

Waterford  
Early  
Math &  
Science

**RESEARCH SUMMARY**

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*This document is intended as a review of research relevant to the development of Waterford Early Math & Science, created by the Waterford Institute and published by Electronic Education.*

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## Waterford Early Math & Science - Preface

*Waterford Early Math & Science is a sequential, research-based curriculum developed for pre-school and kindergarten, containing a full year of instruction in over 130 objectives. It is one of the nation's first technology-driven reform models in mathematics and science.*

*Waterford Early Math & Science* was developed by the Waterford Institute, a non-profit organization with the goal of improving education through the use of technology. Its flagship early literacy program, the *Waterford Early Reading Program*, was developed in 1996, and is currently being used successfully at over 10,000 sites nationwide.

Building on the success of the *Early Reading Program's* instructional model, the Waterford Institute's research team, comprised of experienced elementary teachers and professionals in the field of computer development, spent over five years reviewing theories in child development to determine what would be the best sequence of instruction for a technology-based early childhood mathematics and science program. They reviewed research into the cognitive capabilities of pre-schoolers and kindergartners, including studies by cognitive psychologists specializing in child development such as David Geary, Jean Piaget, and Lev Vygotsky.

In addition, national and state standards were consulted to define the new program's content, including an in-depth study of the NCTM Standards, the National Science Education Standards (NSES), many state and local standards, and a careful review of current math and science texts.

In the fall of 2001, the kindergarten level of *Waterford Early Math & Science* will be available to schools throughout the country. This document is an introduction to the guiding principles behind this innovative new instructional model.

## Society's Need for Math & Science Skills

*"We live in a time of extraordinary change. New knowledge, tools, and ways of doing and communicating mathematics continue to emerge and evolve...The need to understand and use mathematics in everyday life and in the workplace has never been greater and will continue to increase."*

- NCTM Principles and Standards

We live in a world of increasing complexity, where the demand for mathematics and science skills is now at a premium. The nations of the world look increasingly to new technologies and discoveries to compete in a new global economy, and the key to their success is well-educated children who leave school prepared for this challenging new marketplace.

Worldwide, new high-tech jobs and careers are in high demand, and require more math and science skills than ever before. Since 1996, national productivity has increased an average of 2.6% per year, gains that are unsustainable without a workforce educated in mathematics, science, and technology.

- Jobs in the technology sector will add about 20 million jobs to the American economy by 2008.
- Jobs in the health sciences and computer industries requiring mathematics and science skills will increase by 5.6 million by 2008 (Glenn Report, p. 12).

We are entering a brave new world of possibilities, where the future belongs to children who are well-educated in mathematics and science.

## The Achievement Gap

*"To grasp the magnitude of the current mathematics crisis in education, it is essential to recognize that at least one-third of America's children are at risk of failing in school, even before they enter kindergarten (Savodnik, Cookson, & Semel, 1994)"*

### • U.S. Students Fall Behind – TIMSS Results

The statistics are staggering: nearly one-fourth of all preschool children in the United States live in poverty (Sadovnik, p. 366). Over 15 million children are being raised by single parents with incomes under the poverty level, defining them as "at risk" students. At least 2 million school-age children have no adult supervision after school.

Recent studies suggest that our country may be losing its competitive edge in science and technology as children in homes with little parental support or access to resources start below the standard of grade level achievement, and then fall further behind their peers as schooling progresses.

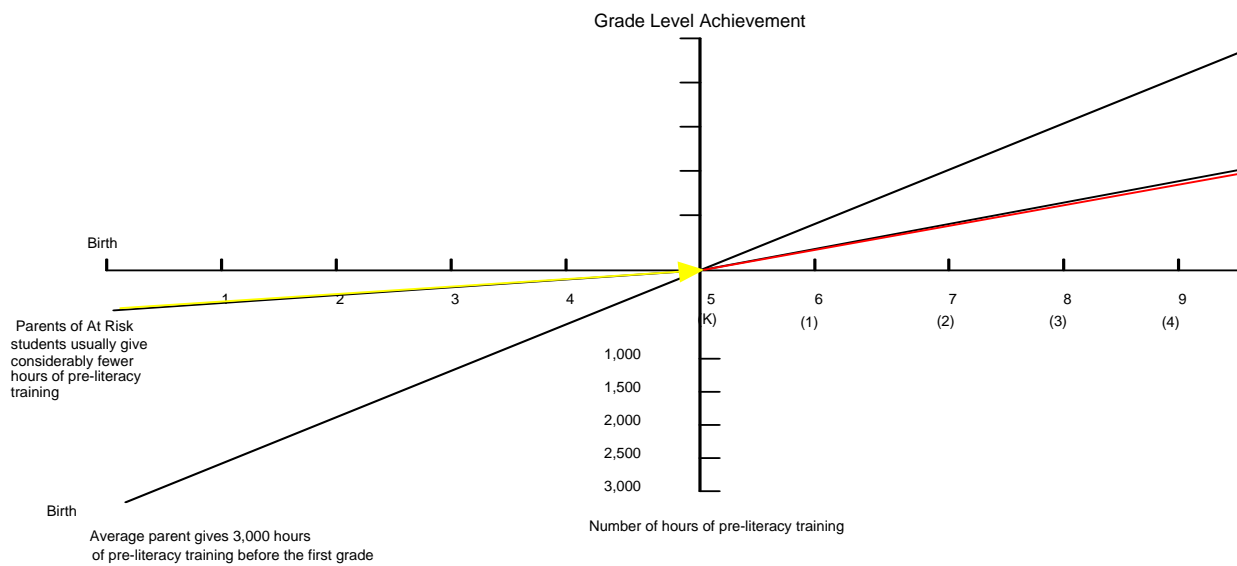
This weakness was dramatically illustrated in 1997 (and revised in 2000), when the results of the Third International Mathematics and Science Study (TIMSS) were released, evaluating the performance of students from 41 developed countries in grades 4, 8, and 12. While U.S. fourth-graders scored above the international average, by twelfth grade the U.S. was in the bottom third of all nations.

- The Struggle to Close the Gap

Students who struggle in the early grades tend to continue to do poorly into the upper grades. A recent report by the U.S. Department of Education revealed that almost 90% of children who have difficulty reading at the end of first grade display similar difficulties in fourth grade.

In the figure below, the grade-level achievement of students is represented graphically on the vertical and horizontal axes extending up and to the right. Average achievement is represented by the solid black line, while the “at risk” student is the broken line below. As grade level/age increases, so does the level of expected achievement.

The number of pre-literacy hours is also graphed. While the average parent gives 3,000 hours of pre-literacy training (counting activities, songs, or books) to their children, parents of at risk students usually receive considerably fewer hours. Marilyn Adams in her book *Beginning to Read* estimated that at-risk students received less than 200 hours during this same time period (Adams).



- The Need for Early Intervention

As years go by, the gap that was not immediately apparent in the early grades begins to widen, and the need for intervention grows exponentially. “If kids are at risk, we can address it with 30 minutes of intervention a day at the kindergarten level. By the time children are 8 or 9, it takes at least two hours a day of special training to achieve the same effect (Newsweek)”.

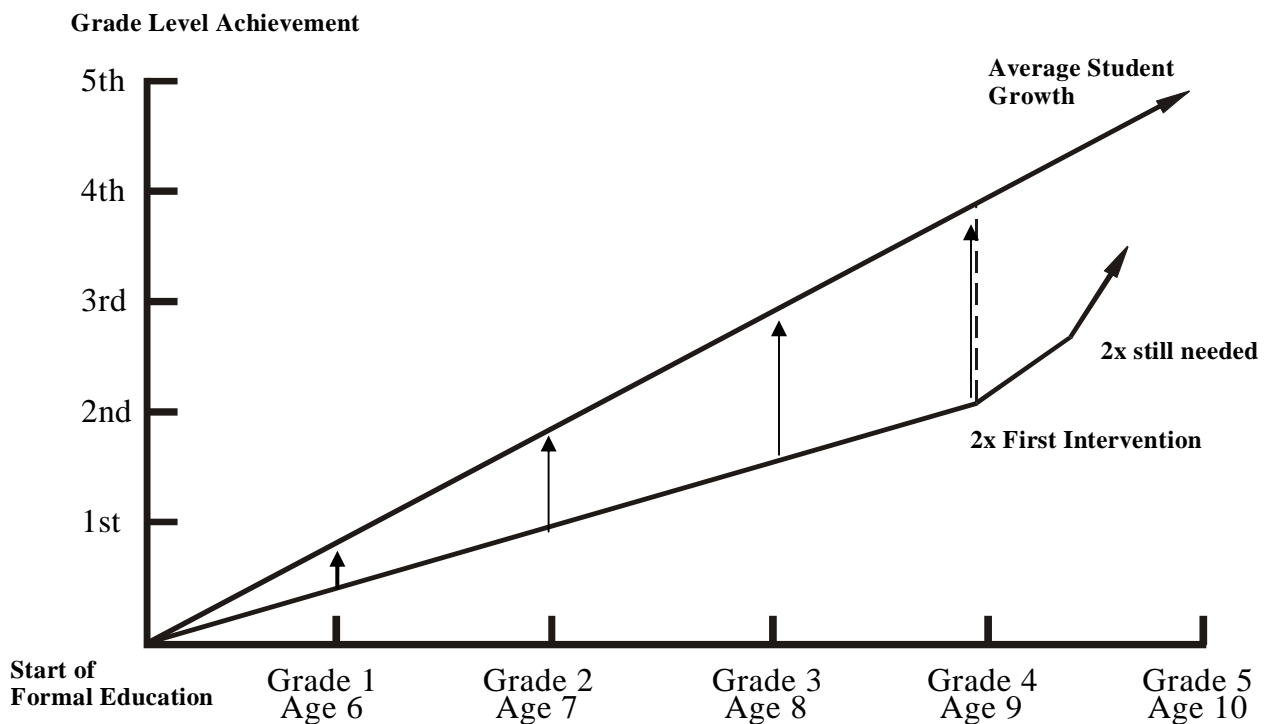
Even if tutors or technology is introduced too late, the struggling student may have to gain 2 to 4 times his peers in order to match their rate of growth. This is, by definition, extremely difficult for the neediest students. According to U.S. Department of Education statistics, 75% of students who are poor readers in third grade will remain poor readers in high school.

The chart below illustrates the problem of delaying intervention until later in the primary grades.

Once again, the horizontal line represents the progress of formal education through grade five. The vertical axis represents the increasing expectations for grade level achievement in math, science, and literacy. The average student's performance is illustrated by the bold diagonal line.

The line below represents the "at risk" or struggling student. The vertical arrows represent the amount of work needed to bring this student up to the level of expected grade level achievement. This intervention at Grade Three or Four may take 4-6 times the amount of resources needed to accomplish the same goal in earlier grades.

What's more, for an intervention to be successful, it must not only double (2x) the child's rate of learning, but multiply it by four times (4x) just for him or her to catch up. Because these children are, by definition, the weakest learners, such a child has a tremendous obstacle to overcome in order to achieve success in this manner.



- The Problem of "Work"

For all students to achieve grade level proficiency, it requires the work of three people: 1) the student, 2) the parents, and 3) the teacher. These partners share equally in the instructional workload. When one of these three breaks down, e.g. support in the home, suddenly the shift in work must be placed on the shoulders of the other two.

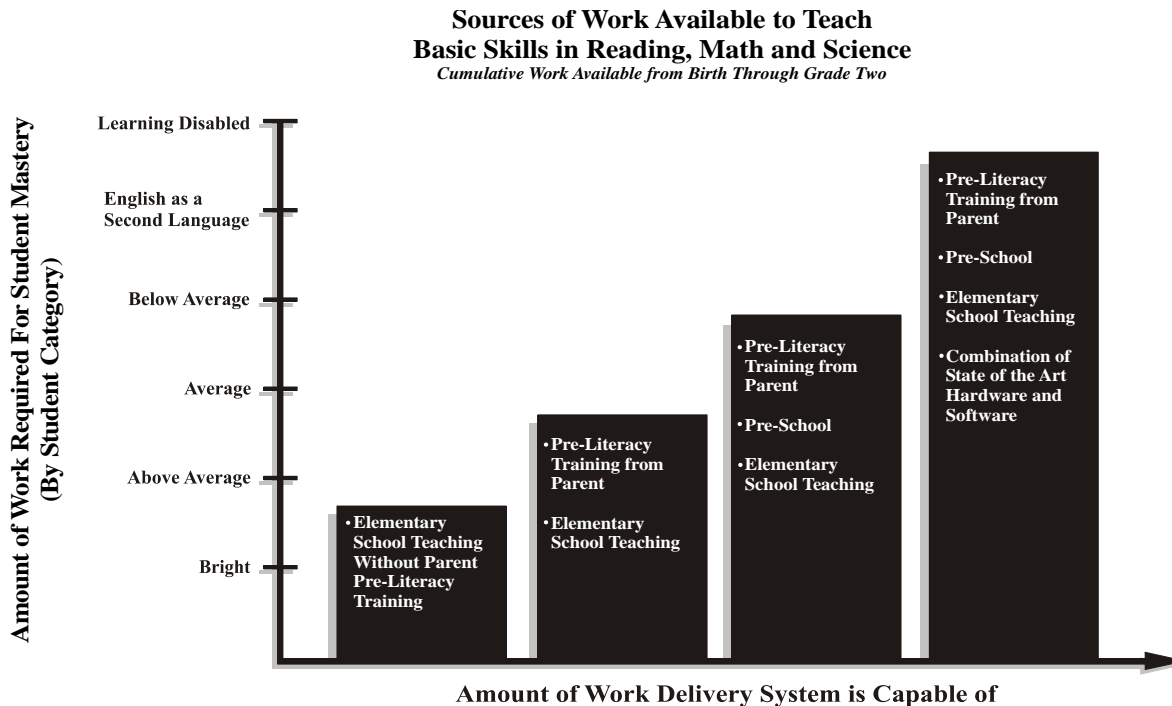
**STUDENT**  
33%

**TEACHER**  
33%

**PARENT**  
33%

- Sources of Work Help

A number of resources can be applied to reform of mathematics, science, and reading instruction in the early grades, and each one increases students served: 1) improved elementary school teaching, 2) pre-literacy training for the parent, 3) pre-school, and 4) state-of the art hardware and software.



## Waterford Early Math & Science

*Waterford Early Math & Science* has been designed by the Waterford Institute to give teachers and parents the tools they need to succeed. In the pages that follow, we will review the instructional elements that make *Waterford Early Math & Science* a unique and powerful instructional program:

- Specific design for early intervention: pre-school or kindergarten.
- Integration of technology and curriculum; students engaged in a non-threatening environment.
- Individualized instruction for each student – equity through technology.
- Curriculum enhanced with good art, music, and literature.
- Balancing the teaching of basic skills and conceptual skills.
- Math lessons complemented with science content.
- Parents involved through tools that reinforce math/science in the home.
- Regular assessment and review of skills and concepts.

## Designed for Pre-School or Kindergarten

*Waterford Early Math & Science is an interactive, multi-modal center for children of ages 4-6. It is designed to create a solid foundation for the child in pre-school and kindergarten.*

- Pre-school education can have an impact on mathematical achievement

Within mathematics there is a definite progression of concepts and techniques--one concept needs to be mastered before the next one can be introduced. For example, a student must be proficient with the names of numbers before traditional addition methods involving paper and pencil can be taught. Therefore, it is important to provide a solid foundation for the learning of later mathematics. That foundation, as in language and literature, is constructed in the earliest years of a student's education.

Various studies in early childhood education indicate that early education can provide a solid foundation in math and science as early as age three or four. One study found that "preschool education has a significant impact on mathematical achievement," (Horton, 1996) and one by Clay (1980) found that children who participated in day care with a structured mathematics program achieved significantly higher grade placement than either of the comparison groups in the study.

Children can learn basic facts, operations, and introducing methods of exploration and encouraging curiosity at an early age. Charlesworth and Lind state, "The skills most appropriate for preschool and primary students are the basic skills of *observing, comparing, classifying, measuring, and, communicating*. Sharpening these skills is essential ...for the future study in science and mathematics."

- Children are developmentally ready to learn math and science by kindergarten

"One study in the psychology of learning found that the numerical facility of kindergartners encompasses counting, simple arithmetic, working memory for numbers, and general knowledge about quantitative relationships (Osborne and Lindsey, 1967). Another study conducted by Meyers and Dingman (1960) found that the numerical skills of children ages 5 to 7 are identifiable as a relatively distinct skill. These, and similar studies, indicate that the appropriate ages to start building a solid math and science foundation are the earliest years of a child's education.

The research emphasized that children, even in kindergarten, should also have a full science curriculum. "Science should be used to integrate, reinforce, and enhance the other basic curricular areas so as to make learning more meaningful for children." (Tolman et al. p.129).

## Integration of Technology and Curriculum

*Waterford Early Math & Science software runs as a center in a classroom or lab. Individual headphones for students reduce distractions and increase program effectiveness.*

- **Technology is required by new national standards**

The National Council of Teachers of Mathematics (NCTM) has added standards that include integration of technology into instruction: “Technology is essential in the teaching and learning of mathematics; it influences the mathematics that is taught and enhances student learning (2000).”

They further state: “...Computers are reshaping the mathematical landscape, and school mathematics should reflect those changes. Students learn more mathematics more deeply with the appropriate and responsible use of technology” (NCTM, 2000).

National Association for the Education of Young Children (NAEYC) guidelines require “appropriate technology integrated into the regular classroom environment and used as one of the many options to support children’s learning.”

- **Students need more than just “drill-and-kill”**

Studies have proven that drill-and-practice software can help young children with the development of their counting and sorting skills, (Clements and Nastasi 1993). Haugland (1992) found that young children who used discovery-oriented software made significantly higher gains in intelligence, nonverbal skills, structural knowledge, long-term memory, complex manual dexterity, and self-esteem.

Students who were exposed to appropriate software (software involving problems that require student exploration) showed gains over groups of students who did not use computers or groups that used only drill-and-practice software. In fact, the students who used a combination of computers followed by closely related class activities showed more than twice the gain as the drill-and-practice software users while spending only about one-third of the time on the computers (Hauglund 1992). *Waterford Early Math & Science* employs a combination of classroom and computer-related activities.

- **Good technology is integrated with classroom activities**

*Waterford Early Math & Science* provides immediate feedback for the student about correct or incorrect answers, a factor that is important for the motivation of children. Since the computer tracks the progress of each student, the teacher will have more time to prepare the classroom lessons and activities.

The use of technology by well-informed teachers can be a valuable aid in the process of teaching and learning of mathematics. In a study by Linda McGarvey (1986) on the effects of the use of computers by kindergarten children found that the use of computers facilitated the acquisition of school readiness skills.

*Waterford Early Math & Science* integrates classroom activities with the software because that has proven to be the most effective in the learning of math for children (Haugland, 1992). Students using *Waterford Early Math & Science* learn in a non-threatening environment where students are encouraged to learn at their own pace, without fear of criticism or failure.

## Individualized Instruction for Each Student

*Because each student is unique, each student learns in a unique fashion. Waterford Early Math & Science enables the teacher to individualize the lessons for each child and hence allows the child to learn in the manner best suited for him or her. The computer tracks the progress of each student, and the teacher has more time to prepare classroom lessons and activities.*

Program is sequenced for students, but teachers have the option to special assign or block particular lessons

- Daily, Individualized Sessions

“Studies with infants have found that long-term retention is enhanced when information is distributed over multiple, temporally discrete sessions instead of being presented in a single, massed session,” writes researcher Carolyn Rovee-Collier of Rutgers University (1995). In his book, Geary (1994) confirms this principle, stating “practice should occur in small doses (about 20 minutes a day) and over an extended period of time.”

*Waterford Early Math and Science* students follow a fifteen-minute instructional period each day on one of the computers in the classroom. The program uses music, advanced graphics and animation, and simple, straightforward controls and instruction to keep the student engaged in learning.

The progression of the curriculum is a combination of new concepts, reviewed concepts, and assessments that ensure that the student has mastered the topic before it is considered completed. Each day the student will receive instruction that is comprised of several of the following activities, in varying lengths and orders: a daily number song, a math warm-up, a calendar activity, a skill for the day, a science lesson, a number lesson, and a session of play and practice.

If the student does not pass an assessment for a particular concept, the concept is reintroduced into the student’s curriculum after several days in a review form after which the student is re-assessed. This process continues until the student has mastered the concept. Concepts in science are used both to nurture curiosity and inquiry in young students as well as to introduce learned mathematical concepts into a real-world situation.

## Engaging Students in the Learning Process

*Each child using Waterford Early Math & Science receives 38 full-color books and four full-length video tapes to use throughout the school year. Engaging songs teach early skills and concepts.*

- **Each student has books to read in the home**

Having math and science-related reading materials in the home is essential to children's early success. "Studies indicate that the number of books in a family's home relates to the academic achievement of its children... whether parents read to their children can impact the degree of educational success." (Shaw and Blake, p. 74)

"Books portray mathematics not as a sea of symbols and potentially frustrating mental tasks that have no meaning for children, but as tools for making decisions and problem solving. By connecting some of these books to the daily events that occur naturally in many classrooms, children come to see mathematics as an integral part of living together in a learning community," writes Whitin (1994).

- **Engaging music and multi-media teaches concepts and skills**

Studies have shown that the normal forgetting that occurs over time isn't due to a loss of the memory but rather a lack of appropriate retrieval cues. Fagan, Prigot, Carroll, Pioli, Stein, and Franco of St. John's University and Iona College have addressed the role of music for infant memory (1997) and have determined that music is an excellent tool for defining and lending meaning to learning situations.

*Waterford Early Math & Science* introduces key concepts in a musical context that provide the learning child with several means to recall information. The fun songs engage both the audio and visual sensory functions of the brain and present the fundamental principles in a more memorable and entertaining manner. By appealing to multiple senses, *Waterford Early Math & Science* increases the likelihood that the children will gain the necessary skills of good math and science students.

## A Balanced Approach to Math

*Waterford Institute researched two basic philosophies of mathematics instruction, conceptual math and basic skills, and developed a balanced curriculum that includes the best of each approach.*

- Children must learn the concepts of number sense and problem-solving

Conceptual math or “constructivism” de-emphasizes the ability to read, write and order numbers. It emphasizes the meaning of operations, calculators, mental computation, estimation, and thinking strategies, while it de-emphasizes complex computations, long division, rounding, and paper and pencil computations of fractions. In geometry, conceptual math stresses geometric relationships, measurement and spatial sense, and de-emphasizes naming geometric figures and memorization of equivalent units of measurement.

- Basic skills must be practiced until they are memorized

Proponents of skill practice argue that a student cannot be expected to understand a concept until they understand the process of how to solve it. The theories and proofs have already been created, they argue, so why have a student come up with these ideas on their own?

D.J. Briars and Robert Seigler, cognitive psychologists, state that, “the argument that drill and practice and the development of basic cognitive skills, such as fact retrieval, are unnecessary and unwanted in mathematics education fails to appreciate the importance of basic skills for mathematical development . . . drill and practice provide an environment in which the child can notice regularities in mathematical operations and glean basic concepts from the regularities.” (Briars and Seigler, quoted in *Children’s Mathematical Development*).

- Both approaches are needed to achieve balance

According to Phil Dar, member of the California Mathematics Project and current head of the national New Standards project, “what is missing from the debate . . . is a practical, moderate viewpoint that values a balanced approach to mathematics instruction . . . there are three aspects that need to be addressed in mathematics curricula: basic skills, conceptual understanding, and problem solving and applications.”

Researchers at Waterford agree, and have worked to blend the two teaching methods. Richard Askey Professor of Mathematics at the University of Wisconsin says, “Some people believe that if students have conceptual understanding alone, they can solve problems they have not seen before. This was the philosophy of the New Math of the 1960’s. Unfortunately, this does not work for most students. In addition, to understand –whether ‘conceptual’ or a more serious kind of understanding – students need to learn technical skills and have to have considerable experience doing multi-step problems.”

The most recent version of the NCTM Standards recognizes the fact that a certain amount of drill-and-practice is desirable for each student’s mathematical growth. In fact, one of the major reasons behind the revision of the 1989 Standards was the strong reaction from many parents, educators, and professional mathematicians indicating that NCTM had overemphasized the “discover everything anew” approach to mathematics education and had left the children with very little practice in arithmetic computation.

## Complementing Math with Science

*During the course of the school year, approximately one-third of the Waterford student's time is devoted to science instruction. This is a full, inquiry-based curriculum corresponding to NSES standards.*

- Teaching math and science together allows the student to enrich their mathematical skills in real-life science situations

“Science provides real-world opportunities to apply math skills...As we estimate and measure, we use math skills. As we use or prepare graphs and we read thermometers, we use math skills...There is little doubt...that constant effort to apply skills from one curricular area as we study another can enhance both” (Tolman and Hardy, 1995).

- Science education should encourage the use of hands-on manipulatives, experiments, and observation

Science is best learned through a student's active engagement in inquiries that are interesting and important to them (*National Science Education Standards, p. 13*). Science should provide children with opportunities to observe, manipulate, ask questions, and experience science concepts. (Charlesworth et al. pp.8-12).

Science instruction should appeal to children's emotional and intellectual interests (Harlan et al. pp.10-17). *Waterford Early Math & Science* integrates music, art, stories, and activities to engage and educate students while they are learning about their world.

- Hands-on activities do not constitute a full science program

Hands-on activities alone do not constitute a full science program. Students need to be guided through inquiry, then given background information to help them understand “why” or “what” they have observed (Tolman et al. p.24). *Waterford Early Math & Science* provides direct instruction on the computer, then students are able to experience hands-on activities in the classroom, as the teacher follows activities, hints, and discoveries outlined in the Teacher's Guide.

- Science teaches scientific inquiry and significant people from history.

In science, students should learn not just the “answer”, but how scientists arrived at it. Then they can be encouraged to find out how scientists have researched what we know about science. “Students should learn that all sorts of people, indeed people like themselves, have done and continue to do science.” (*Benchmarks for Science Literacy* pp.3-4).

One unique feature of *Waterford Early Math and Science* is the inclusion of the biographies of well-known scientists. Students are introduced to Jane Goodall, George Washington Carver, and the Wright Brothers through books and off-line activities. Students learn how these scientists became interested in science and what important contributions they each made to the field of science. The students are then shown how they can emulate each scientist through application of the scientific process.

## Involving Parents

*Books, videos, and printed materials extend learning into the home for every child.*

- **Family involvement is a critical factor in mathematics achievement**

The use of computers in the classroom has quite an impact on the learning of mathematics in the classroom. With the family involved the effect is amplified. Family factors have a great influence on language and literacy, and their effect on mathematics development is also important.

According to Frances Campbell (1996), the quality of the home environment was closely related to the math scores on certain standardized tests of reading and mathematics. Similarly, Henderson and Berla (1994) found that “family involvement is a critical factor in student achievement from the earliest childhood years through high school, and that efforts to improve a child’s performance are much more effective when the family is actively involved.” Studies show that children from low-income or minority families benefit most when their parents are involved with school (Shaw, p. 76).

*Waterford Early Math & Science* uses several items to extend learning into the home:

1. **Videotapes** corresponding to math and science are sent home with every student.
2. **Math and Science Books** are sent home with every student to reinforce number concepts and science themes.
3. **Math and Science Newsletters** are sent home with each unit to inform parents about their students’ progress and also to foster continued learning at home by providing a connection between classroom instruction and the home.
4. **Math and Science Worksheets** are available at the end of a lesson for homework or extra practice.
5. The Math Newsletters provide **Reading Lists**. The books on these lists are designed to reinforce the various math and science concepts and can be found at most local libraries.

- **Parents help children develop positive attitudes towards science**

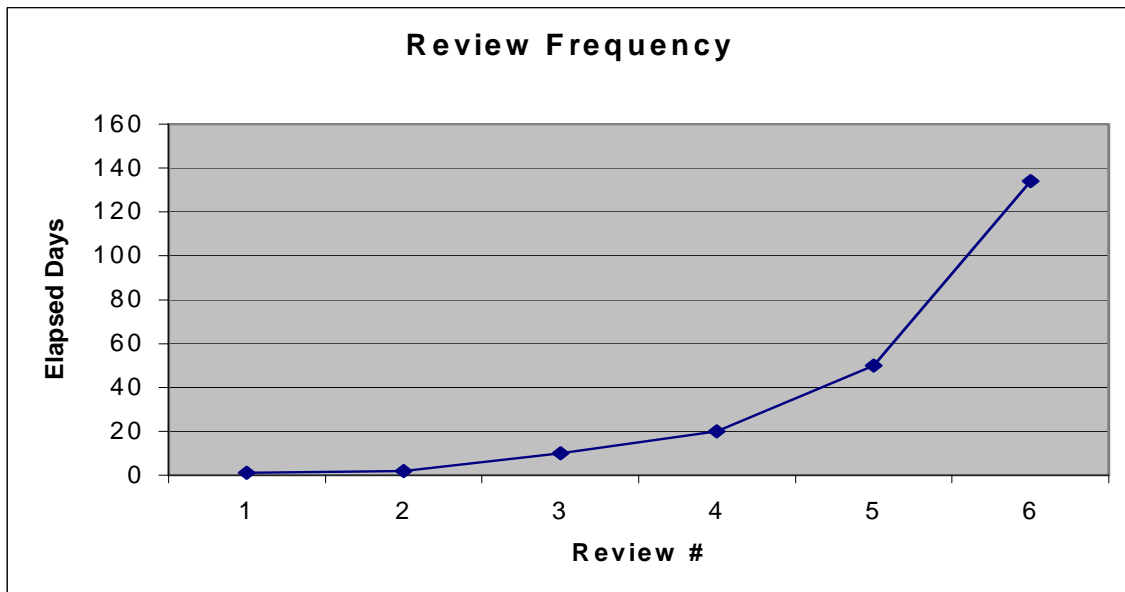
The National Science Teachers Association (NSTA) gives priority to encouraging parents to help their children by seeing science everywhere and doing science activities together. Studies have shown long-lasting positive effects of parental encouragement in science (Harlan et al. pp.22-23).

## Review and Assessment (EMS Sequencer)

Daily instruction and assessment is managed through the use of a database tool called the Early Math & Science (EMS) sequencer. This software individualizes instruction based on mastery of core objectives.

- An innovative sequencer database allows for “automated review” of critical skills and objectives

One of the unique features of the EMS Sequencer is “Automated Review”. This feature attempts to compensate for *learning decay*, a concept developed in Brainerd and Reyna’s research on “forgetting rate” and Carolyn Rollee-Cover’s work on “time windows” of cognitive development (1995). The concept is simple: when we learn something new it is immediately stored in our short-term memory. As we exercise this knowledge, it makes its way into our long-term memory. If the knowledge is not exercised, it decays over time.



The EMS Sequencer attempts to model this decay and counteract the decay by forcing a review of the new material. When a new skill is first mastered, a review will be scheduled almost immediately. Over time, review becomes less and less frequent. Review frequency can be adjusted on an individual basis.

- The Sequencer provides remediation when needed

Another useful feature of the EMS Sequencer is Automatic Remediation. If a user fails to master an objective, the Sequencer will attempt to provide remedial material. The Sequencer looks for a related objective that is less difficult than the one the user failed. Once an easier objective on a similar topic is found, the Sequencer selects activities suitable for use in remediation.

## Conclusion

*Waterford Early Math & Science* has a unique mission – to improve and enhance the education of all students, while narrowing the gap for those students who need help the most.

Some students enter school prepared to learn, others do not. Many have had the advantage of having parents spend time with them, participated in day care, or provided a solid foundation for learning. Others have had very little preparation, and need extra help trying to catch up with their peers.

*Waterford Early Math and Science* was developed to give students with a variety of backgrounds access to a carefully sequenced math and science curriculum that they can work through at their own pace. Performance is assessed and re-taught as necessary to ensure that a solid foundation is built before they go on to more advanced concepts. Mastery is achieved, and self-confidence grows.

Through the application of innovative technology and quality curriculum, every child is prepared for a lifetime of discovery.

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