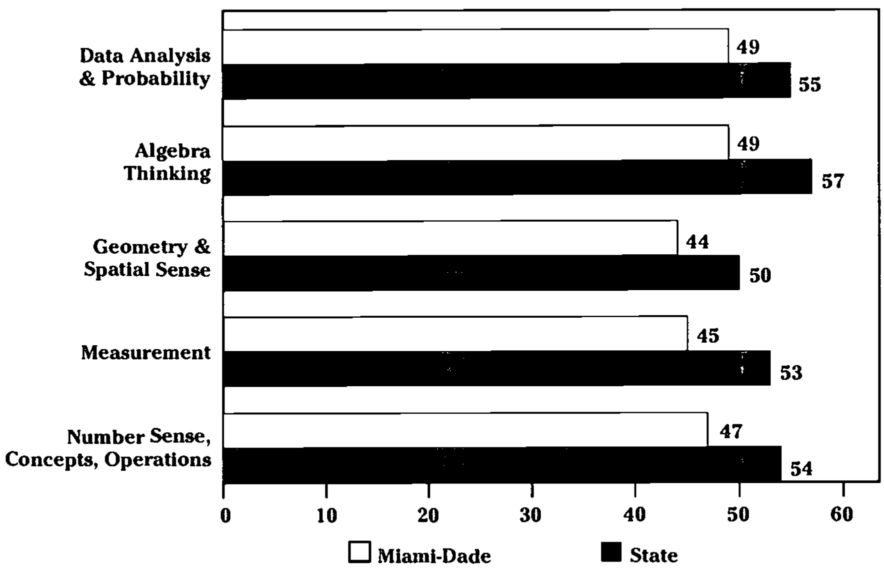


Figure 2
Grade 8, 1999 Subscores

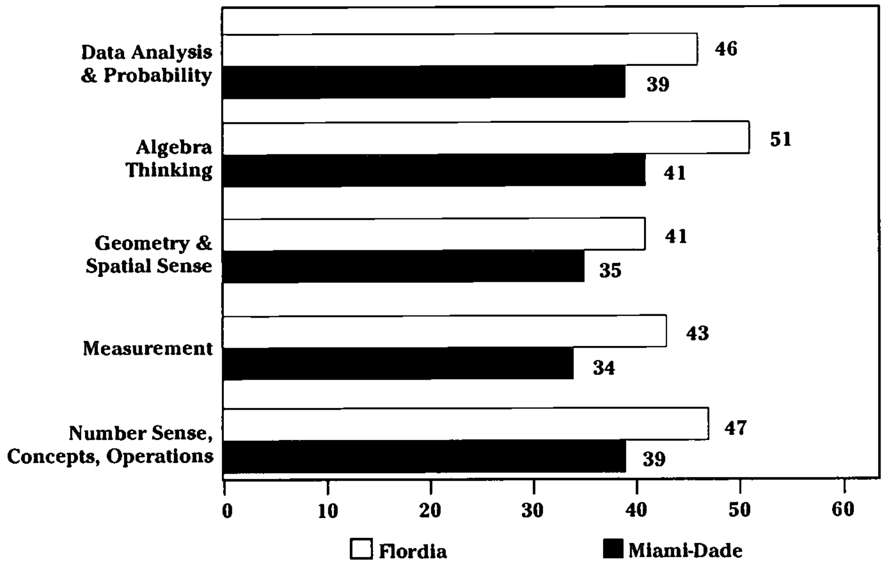
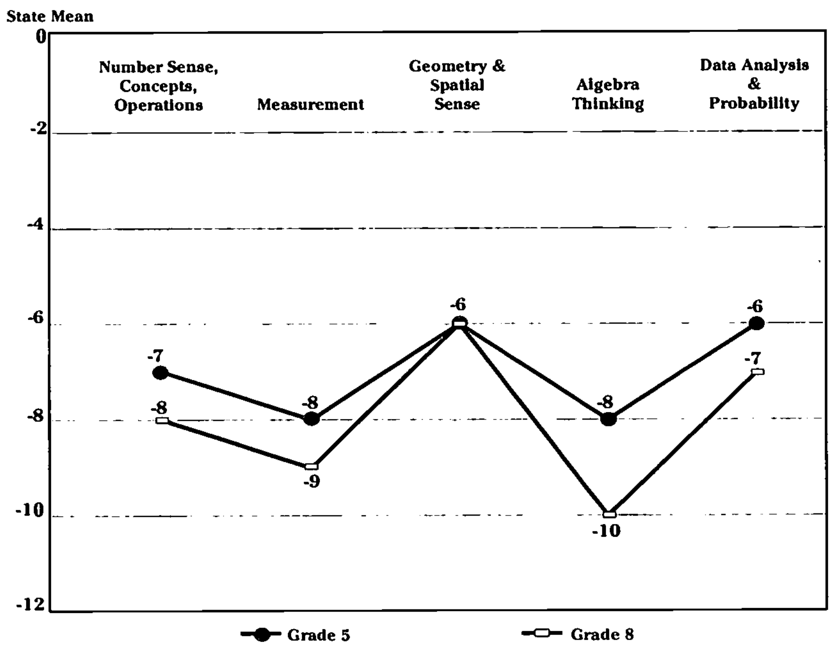


Figure 3
Grade Difference vs. State Mean



In the recommendations section of this paper, we suggest supplementary materials that address algebraic thinking concerns. Except for less-significant improvement at the eighth-grade level, especially in algebraic readiness, one can easily conclude that mathematics instruction in Miami-Dade has been on a positive trajectory and will be maintained. However, considerable work remains to be completed, especially in the middle school grades, and it is our belief that the work of the Urban Systemic Initiative is on track and should be given even more prominence.

Section III. Exemplary Uses of Technology: Increasing Student Learning in Mathematics

Critics and proponents of technology agree that effective use of technology requires attention to larger systemic reform efforts. After meeting with numerous experts, the Milken Exchange on Education Technology determined in *Technology in American Schools: Seven Dimensions for Gauging Progress* (Lemke & Coughlin, 1998) that technology can be used optimally in education only when attention is given to reform efforts in seven dimensions. Those seven dimensions are learners, learning environments, professional competency, systems capacity, community connections, technology capacity, and accountability. Like links on a chain, if any one of the seven is not addressed, then all the other are weakened in their ability to maximize the use of technology in schools. All of the seven require new professional competencies for teachers and administrators.

In *Professional Competency Continuum: Professional Skills for the Digital Age Classroom* (1999), Coughlin and Lemke listed the following kinds of professional development that teachers must have if they are to be successful in effectively using technology to improve learning:

- Educators must become proficient in the use of technology tools.
- Educators must be skilled in the use of a variety of models of curriculum design and learning strategies supported by technology.
- Educators must develop new organizational and management strategies to support innovative learning in technology-rich environments.
- Educators must use technology to support new, collaborative, professional practices.
- Administrators must be prepared to lead significant change initiatives that support classroom teachers in developing the proficiencies described above. In doing so, they must take an active role in the professional development of all staff under their responsibility. (See Introduction.)

Technology use and expectations have evolved over time. Valdez, et al. (1999) in *Computer-Based Technology and Learning: Evolving Uses and Expectations* concluded that definitions of exemplary uses of technology and understanding of technology research required recognition that there have been three phases of technology use and expectations during the past 20 years.

The three phases are print automation, expansion of learning opportunities, and data-driven virtual learning. The first phase, print automation, represents our early efforts to use computers. Education programming for personal computers was unstructured and limitations resulted in largely sequential programs based upon principles of programmed instruction. Educational software consisted mostly of textbooks presented in electronic print formats. Often the software was created by noneducators, which resulted in serious compatibility issues between learning design and content expectations. It was not unusual to have software with content intended for elementary students but with reading levels at the high school level.

Phase two, expansion of learner-centered opportunities, used technology to empower students by making learning more relevant to real-life world issues. Technology also was seen as a tool for educational reform that helped teachers move from largely isolated learning activities to applications that expected students to work in groups. Teachers emphasized work that created products that were to be shared. The intent of technology use in phase two was to provide new ways of learning rather than deliver content.

Phase three, data-driven virtual learning, represented a merging of two very different learning expectations. The emergence of the Internet and multimedia CD-ROMs allowed learning to be virtual. At the same time there were increased expectations for educational accountability from policy and fiscal officials that technology demonstrate it was an effective intervention from the standpoints of both increased student learning and cost-effectiveness.

McNabb, Valdez, Nowakowski, and Hawkes in *Technology Connections for School Improvement: Planners' Handbook* (1999) noted that the following characteristics were desirable for the effective use of technology. (It is not surprising that exemplary use of technology closely reflects exemplary mathematical instruction. Readers should note that in most cases, the word "technology" could be replaced with "mathematics" and much of the same logic of the statements would be equally relevant for mathematics.)

- Technology skills are defined for all students, and strategies for achieving them are integrated into the curriculum.
- Technology is designed to improve both the quality of curriculum available to students and the instructional methods used to teach them.
- Technology is designed to permit teamwork, allowing students to engage in joint projects with their classmates and with students from other states and regions.
- Technology is used to improve learning by offering more hands-on practice, more time, more content, more problem solving, and more individualized planning.
- Technology should allow students to access information that interests them, yielding learning experiences that increased motivation and attendance.
- Technology should reflect the level and kind of reform in the school—neither moving past, nor failing to encourage, present reform momentum.

- Technology should outline strategies to train all teachers to use it more effectively.
- Technology should connect schools to important organizations and resources, including museums, universities, community groups, and health and social service agencies. (pp. 3-4)

Valdez and McNabb (1997) in a comprehensive review of technology found that using computers in classroom activities collectively shows few significant effects if teaching practices do not change as well. They believe, based upon their examination of research and best practice, that:

- The success or failure of technology-enabled learning experiences often depends on whether the software design and instructional methods surrounding its use are congruent. Some educational technology applications are highly adaptable while others have a single purpose. Each has been designed according to particular philosophies and theories of learning. Educators need to clearly define their purposes for using particular technology applications.
- The success or failure of technology applications in educational settings depends on an appropriate match between technology applications and reform readiness of the setting in which it is being used. The degree of congruence between reform and technology significantly determines whether or not educational uses of technology will result in positive or negative impacts.
- The usefulness of technology depends on having a critical mass of computers. Researchers and practices indicate a minimum of one computer for every four to five students is necessary if students are to be able to use technology in a manner that will enable significant results within the classroom.

The authors' conclusions were that given societal economic considerations, technology needs to be integrated into the very fabric of curricular programs across America regardless of economic condition and geographic location to ensure equity in our public schools and enrich the future of today's children.

NCTM was the first of the major content organizations to officially recommend the use of technology. The report from the National Council of Teachers of Mathematics, entitled *Curriculum and Evaluation Standards for School Mathematics* (1989), was very direct in its support for the use of technology. That document associated technology with providing students with mathematical power. The document indicated that hands-on learning experiences fostered through today's interactive technology applications empower students with the level of mathematical power they cannot achieve otherwise.

The NCTM recommendations were that:

- Appropriate calculators are available to all students at all times.
- A computer be available in every classroom for demonstration purposes.
- Every student have access to a computer for individual and group work.
- Students learn to use the computer as a tool for processing information and performing calculations to investigate and solve problems.

Technology also is changing content areas. Specifically in mathematics, McNabb, Valdez, Nowakowski, and Hawkes in *Technology Connections for School Improvement: Planners Handbook* (1999) indicate their belief that because the new technology made calculations and graphing easier, it changed the very nature of the problems that mathematics can solve, as well as the methods in mathematics used to solve them. They noted that "in mathematics education technology serves as a tool for:

- Processing numeric information.
- Performing calculations.
- Graphing and communicating numeric information.
- Investigating and solving problems with mathematical premises.
- Creating and running models and simulations.
- Scaffolding higher-levels of abstraction." (pp. 28-29)

Bittner and Hatfield (1998) stated that the most powerful uses of technology in mathematics were to find and link information from the Web that combines text, graphics, sound, and video. They stated that Web sites on many mathematics topics are available and provide limited resources for students and teachers. They noted that "1.3 million pages of information are added to the web each month which means that an unending supply of current databases of information can be used as problem solving and research tools" (p. 37). Another very significant use of technology for mathematics in the middle schools, Bittner and Hatfield believe, is the use of calculators, which now have extensive applications that make their use far more relevant and targeted.

Bittner and Hatfield believe use of technology in middle school mathematics is important because:

- Technology can make mathematics into a study of highly motivational real-world problems.
- Technology can play a role in enhancing mathematical thinking, student teacher discourse, and higher-order thinking by providing the tools for exploration and discovery.
- Teachers who use calculators with their middle grades students can elicit higher levels of active student thinking and encourage problem solving. Students can perform mathematical computations quickly and efficiently, freeing them to explore the data and note resulting changes.
- The computer provides many options for integration of technology into the mathematic curriculum. Geometry construction tools allow students to explore realistic situations and to integrate science, social studies, and other disciplines. Technology also has potential for exploring mathematical theories. (pp. 36-37)

Numerous studies show that drill and practice software does improve test scores in mathematics (Valdez et al., 1999). Positive results were most evident when there was a good match in the desired outcomes of treatment and the outcome that was measured. Results, also, were more positive when software served as an application to promote better conceptual understanding of the content. Kulik and Kulik (1991) conducted the most comprehensive study on the effectiveness of using computers to increase student achievement. In 81 percent of the studies examined, the experimental group had higher exam scores than students who were taught by conventional method without computer technology. The typical student in the average computer-supported class performed at the 62nd percentile on achievement exams as contrasted to the 50th percentile for students taught in conventional classrooms (pp. 6-7).

There have been surprisingly few well-designed studies that have examined the impact of technology on mathematical instruction at the middle grades. There are far more studies at the elementary and high school levels. Some studies of note showed increases in student learning if other instructional innovations also were present. In a study conducted in New Zealand (cited in Valdez et al., 1999), researchers found that the use of computers contributed to the improvement of test scores when technology activities focused on problem solving and simulations. The National School Certificate Project revealed that students participating in the reform efforts that included computers scored significantly higher than those who did not. However, because many change variables were present, it was difficult to attribute all of the gains to technology.

Probably the most significant study on the impact of technology at the middle grade levels was the Educational Testing Service study by Harold Wenglinsky, entitled *Does It Compute? The Relationship Between Educational Technology and Student Achievement in Mathematics* (1998). Wenglinsky took his data from fourth and eighth graders who took the math section of the 1996 National Assessment of Educational Progress test administered by the U.S. Department of Education.

In this study, Wenglinsky determined that technology has positive effects when used in mathematics instruction. However, he cautioned that those benefits depend on how technologies were used. Wenglinsky, after adjusting for class size, teacher qualifications, and social economics, found that technology has more impact in middle schools than in elementary schools. He found that in the eighth grade, where computers were used for simulations and applications, students had higher test scores that were the equivalent of half a grade level. They did not have those gains when computers were used for drill and practice.

Wenglinsky found that fourth-grade students who use computers primarily for math learning games scored higher than students who did not. Unlike the eighth graders, fourth graders did not show differences in test score gains for either simulations and applications or drill and practice.

Students of teachers who had appropriate professional development on the use of computers scored one-third of a grade level higher than students of teachers who did not. The study revealed that overall, African-American students at the eighth-grade level use computer slightly more than white students. However, 31 percent of white students and only 14 percent of African-American students use computers mostly for simulations and applications. At the other end of computer use, 50 percent of

African-American students use computers primarily for drill and practice in contrast to only 30 percent of students in primarily white student classrooms. In other words, while the computer access was equitable, the use for those computers was quite different. African-American students, more often, were using computers in ways that appear less effective in raising test scores.

Middle School Mathematics Software

In *Computers and Classrooms: The Status of Technology in Schools* (1999), Coley, Cradler, and Engle noted, "Effective courseware needs to reflect the research on how students learn, be matched to national, state, or district educational standards, and be integrated into the teaching and learning activities of the classroom....The California Instructional Technology Clearinghouse has rated only 6 to 8 percent of evaluated courseware as 'exemplary,' and from 33 to 47 percent as 'desirable.' Less than half of the courseware submitted to the Clearinghouse had sufficient quality to merit review" (pp. 7).

Reviewing software is expensive and difficult. We know of five independent organizations that have reviewed middle school mathematics software: The California Instructional Technology Clearinghouse, the Nova Scotia Department of Education and Culture, the Fermi-NCREL Center, the Association for Supervision and Curriculum Development (ASCD), and the Eisenhower National Clearinghouse. The Nova Scotia Department of Education and Culture reviews give considerable detail as to why certain packages were found unacceptable and thus are especially valuable in locations where there is a great deal of local autonomy.

Few of the packages have detailed student-gains data. Cognitive Tutor Algebra and Geometer's Sketch Pad are two software packages that have in-depth research and have shown impressive gains in carefully designed studies and thus are on most exemplary lists. Because they are noted in the recommendations section, the following are summaries of those packages.

Cognitive Tutor Algebra

Cognitive Tutor Algebra (also known as PACT Algebra or Pump Algebra) is a full-year, first-year algebra course that uses technology intensively. It can be used with students of all ages. The U.S. Department of Education document *Exemplary, Promising Mathematics Programs* (1999) notes characteristics and statistically significant results as the basis for Cognitive Tutor's classification as an "Exemplary Program." According to the document, the program has text, assignments, assessments, activities, and curriculum-integrated software, including user guides and teacher guides. The intelligent computer tutor software and support materials are based on research from cognitive psychology and artificial intelligence and provide each student with an individual coach or tutor. Cognitive Tutor provides instant feedback and assistance to the students as needed. The program is designed to have students work on cooperative problem-solving activities three days a week in the classroom and on similar individual computer-based problems in the computer laboratory on the other two days. "Students investigate and solve real-world problem situations with attention to the entire problem-solving process. Students link numeric, verbal, graphic, and symbolic representations, while using tools such as spreadsheets and calculators" (U.S. Department of Education, 1999, pp. 10-11).

This program was developed by cognitive psychologists and computer scientists at Carnegie-Mellon University. The mathematical content of Cognitive Tutor Algebra follows NCTM standards and uses variables and functions to model mathematical situations. It integrates major standards of mathematics, such as statistics and geometry, with algebra and focuses on depth rather than breath of coverage. The program is built around active learning as evidenced by the use of real-world situations that require mathematics to solve problems. The program provides familiarity and practice with problem-solving methods, algebraic notation, algorithms, and geometric representations.

Cognitive Tutor Algebra has been tested in many locations and settings and, as of February 1999, was in use in more than 75 schools. Reviewers indicated that the program was particularly appropriate for the urban underachiever. Assessment results in two Pittsburgh high schools and one Milwaukee high school are quite impressive. Program students scored 50 to 100 percent higher in problem-solving tests than students in traditional classrooms. Data from one high school in Pittsburgh showed that project students were twice as likely as traditional students to enroll in Algebra II two years later after a full year of traditional geometry. At that school, 66 percent of students in Cognitive Tutor passed the Algebra I course as compared to 44 percent of traditional algebra students. In a 1994-1995 study, project students scored significantly higher than control group students on performance-based assessment focusing on areas such as defining variables, making a table, writing equations, constructing a graph, finding slopes/intercepts, and finding points of intersection. Using a survey to collect quantitative data on students' attitudinal change, the developer found that Cognitive Tutor students had less computer anxiety, to a statistically significant degree, than comparison students.

This program is expensive. The site license is $25,000 per site, although there are discounts for multisite districts. This fee includes the initial teacher preparation of five days, ongoing updates, and upgrades of software and printed materials. The developers and reviewers indicated that professional development was absolutely essential if this program was to be successful.

Geometer's Sketch Pad

Geometer's Sketch Pad software is ranked very high by almost every organization that evaluates software. The Eisenhower National Clearinghouse Web site (www.enc.org/) describes it as follows:

> This software package, developed for grades 5 through college, permits student investigative observation and teacher demonstration of geometric concepts. This software is designed to provide fast, precise, and accurate geometric figures and reveal essential geometric relationships. Geometric conjectures about real world situations are constructed and then dynamically explored. For example, students can use the electronic compass and straightedge to construct a triangle's

circumcenter by constructing the perpendicular bisectors of the sides of the triangle. Dragging a vertex demonstrates that all acute, right, and obtuse triangles possess a circumcenter that is either in the interior, on a side, or in the exterior of the triangle. In another example, to demonstrate the conjecture that the sum of the exterior angles of a polygon is 360 degrees, students can draw a polygon with its exterior angles. Dynamic dilation reduces the polygon to a point, while keeping the angle measures the same, to demonstrate the conjecture's validity.

Sketches are visual, geometric drawings created with sketchpad. Creating sketches is a result of drawing and combining objects (points, circles, segments, rays, and lines) to construct figures and to investigate geometric principles. Scripts are verbal recordings of geometric constructions of objects and their relationships to one another. When a script is played, a sketch is constructed. Scripts provide a tool for communicating mathematics. Software provides presentation sketches, such as billiards, where a user is able to drag the cue stick to determine at what angle the ball must be hit to enter a desired pocket. Sample sketches, such as the rose petal, permit observing the effects of changing the polar equation's radius or angle by changing the length of a control bar. User guide, teaching notes, and sample activities are included. (Author/LDR)

Geometer's Sketch Pad costs $169 for a single copy. Multiple copy discounts are available from Key Curriculum Press.

Mathematics in Context

Mathematics in Context was developed at the University of Wisconsin-Madison and the University of Utrecht, The Netherlands. It has extensive research behind it that shows impressive student gains and improved student motivation. It is a comprehensive middle school mathematics curriculum for Grades 5 through 8. The major feature of Mathematics in Context is its own efforts to make connections between mathematics and meaningful problems of the real world, which are in turn, tied to other disciplines. The intent of Mathematics in Context is to make mathematics dynamic and reflect its real uses. Students are expected to explore mathematical relationships; develop and explain their own reasoning and strategies for solving problems; use problem-solving tools appropriately; and listen to, understand, and value each other's strategies. Students are expected to explore mathematical relationships.

The complete Mathematics in Context program contains 40 units, ten at each grade level. The units are organized into four content strands: numbers, algebra, geometry, and statistics. Most of the units use manipulatives that are commonly found in schools and at home. This program is very good for its use of calculators that focus not on computation but on problem solving and empowerment of students.

Section IV. Major Recommendations and Suggestions

Recommendation 1: Miami-Dade Public Schools may wish to offer a professional development opportunity that helps teachers better understand what is meant by reform pedagogy and content.

Professional development for all middle school mathematics teachers is an essential first step. There are two very recent and excellent publications that every mathematics teacher should become familiar with and that Miami-Dade Public Schools may wish to give special attention to in its professional development offerings. We believe that *The Teaching Gap* (1999) by James W. Stigler and James Hiebert provides the best analysis of how mathematics education must change and the best vision of how professional development might be designed and implemented to address the problems facing American mathematics education in the middle schools.

We also highly recommend *Knowing and Teaching Elementary Mathematics* (1999) by Liping Ma. This book is focused on comparisons of how mathematics content is taught in China and in the United States. It is remarkable for its detailed analysis of the strengths and weakness of mathematics content knowledge by both very good teachers who really understand mathematics and by teachers who are attempting to teach mathematics with only a minimal understanding of the fundamentals. Through in-depth examination of how expert and content-deficient teachers attempt to teach four essential mathematics operations (subtraction with regrouping, multidigit number multiplication, division by fractions, and the relationship between perimeter and area), we come to understand how much of the difficulty students are experiencing in mathematics can be directly linked to inadequate understanding of mathematics by their teachers.

Recommendation 2: Miami-Dade Public Schools may wish to focus on a limited number of best practices, best programs, and selected technology, especially software that offers the greatest potential for maximum results.

It is commendable and highly appropriate that Miami-Dade Public Schools use the building as the focus of change. Research indicates that meaningful and long-term change has to be focused at this level. However, it is our observations that local control needs to be balanced with recommendations and targeted support focused on a limited number of best practices, best programs, and selected technology. This is especially true of software, where there are so many choices and so few that truly offer the significant potential for increased student learning. It is our recommendation that Miami-Dade Public Schools limit building-level choices to a smaller number of options that they can support with professional development that will make their use more effective. Obviously those options should be selected and informed by research and best practices and have great potential for improving student learning.

Recommendation 3: Three programs that Miami-Dade Public Schools may wish to target, and that use technology quite extensively, are Mathematics in Context (primarily calculators), Cognitive Tutor Algebra, and Geometer's Sketch Pad.

The Miami-Dade Public School District has wisely chosen to align its middle school mathematics programs with the National Council of Teachers of Mathematics Standards. Several research studies have shown that only a small number of programs, textbooks, and software are closely aligned with those standards. Given what we know about Miami-Dade Public Schools, we concur with the existing attention given to Mathematics in Context. We are aware that Mathematics in Context is being used in some Miami-Dade schools, and we believe that focused support for that program is very important.

We recommend that a number of schools sufficiently large enough to constitute a reliable sample be encouraged to use Mathematics in Context, Cognitive Tutor Algebra, and Geometer's Sketch Pad, and that Miami-Dade Public Schools develop strong professional development support for those programs. Further, we recommend that a careful study be developed to see whether Miami-Dade Public Schools will be able to achieve the remarkable gains found in other locations where the programs have been given the necessary support required to implement them effectively.

Recommendation 4: Miami-Dade Public Schools may wish to explore special purpose software.

Although we do not have sufficient item analysis data to make specific recommendations, we do know that certain software and Web sites are especially responsive for each particular concept or need. Item analysis would be able to show what particular problems students were experiencing for especially challenging mathematics concepts and thus provide the information necessary for targeted interventions. For example, schools where students have high basic mathematics skills needs may wish to test the viability of highly rated skill software, especially the Pizza Perfect Caper, Corner Stone Mathematics, Target Math, BasketMath, The Logic Box, and Factory Deluxe. Again, we believe that research pilots be considered for further study.

Recommendation 5: Miami-Dade Public Schools may wish to increase parent-training opportunities focused on *Family Math: The Middles School Years: Algebraic Reasoning and Number Sense* (Thompson & Mayfield-Ingram, 1998).

Family Math, developed by Virginia Thompson and Karen Mayfield-Ingram, is a product of Project Equal, which is based at the Lawrence Hall of Science, University of California at Berkley. This middle school product provides great opportunities for involving parents in improving mathematics learning by students. The first half of the document is focused on algebraic reasoning that is of special concern for Miami-Dade Public Schools. It tutors parents on the most important components of Algebra I and gives them activities to do at home that show the practical aspects and fun of algebra.

Recommendation 6: Miami-Dade Public Schools may wish to access materials found on Web sites that are especially useful for their curriculum needs. There are hundreds of Web sites that can assist with the improvement of math at the middle school level.

If the sites are to be useful, content item analysis would need to take place and then linkages made to specific portions of these very large sites. The following Web sites could be starting points:

Ask Dr. Math

http://forum.swarthmore.edu/dr.math/dr-math.html

Ask Dr. Math provides answers to questions from K-12 math students. These answers are appropriate to the grade level teachers teach. The site has a search engine that lets you search by topic and grade level.

AskERIC

http://ericir.syr.edu/Virtual/Lessons/

The AskERIC Lesson Plan Collection has hundreds of lesson plans that have been submitted by teachers.

Developing Educational Standards

http://putwest.boces.org/Standards.html

This is an exceptional site and, together with the Eisenhower National Clearinghouse site, should be a starting point for examination of mathematics and other curriculum. It has exceptional information about educational standards and curriculum frameworks.

Eisenhower National Clearinghouse (ENC)

http://www.enc.org/

ENC is the official mathematics and science clearinghouse established by Congress. While it has about everything you want to know about mathematics and science, it is especially valuable for its collection of useful resources that includes best Web sites.

The Geometry Center

http://www.geom.umn.edu/

If you are teaching geometry, then the Geometry Center is a must stop. The resources include multimedia documents, geometry archives, software, video production, and other materials.

Mid-Atlantic Eisenhower Consortium for Mathematics and Science Education

http://www.rbs.org/eisenhower/index.html

The Mid-Atlantic Eisenhower Consortium is a partnership that brings together Research for Better Schools (RBS) with other key agencies in the region to improve mathematics and science education for all students. It is especially noted for its resources related to the Third International Mathematics and Science Study.

National Council of Teachers of Mathematics

http://www.nctm.org/

The home page of the National Council of Teachers of Mathematics updates viewers about the activities and resources of NCTM.

North Central Regional Educational Laboratory

http://www.ncrel.org/

The North Central Regional Educational Laboratory is an excellent resource for educators. It actually has several Web sites available from this address. Most significant for mathematics are Pathways; the Midwest Mathematics and Science site, especially the exemplary units; Gateways; and the various technology sites.

Northwest Regional Educational Laboratory

http://www.nwrel.org/

The Northwest Regional Educational Laboratory contains information on school reform and equity issues related to technology in the classroom and on funding, especially the E-rate.

Science and Mathematics Consortium for Northwest Schools

http://www.col-ed.org/smcnws/

The Science and Mathematics Consortium for Northwest Schools seeks to enhance schools' ability to teach mathematics and science through providing lesson plans, grant information, and much more.

Teachers Helping Teachers

http://www.pacificnet.net/~mandel/

One purpose of this site is to create a means for experienced teachers to help inexperienced teachers who are encountering difficulty.

U.S. Department of Education

http://www.ed.gov/

This site links all of the organizations and work funded by the U.S. Department of education.

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