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On behalf of the Software & Information Industry Association (SIIA) and our member high-tech companies, thank you for inviting me to provide testimony about the role of technology in math education. I am Mark Schneiderman, SIIA's director of education policy.

SIIA is the principal trade association for the software and digital content industry. SIIA provides global services in government relations, business development, corporate education and intellectual property protection to more than 800 leading software and information companies.

SIIA Members:

- Depend on the nation's schools for a skilled, high-tech workforce and are concerned with the nation's challenge in producing students with necessary science, technology, engineering and math skills.
- Seek employees with 21st century skills including in the areas of problem-solving, communication, collaboration, information literacy, computer literacy and the ability to be self-directed life long learners.
- View technology as a core component of modernizing our educational institutions and practices in order to better meet these and other educational needs.

And many SIIA members – including Texas Instruments, Carnegie Learning and the Mind Institute – develop and deliver educational software, digital curricula and related technologies and services for use in education. To that end, SIIA and our members are most interested in the panel's findings in order to inform their research and development efforts. SIIA members work to ensure their digital content and technology tools are rich and engaging, learner-appropriate, and safe, aligned to the curriculum and state academic content standards, and incorporate effective pedagogy and instructional design. SIIA and our member companies have long collaborated with researchers, educators, government officials and other stakeholders to enhance these innovative technologies and their impact. We applaud the Math Panel's efforts to investigate both the research base and the evidence of effectiveness of math curriculum and instruction in an effort to guide future research and practice and ultimately improve student achievement.

I was invited to present to you today a framework and context for understanding what, how and why technologies are being used today in mathematics curriculum and instruction. I hope this outline of the range and purpose of technology tools will help set the stage for the other panelists who will demonstrate and discuss the related research.

My testimony will make the following key points:

1. Educators and students are increasingly employing information and communication technologies to meet their teaching and learning needs, and this use and demand is growing in light of various practical considerations and promising impact.

2. We must recognize the technology-rich environment in which today's students live, and the impact of that on what and how they learn. Similarly, schools must better recognize and leverage the technology tools aiding institutions in all other sectors of our society.

3. Math-related educational technologies and e-learning come in many forms, designs and pedagogical approaches and serve many purposes and needs -- from assessment to instructional management, from tutoring to simulation, and from individual to whole-class instruction.

4. Many technologies can be thought of as tools or alternative means/mediums for achieving traditional educational needs, adding efficiencies and functionality not otherwise possible, such as the interactive, multimedia smartboard replacing the blackboard. Valid evaluation of effectiveness should measure this utility, often an intermediary step to improved teaching and learning.

5. Differentiated instruction is perhaps the most promising and overarching use of technology to increase student achievement. Sophisticated software provides educators the tools to dynamically assess students, identify learning needs in real-time at a granular level, align curriculum and instruction to fill those gaps, and deliver computer- or teacher-based instruction to address each student's unique learning needs and pace, including for students with disabilities.

6. Curricular and instructional technologies are dependent on the underlying cognitive, pedagogical and instructional research. These applications should therefore be examined both independent of and in conjunction with this design, distinguishing between the learning research and the technology value-adds. In other words, the technology is only as good as the content and pedagogy it delivers. At the same time, the technology brings certain utility and functionality that can not be achieved absent this medium.

7. E-Learning is not just for students. Technology can transform teacher professional development from a one-time, disconnected activity to a targeted, "just in time" model. Teachers can better leverage anytime, anywhere online learning and virtual peer communities to improve their math content knowledge and teaching skills.

8. While software and digital content are increasingly serving as the core basal curriculum, many are designed and used under the premise that no single instructional material or program is sufficient to address the unique learning needs of each student. Use of

multiple learning resources and media expands instructional options and allows for reinforcement, remediation, differentiated instruction, and the filling of curriculum gaps.

9. Research into technology's impact on student achievement and other educational goals is promising. There is solid research showing effectiveness, which will be evident from the other panel presentations. At the same time, as in all other areas of education, the research is ongoing and much more must be learned. SIIA members are investing in this effort, and they seek public-private partnerships to ensure an ongoing research agenda. Such research must use varied measures and methodologies in light of technology's many roles and purposes.

10. Many systemic and practical issues must be overcome to replicate and scale the promising technology successes experienced by some, but not enough, schools, teachers and students. To that end, any research must control for the fidelity of implementation – technology, like all interventions, can not be successful if not appropriately used.

My testimony is presented in the following three sections to address these key points.

- First, my testimony will frame the key factors driving the increased interest in, and use of, innovative information technologies to meet teaching and learning needs across education, including in math education.
- Second, my testimony will describe, and provide a framework for cataloguing, many of the key educational technologies employed in our schools today, with a focus on those most relevant to math instruction.
- Third, my testimony will frame and examine several of the key research issues and challenges facing educational technologies and e-learning.

Before exploring these three points in depth, let me first briefly set the scene with an overview of educational technology. From diagnosing learner needs to data-informed instruction/decisions and from distance learning to individualized instruction, there are promising signs that technology is helping improve educational opportunities, productivity and outcomes. We, of course, invite this panel to directly examine that research.

Differentiated instruction is perhaps the most promising and overarching use of technology to increase student achievement. Sophisticated software with rich curriculum and embedded diagnostic assessments enables customization to the individual's unique learning needs, styles, and pace, including for students with learning disabilities and other special needs. Instructional management applications enable educators to assess student skills, and identify and deliver curriculum and instruction to fill in student skill gaps. This individualization can be both automated at the student level (i.e., computer tutorials), as well as managed by the teacher (i.e., use of data to inform and tailor teacher instruction).

It is of course also important to clarify between the vision and reality of technology's use in our schools. The reality is that much is known about how to effectively design and use technologies to improve education, and many teachers, students and schools are engaged in successful implementations today. The other reality is that too few educators and institutions today are adequately successful in adopting these innovative strategies and interventions to drive school change and educational improvement. Many systemic and practical issues remain to be overcome. Education should not be the only sector of our society still debating if technology should be employed.

TECHNOLOGY DRIVERS

Technology today plays an increasingly integral role in the nation's schools. Educators and students are looking to leverage innovative strategies and interventions to meet teaching and learning needs, and this use and demand in technology is growing in light of various practical considerations and demonstrated impact. These technologies present new and exciting opportunities not available, or even imagined, just a short time ago.

What is driving this interest?

Tom Houlihan, outgoing Executive Director of the Council of Chief State School Officers, which represents state superintendents, summarized the driving factors for education technology when he recently wrote: "Education agencies are under pressure to close achievement gaps and better prepare students for college and the workforce in a rapidly changing global economy. At the heart of many promising practices for addressing these challenges is the innovative use of technology." (America's Digital Schools 2006; www.ads2006.org)

We can examine these drivers from the perspective of student, teacher, school administrator, and parents and community stakeholders:

First, the **student perspective**. Today's students matured in a digital world and are masters of technology. They seamlessly integrate multiple technology tools and digital resources into their daily lives, but are too often forced to leave these skills and aptitudes at the classroom door. As a result, students are increasingly disengaged in school, forced to adapt to a learning process and medium that stands in contrast to that which is most comfortable and successful for them.

This is not just an issue of making learning fun through video, games and other technologies. More importantly, students want and need instant feedback in their learning, similar to what they receive playing video games or searching online. They learn, in part, by creating their own knowledge like they do in writing a blog or making a home movie. And they want to learn collaboratively like they do when participating in an online game or chat room. And students will apply their math knowledge in a technology world, and so it makes sense for them to learn with these same tools with which they will apply their math skills outside their formal education.

Educators also increasingly recognize that students learn in different ways and at a different pace. No Child Left Behind Act accountability has further exposed the variances among students, and is appropriately driving educators to individualize instruction in order to ensure all students become proficient. And "paper" teachers increasingly recognize that their traditional methods and materials are less effective with digital-age students. Varied methods, mediums, and time on task are needed for many students to augment the regular and traditional curriculum and instruction. Educators need tools to help identify and address student needs in real-time. They are looking to transition much of their class time from whole class instruction to group learning and even one-on-one instruction as appropriate to enable differentiated instruction. Finally, they are seeking embedded training and real-time professional support to enhance their subject-matter knowledge and instructional skills.

School officials recognize the need for improved data systems and other business applications to efficiently and effectively manage their institutions. Schools are enterprises, but our institutions of learning have not yet gained the efficiencies and productivities seen by the private sector through modernizing their systems through technology. Administrators are seeking better data in terms of its depth, accuracy and timeliness, and they are working to better analyze and manage that information to inform decision making. Schools have too long operated largely in the dark without the robust data needed to evaluate and make needed adjustments to their teachers' capacity, instructional materials, and other resources.

Parents and other stakeholders similarly are looking to enhance the home-school and home-community connections for increased involvement and accountability. Parents are increasingly accustomed to real-time data, and no longer are willing to wait to end-of-semester to see their children's grades. They want increased communication with their teachers, and they want each night to know their children's homework assignments. Local, state and federal officials, business and community leaders, and other stakeholders also seek more robust, timely information on the effectiveness of their schools.

Other drivers include the need to:

- provide students with access to courses and qualified teachers not otherwise available, including for home-bound students and those in rural or high-poverty communities;
- more seamlessly access professional development, peer learning communities and resources in order to improve their curriculum and instructional practices;
- integrate and align fragmented elements of the educational process such as curriculum, instruction, assessment, professional development, and institutional resource management; and
- provide effective instruction of all students, regardless of barriers of geography, mobility, language, or disability.

With regard to this last driver – student disabilities, the Council for Exceptional Children states in its Teaching & Learning Center that: "Every year, new technology comes on the market that can enhance the learning of students with exceptionalities. The right technology can provide a student with a disability access to learning opportunities few dared to dream of just a decade ago and provide them the means for academic success." (http://www.cec.sped.org) Indeed, assistive and adaptive technologies are among the most established as many students with physical and learning disabilities would be unable to succeed without them.

And a recent U.S. Department of Education funded study looking at serving struggling students, including those with disabilities, concluded that: "Technology-based innovations can form the basis of effective approaches to help students who have difficulty with math strive to achieve parity with their peers." ("Technology-Supported Math Instruction for Students with Disabilities," Hasselbring, Lott, and Sydney; Center for Implementing Technology in Education, American Institutes for Research)

All of these factors are driving education stakeholders increasingly to technology and e-learning as a means for addressing challenges, some of which can not be practically or efficiently met absent this modernization of practice.

A few data points help demonstrate student and teacher technology use and interest in K-12 education today:

- According to a recent survey of the 2,500 largest school districts, "Over 75% of district superintendents agree or strongly agree with the premise that "ubiquitous technology can reduce the time, distance, and cost of delivering information directly to students and that teachers can spend substantially more one-on-one time with each student and personalize the education experience to each student's needs." (America's Digital Schools 2006; www.ads2006.org)

- In this same survey, more than 90% of curriculum directors reported that their textbooks will gradually be replaced by a new generation of digital instructional materials over the next five years. 68% cited the following as very important digital materials factors: "capable of assessing/diagnosing student performance," "offers interactive exercises or manipulatives (applets)," and "can simulate hard-to-understand concepts."

- According to a recent survey of 185,000 students and 15,000 teachers in 2,082 schools: "Teachers say that technology is having a positive impact on their teaching and on their students' success." As a result of technology, 74% of teachers say their jobs are easier, and 47% say they communicate more with parents about their children's progress, that their lesson plans and student's learning experiences are richer, and that students take a more active role in their learning. (NetDay 2006 Report, "Our Voices, Our Future Student and Teacher Views on Science, Technology & Education;" www.netday.org)

- For students, this same NetDay survey of students in grades 6-12 found that 50% are taking tests online, 30% are using online textbooks, and over 35% are e-mailing their teachers.

- A U.S. Department of Education survey found 328,000 K-12 student enrollments in distance education in the 2002-2003 school year. 72% of districts planned to expand their distance education courses, and 80% cited the most important reason as offering courses not otherwise available at the school. (**"**Distance Education Courses for Public Elementary and Secondary School Students: 2002-03;" U.S. Department of Education; http://nces.ed.gov) Recent estimates put the online enrollment numbers at between 500,000 and 1 million.

The National Council of Teachers of Mathematics (NCTM) includes technology as one of its core principles, stating: "Technology is essential in teaching and learning mathematics; it influences the mathematics that is taught and enhances students' learning." The NCTM principles continue: "Calculators and computers are reshaping the mathematical landscape, and school mathematics should reflect those changes. Students can learn more mathematics more deeply with the appropriate and responsible use of technology."

Summing up the drivers, the U.S. Department of Education in its 2004 National Education Technology Plan, "Toward A New Golden Age In American Education," proclaimed that "No Child Left Behind sets forth a bold and systemic framework for reform to close the achievement gap . . . To enable such important and sweeping changes to take place will require not only a rethinking and realignment of the industrial age factory model of education, but a rethinking of the tools available to support such change. From the back office to the classroom, schools of the information age will need to effectively employ technology to better meet the needs of students, parents, teachers, and administrators."

TECHNOLOGY TYPES & USES

Identify a school function or instructional practice, and there is a technology to improve its efficiency and effectiveness. In math education, educational technologies come in many forms and designs, and serve virtually every educational purpose and need. With technologies constantly evolving and the lines blurring between form and function, there is no single framework or typology by which to catalog them.

My testimony will catalogue technologies used in education according to their teaching and learning functions. Broadly, these would include: (1) Curriculum and Instruction; (2) Teacher Instructional Support; and (3) School Instructional Supports. These will be explored in detail below. Curriculum an instructional technologies can be further divided into: (1A) courseware and digital content; (1B) technology-mediated distance learning; and (1C) learning tools. Because the reader's experience with these technologies may vary, my testimony will assume very limited knowledge and so will provide many basic descriptions that those more familiar may want to skim through.

First, it may be instructive to identify the core technology types, but from a technology rather than educational perspective. These would include: hardware and devices, software applications and digital content, and web-based services. When most people think of technology, the computer or other hardware first comes to mind. Of course, in most cases that technology is the platform or means for delivering software, digital content and e-learning applications.

Hardware and devices of course range from computers to calculators to smartboards to cameras – all of which are used in the math classroom. Some are designed specifically for educational purposes, while most are adapted to meet teaching and learning needs. Most are a vehicle for delivering information, some enable information collection, and many are interactive and promote both such as through hosting an interactive software application.

Following is a brief outline of these hardware and device types used in education:

- computer devices from desktops to laptops to personal digital assistants;
- data collection and scientific devices from calculators to student response devices to probes to microscopes;
- displays from smartboards to televisions to LCD projectors;

- consumer electronics from cameras to iPods to mobile phones; and
- assistive technologies designed for those with disabilities.

Some of these will be explored in more detail below, while others are beyond the scope of this testimony, including the hardware infrastructure of servers, routers, etc.

Taking a step back, my testimony will now review the technologies in terms of their teaching and learning functions: curriculum and instruction; teacher instructional support; and school instructional supports. Those can of course be subdivided in several ways as well. And most employ a combination of hardware, software and web-based services. I'll focus on the first two in reverse order. I will not address school instructional supports, which could include student information systems and other technologies used to manage non-academic functions of the education enterprise.

Teacher Instructional Supports

Teacher instructional Supports are those technologies that provide teachers with the tools, resources and capacities to teach the curriculum. While there are exceptions and overlap (such as assessment), these are generally not used directly in the teaching and learning process. They include the following:

- Technology-Based Assessment: Assessment items can be delivered to and/or answered by the student on a computer or other device such as a networked graphing calculator. Educators can build their own tests using test-maker applications, rely on the provider's tests, or employ a combination of the two. Where a computer is not available for all students, scanning technologies are often employed with results returned electronically to the teacher. These technologies provide educators with robust, granular data on each student's understanding of each learning standard to inform instruction in real-time at a scale otherwise not possible. Districts and states are increasingly employing similar technologies for summative assessment to increase efficiency and timeliness. Without this technology, educators can only estimate the level of student learning until paper-pencil tests are scored, and teach to the perceived class mean rather than the individual.

  These technologies also enable an ongoing feedback loop between students and teacher to better engage each student in the learning process. Similarly, student anonymity can be provided, the absence of which often keeps students from sharing their difficulties and successes. Increasingly popular are student response devices by which the teacher delivers a question and the students use the device to respond. Questions can range from "do you understand?" to "which is the correct answer?" By incorporating anonymity and timeliness, these technologies provide the educator with a real-time window into the understanding of the class and each student in a way not otherwise possible.

- Teacher Observation Tools: A second major revolution in assessment brought by technology is the teacher observation tool. Pioneered in reading assessment, these technologies provide a time-saving, mobile platform by which teachers can assess and record student skills and knowledge through direct observation. These data are then synched at the teacher's desktop to facilitate further data management and analysis and ultimately instructional prescription. The result is increased educational efficiency.

- Professional Development: Technology, and especially the Internet, enable educators to access training, counsel, resources and collaborative peer communities at anytime from their classroom or home. Online distance learning enables teachers to take additional math content, pedagogical and other courses to improve their core knowledge and skills, something especially important in algebra-readiness where many are teaching out of field. E-mail provides ongoing support from trainers and master educators that provide for more authentic, ongoing, embedded, real-time professional development. Virtual spaces help end the isolation of the classroom teacher, helping build professional communities for sharing lesson plans, learning objects and instructional counsel.

- Instructional Management Systems: This broad and ever-evolving class of applications is aimed at providing educators with a single platform by which to manage and integrate curriculum, content, assessment and student data. Core to these systems are data management applications that include not only summative test scores, but also performance data organized by learning standards and assessment item. These data applications are invaluable to enable educators to identify each student's learning successes and challenges and inform their instruction.

  Of course, diagnosis is inadequate without remedy, and so these systems also enable educators to identify appropriate instructional resources that map directly to standards and student needs. Core to these systems are the organizational structures that help digitally house, align, and connect the various components of learning standards, lesson objectives, learning objects, and assessment items. IMS and related systems enable seamless, systemic integration and coordination of curricular and instructional resources with professional development and school administration. It is the integration of previously disconnected functions that provides much of technology's added value.

- Parental Information and Communication: These tools remove the barriers of time, distance, and lack of information and so help facilitate critical parental involvement. These include e-mail, telephone, and school websites. Sophisticated school web portals enable parents to check student assignments and grades, and students to access electronic learning resources from home to enable parental assistance with studies. No longer can students claim they do not have any homework, and no longer can parents claim they do not have the supports needed to assist their children.

Curriculum and Instruction – Courseware & Digital Content

As noted above, curriculum and instructional technologies can be divided into courseware and digital content, technology-mediated distance learning, and learning tools.

Courseware and digital content is intended for use by teachers and students in the development of student skills and knowledge. These applications are understood to integrate to varied degree both information and pedagogy – the material to be mastered and techniques to teach and learn it. They can address the what, how and why of math education – declarative, procedural and conceptual knowledge – as well as the interaction of all three. "Declarative knowledge is developed through technologies that help build computational fluency. Challenges with procedural knowledge are surmounted with the assistance of technologies that help with converting mathematical symbols and notations, calculating mathematical operations, and inputting/organizing data. Finally, conceptual knowledge is enhanced by technologies designed to build conceptual understanding, problem solving, and reasoning." ("Technology-Supported Math Instruction for Students with Disabilities," Hasselbring, Lott, and Sydney; Center for Implementing Technology in Education, American Institutes for Research)

Most such technologies are highly interactive and adaptive, providing a core distinction from printed materials. Some, such as a simple digitized version of a textbook, are often short on interactivity, but this category will not be covered here. Many courseware and digital content applications are intelligent – preprogrammed to anticipate student misunderstandings and mistakes and reacting with further instruction designed to address that gap. Many include scaffolding. "Computer tools can provide a form of scaffolding as the tools help offload some of the learner's cognitive task to the computer. . . . As the students use these tools, they should begin to internalize this guidance, making the tools unnecessary." ("Technology-Supported Math Instruction for Students with Disabilities," Hasselbring, Lott, and Sydney; Center for Implementing Technology in Education, American Institutes for Research) Examples include converting text, symbols, and mathematical notations; representation techniques (e.g. pictorial instruction); and cognitive strategies (e.g. heuristic procedures) for problem solving.

These electronic learning resources have traditionally been viewed as supplemental to the textbook and basal program, but they are increasingly being used as core to the instructional program to replace or act together with the print as the primary instructional medium (as is the case with Carnegie Learning's Cognitive Tutor). Like print resources, this courseware is intended to be learner appropriate, aligned to state standards, and built around effective pedagogy and instructional design.

Other value-added characteristics of courseware and digital content include:

- integrate multimedia and interactive content, including to represent content in alternative, reinforcing modalities and engage the learner;
- integrate assessment to facilitate the adaptive software and/or to allow for real-time tracking of student performance to inform instruction and provide accountability;
- adapt to support differentiated or personalized learning, including for students with alternative learning pace or needs;
- keep knowledge current, information accurate and pedagogy update due to ability to make real-time updates, especially for web-based resources.
- enhance accessibility for physical or learning disabled students through assistive technologies, tools and presentation of content in alternative modalities;
- support accountability needs through integration of assessment, content management and alignment, classroom management and other courseware tools; and
- expedite delivery, enhance access and increase mobility through electronic or online delivery.

The fourth and seventh bullet points above may be of special interest to the Math Panel. With traditional print materials, it may be 6-8 years before curriculum recommendations made by the Panel would find their way into the textbooks of all students. With digital materials, updates can be made within months.

Courseware and digital content can be viewed through a variety of cognitive, pedagogical, instructional and curricular frameworks. For example, we could look at the degree to which these applications address each of the following steps in the learning process:

(1) Identification of existing knowledge / formative assessment
(2) Acquisition of new information / development of new skill
(3) Application of new information / practice of new skill
(4) Demonstration of mastery / summative assessment
(5) Refinement of Meta-skills

As many on the Panel are aware, courseware and digital content types include the following:

- Tutorial: Programs of this type introduce math concepts and then provide practice, assessing mastery as students progress. Focus is on the (1) and (2) learning processes listed above, with secondary focus on (3) and (4). Topics are taught through text, graphics, or both, and then provide opportunity for practice and application. Math concepts are brought to life through dynamic, interactive visual representation. For younger students, the software often includes entertaining, animated format with a storyline and characters. For older students, simulations and demonstrations are used. Some play the role of "electronic textbooks."

- Skill-Building / Drill & Practice: These applications assume previous knowledge (unlike tutorials) and provide multiple opportunities to apply this knowledge and reinforce discrete skills that have already been introduced. Focus is on the (3) learning process listed above, with secondary focus on (2) and (4). Practice opportunities include an escalating level of difficulty, often in a game-like format, which adapts to the students particular learning needs. Students are often provided a step-by-step solution path, and are guided along the way with hints, explanations, and graphical representations.

- Comprehensive Courseware: These programs cover most or all of the essential learning topics and steps in the learning process, often through a combination of tutorials, practice, and assessment, and may be used as core curriculum. Some applications of this type specialize in math fundamentals/remediation; because students using this courseware are by definition attempting to "catch up" to the higher math learning for their grade levels, individual skill mastery is carefully tracked. Most now include student data management functions for reporting and to inform teacher instruction.

- Problem-Solving: Programs of this type present challenges or puzzles that require specific math skills to solve, often in a multi-stage process. Focus is on the (3) and (5) learning processes listed above. Problem-solving situations presented by these programs may be either convergent (with one correct answer and/or one solution path) or divergent (with multiple correct answers and paths).

- Test Prep: Similar to skill-building/drill and practice (see above), but focused on assessment performance, particularly standardized tests. Focus is on the (3) and (4) learning processes listed above.

- Simulations & Visualization: Video, animation and graphic simulations are often embedded in the courseware and content categories above, but also exist as distinct applications. These programs provide engaging visual representations of math concepts, often creating a "virtual" world for concept modeling and allowing students to explore cases and impacts in a vividly graphic way. As a result, students can visualize mathematical concepts that might otherwise be purely abstract, or apply conceptual learning to real-world situations. A number of video-based simulations focus on the visualization aspect and are less interative. Increasingly, video is being divided into shorter segments directly aligned to learning standards for more targeted use by teachers. Focus is on the (2) and (3) learning processes listed above.

- Educational or Serious Games: While entertainment, animation and games have long been a part of many courseware and digital content products, a new category of courseware is emerging designed around more authentic gaming concepts. These applications provide more immediate and ongoing feedback, require more concentrated and lengthy attention, allow repeated practice, motivate increased time on task, and employ a very leveled and contextual approach to building skills and knowledge. My fellow witness the Mind Institute employs many of these techniques. Focus is on the (2) and (3) learning processes listed above, with secondary focus on (1), (4) and (5).

In practice, these distinctions may work best in the abstract as technology types merge and evolve, and class lines blur. In practice, the same technology application may integrate all of these types or be used by different learners and teachers in entirely different ways. Many of these applications also include assessment and instructional management features. And they may be delivered on any software platform, network (web-based or local network), hardware device or other computer-based technology.

It is also helpful to characterize these courseware and digital content applications according to several dimensions. These include:

- Relationship to Core Curriculum: Some are intended as core or primary, in the sense that they will provide the main body of knowledge (perhaps replacing a textbook). Many are supplementary, intended to enrich and extend the core. Still others are more properly defined as complementary.
- Teacher Role and Learner Grouping: Applications may be intended primarily for relatively independent use by a student (as in the case of a self-paced tutorial), for use by a group of students (as in a collaborative project) with the teacher as a "guide on the side," or by a teacher working with a classroom full of students (as in certain kinds of online demonstrations).
- Pedagogic Design: Content/curriculum software may be designed for use in structured direct instruction or may allow learner construction of knowledge, or anything in

between. Technologies can incorporate any number of cognitive and pedagogical learning theories.

- Content Focus: The essence of a particular software resource may take the form of information (e.g., multiplication table math facts), skills (e.g., how to multiply three-digit numbers), or both.

Many courseware and digital content applications are designed and used under the premise that no single instructional material or program – adopted or not adopted; primary or supplemental; electronic or print – is sufficient to address the unique learning needs of each student. Use of multiple learning resources and media expands instructional options and allows for reinforcement, remediation, differentiated instruction, and the filling of curriculum gaps. Electronic learning resources are particularly beneficial for students who learn at a different pace or learn best through alternative modalities, and perhaps for whom the traditional adopted program is not sufficient. Many allow teachers to adapt use to the pace of the adopted program.

Curriculum and Instruction – Learning Tools

Learning tools are intended to help the user gather, organize, and present information, or to accomplish other information-handling tasks of the user's own definition. In math, again, we usually think first of the calculator or graphing calculator. As a class, learning tools are more often subject-neutral; a word processor might be used with equal effectiveness in language arts, science, and foreign language. Common generic learning tools range from widely used productivity packages such as word processors or spreadsheets to reference tools such as electronic dictionaries, encyclopedias or the world wide web itself (along with the search engines and web research organizers that students use in conjunction). Other tools are more subject specific such as graphic organizers, history timeliners and graphing calculators.

Learning tool applications typically correspond strongly to application of new information/practice of new skills. They also correspond to the demonstration of mastery/summative assessments, and – depending on the tool and its use – to meta-skills such as study skills and metacognition. Learning tools are often connected more closely to a particular technology hardware or device, or to a specific software platform.

Learning tools employed in math education include the following:

- Simulation, Graphing & Mapping: Video, animation and graphic simulations are often embedded in the courseware and content categories above, but also exist as distinct applications. These programs provide engaging graphical representations of math concepts, allowing students to manipulate variables and observe outcomes in a vividly visual way. Popular types include electronic manipulatives, presentation software, fractal programs, story maps, and geometric sketchpads. Simulations, depending on their exact design and use, are often a blend between a learning tool and courseware/content. The lines are often blurred between these leraning tools and the simulation and visualization software included in the courseware/content category (see above), although one might think of learning tools as more dependent upon initial student input.

- Calculator: A common tool is the calculator used for a variety of purposes, including operations practice and problem solving. Calculators are often reserved for use by students after they have mastered the conceptual underpinnings of the basic operations, although some uses can assist students in gaining those skills. Calculator design and function has evolved significantly. In addition to free-standing device, calculator applications are integrated into many other devices (such as mobile phones and PDAs) amd software (such as productivity packages and math software).

- Graphing Calculator: The graphing calculator allows for collection, visualization, and analysis of data in addition to facilitating complex math operations. It helps students develop their math communications, spatial and representation skills; improves understanding of graphical concepts; and facilitates connections between functions and their graphs. Like calculators (see above), graphing calculators come both as dedicated devices, as free-standing software applications, and integrated into other math software. Many child-friendly graphing programs with rich graphics have found acceptance in math classrooms. In addition, calculators and especially graphing calculators are increasingly networked and used by teachers to observe student learning in real time, thus helping them assess student learning and adjust instruction accordingly.

- Other Tools: Spreadsheets are a basic productivity tool that can play a role in the upper ranges of early math instruction and in the upper grades, particularly for its graphing and modeling functions. The Math Notation/Processor is an emerging type of tool that allows students and teachers to create live formulas on the computer screen.

Curriculum and Instruction – Technology-Mediated Distance Learning

Distance learning, distributed learning, online education, virtual learning, web-based learning, etc. are all terms often used interchangeably to describe an instructor-mediated course delivered via technology (such as the Internet or satellite conferencing) to students at a different geographic location than the teacher, and usually than each other. In K-12 education, the primary goal is to provide effective instruction to all students, regardless of barriers of geography, mobility, disability or local capacity. In other words, distance learning provides access to courses/teachers for students who would otherwise not have access.

Distance learning comes in many forms, with the common thread that technology is used to access the instruction (and curriculum) and interact with teacher and fellow students. This outline will focus on that delivered online. Some courses are synchronous whereby the teaching and learning takes place simultaneously as in a traditional classroom. Others employ asynchronous learning whereby communication tools such as e-mail and discussion forums are used to engage the teacher and students across time, enabling 24/7 learning according to one's schedule and learning pace. Most employ a combination of the two. This format can often break down barriers to student interaction and inquiry, engaging students who otherwise may shy away from asking questions or demonstrating their knowledge in a traditional peer setting. Some courses employ an entirely digital curriculum, while others use a blended approach that includes print materials used by the student. And some courses combine distance with in-person learning.

A consistent body of research and meta-analysis has generally found that, at worst, there is no difference in achievement between students taking traditional face-to-face classroom courses and those taking a formal course online [See Cavanaugh et al. (2004), Falck et al. (1997), Goc Karp & Woods (2003), Jordan (2002), Kozma et al. (2000) and Mills (2002)]. For students for whom distance learning is their only opportunity to access certain courses, this equal quality is a far better option than not taking the course. Yet, it is also apparent that distance learning is not necessarily as appropriate for all students, especially for younger students.

Another variation of online learning is the online tutor. This less formal instruction generally provides a struggling student with 24/7 access to an educator or expert tutor to provide immediate help on a topic or specific homework question. Sessions can range from a few minutes to an hour review session to an ongoing scheduled program. Tutors are trained to provide help, not answers, and to bring every session to an educationally sound conclusion. Sessions are generally conducted through instant messaging and an interactive, online smartboard, allowing student and teacher to synchronously share files, and to view and manipulate the identical information. Sessions are often archived to enable students, parents or teachers to review transcripts.

One final note on virtual or web-based learning is that on must distinguish between these types of instructor-mediated learning and two other common uses of the Internet to deliver courseware and digital content. The first is the delivery of software/content via the Internet as an alternative to software installed on a school computer or a school's local network. This is a purely technical difference. The second is student and teacher use of the Internet and its myriad of resources for educational purposes. This might include virtual fieldtrips or interactions with real-world scientists and scenarios in order to provide a context for a given mathematical concept.

Final Thoughts on Technology Types

Before leaving the technology types portion of my testimony, it may be useful to put forward two final frameworks for understanding the types and role of technology.

First, technology can and is helping redesign and reinvigorate the classroom and the teacher's role. The technology is helping educators

- reach more students, uniquely tailor instruction, and enable greater success for all learners;
- simplify and replace many low-value administrative tasks, thus freeing time for high-value tasks; and
- diagnose student learning needs and deliver appropriate, targeted resources (both computer-based and teacher delivered).

In so doing, technology is empowering educators to shift from delivering the same information to a passive student audience to that of also actively guiding each student in an individualized learning process. And technology can transform professional development from a one-time, disconnected activity to an ongoing model through online learning and virtual peer networks. According to NCTM's Principles, "Technology cannot replace the mathematics teacher, nor can it be used as a replacement for basic understandings and intuitions. The teacher must make prudent decisions about when and how to use technology and should ensure that the technology is enhancing students' mathematical thinking."

Second, we can consider the question – Is technology an efficiency/productivity tool or is it transformational?

Technologies can be thought of simply as tools or alternative means for achieving traditional educational needs, adding efficiencies, functions, expediency, etc.

- The smartboard is a 21st century blackboard, greatly enhancing functionality, interactivity and graphics to better engage students and visually represent challenging concepts.
- The student response device is a substitute for students raising their hands, providing the added value of recording student data and student anonymity.
- A tutor instructing online (as well as software tutorials) can provide many similar services as in-person tutor, with the added benefit of resource efficiency and increased access for students otherwise unable to gain access under current limits of time and place.
- And computer-based assessment in many ways can mirror traditional assessments, but student responses are scored, analyzed and organized to enable teachers (and students) to quickly receive and act on this information.

While each of these technology uses, and many others, on their own are often viewed as tools to improve educational productivity and effectiveness, when combined and used in a manner unconstrained by our prevailing education process – modeled on the industrial-age assembly line and the agrarian calendar – the sum is potentially transformational with learning student-centered and taking place anytime, anywhere and at any pace. I would encourage the Math Panel to view the technologies in both ways, but to view transformation as the long-term goal and value.

RESEARCH CONSIDERATIONS

As noted above, years of research provides both a sound theoretical basis for technology's positive impact on teaching and learning, as well as examples of where that technology can improve the educational process and student outcomes. The other panel witnesses will demonstrate this research in more detail, and we invite the Math Panel to review this research and would offer to work with you to provide that research. At the same time, as in all other areas of education, the research is ongoing and much more must be learned. My testimony will frame several key questions, challenges and considerations that must be addressed for a productive research and evaluation agenda around educational and math-related technologies.

Among these issues are the following:

1) Fidelity of Implementation: While technology has been employed in the classroom for decades to varying degrees and to varying degrees of success, education remains relatively immature in its effective implementation of even proven technologies.
2) Differentiating Tool/Medium vs. Design/Pedagogy: Technology is a tool and a medium, and must be therefore examined both independent of and in conjunction with its design and the pedagogy it delivers.

3) Purposes & Outcome Measures: Technology plays many roles, serves many purposes, and provides certain utility and functionality, and so how should its impact and effectiveness be measured?
4) Collaboration: The education technology R&D agenda is often seen as the responsibility of industry, but it is our students and educational process that stand to gain most from enhanced public-private collaboration.

Fidelity of Implementation

Education stakeholders have collected a growing body of experience and research over the last two-plus decades about what works and what does not work in educational technology. Much of this relates to the technology design itself, but equally important is how the technology is implemented. In its 2000 *Research Report on the Effectiveness of Technology in Schools*, SIIA found that "Technology can improve teaching and learning, but just having technology doesn't automatically translate to better instructional outcomes. Whether a given school experiences the potential benefits of technology depends on the software it chooses, what students actually do with the software and computer hardware, how educators structure and support technology-based learning and whether there is sufficient access to the technology." (See Appendix for excerpted chapters of this SIIA report.)

Like all curricular and instructional interventions, regardless of medium, technology applications require fidelity of implementation. However, with school technology capacities still varied widely and too often inadequate, technology faces an additional burden that will only be overcome with time and leadership. Teacher training, school leadership, technical support, properly configured hardware, robust network infrastructure and Internet access, appropriate pedagogy and instructional use, recommended intensity of use and other conditions and practices are all inseparable from results.

What does this mean for the research agenda with regard to educational technologies related to math education?

- First, further research is needed to better understand not only the conditions and practices that support the effective use of educational technology, but how we can replicate those conditions and practices in schools and classrooms not yet privy to that success.
- Second, educational technology research must take into account this factor to prove valid, reliable and useful to educators and policy makers. This includes research aimed it informing technology design, as well as research aimed at evaluating specific technology products and uses. Randomized control trials, while necessary, are not sufficient if they can only measure impact in a random classroom with random, and likely inadequate, technology capacity and implementation. Also needed are trials where technology capacity is ensured so that value-added technology differentiators can be evaluated.

Differentiating Tool/Medium vs. Design/Pedagogy

Like teachers and textbooks, instructional technologies can follow any number of pedagogical models and employ any number of instructional designs. It is important to separate the two, and to look to independently identify: (1) effective pedagogy and instructional design based on cognitive and other learning theories; (2) the functional value-adds provided by technology regardless of the specific applied design/pedagogy; and (3) finally, the interaction of the two. While many instructional strategies can be implemented without technology, often, they can be employed more efficiently and effectively with the tools and mediums of technology.

It is therefore important to draw on the theoretical framework to infer technology impact in cases where rigorous direct evidence may not yet have been conducted. For example, if we know that visualization is important for understanding math concepts as demonstrated through traditional means, and if we know that the technology employs interactive, multimedia that can efficiently provide visual representations in a manner not possible without technology, then it can be inferred that the use of technology will improve the effectiveness of the curriculum and instruction on student achievement. This should not suggest that direct evaluation of the educational technologies is not needed, but only that we look both independently and interdependently at the tool/medium and the design/pedagogy. In many cases, the technology will add utility and value to the intervention, no matter the pedagogical underpinning. But the research may not be there yet in some cases, just as it is not for traditional methods.

Finally, it is critical that the research and evaluation efforts look not just at each type of technology differently, but look within each type as individual products and uses within a type can vary widely in quality, design, etc.

Purposes & Outcome Measures

As outlined previously, educational technologies serve a myriad of educational purposes. While the ultimate purpose of education, and therefore of technologies employed in education, is to improve student achievement – in this case, math skills and knowledge – many technologies make indirect contribution to this goal and/or serve as intermediaries in achieving this goal. Equally valid is technology's function to change the system of instruction, teacher behavior and the process of learning, including by providing access to courses/content, engaging students, increasing parental involvement, leveraging data, etc. The diverse purposes that technology serves and the many ways in which it contributes to student achievement therefore do not lend themselves to mono-dimensional understanding or singular measures of success.

Any study of the effectiveness of technology in education – and particularly any examination of the impact of technology on student achievement – must consider this diversity. The effectiveness of technology in this complex setting is best measured with equally multi-faceted instruments. For example, we know that diagnosing student learning needs is key to addressing those needs; and that computer-based assessment can help teachers gather and manage student data more efficiently and quickly. While research will help make the case directly, it is also important to look at the utility of these outputs of efficiency and timeliness as ends themselves.

Collaboration

With the integration of technology into education at a relatively early stage, a considerable R&D effort will be necessary to determine the most effective tools and models. While much is known, many questions remain. Yet, despite continued calls for research on education technology, major barriers exist with regard to funding as well as for gaining participation of institutions, educators and students. The community of educational software publishers and other technology developers is key to the research effort. Industry makes significant investments to research, develop and evaluate education software and digital content. But further partnership is needed.

As we know, educators too often do not view themselves as part of the research and evaluation process in the manner that is present, for example, in the medical field. It is challenging for developers to get schools to agree to randomized control trials, for example. Educators and government officials often express skepticism toward industry funded evaluation research, but companies face a dilemma as it will not otherwise get done. Education and government must be an equal partner in evaluating technology, determining what works and why, and supporting development of next generation technologies that incorporate effective pedagogy and design.

Federal, state and foundation R&D should help fund and strongly encourage or require partnerships between education, industry, and institution-based researchers to ensure the efforts are shaped by practice and the results, in turn, help to mold that practice. Publishers try to follow this model now by partnering with educators to conduct their research and development.

Federal R&D should be focused on long-term basic research, large-scale empirical evaluations, development in smaller and under-served niche product markets, and other R&D that better identifies effective models, the factors that determine effectiveness (i.e., what interventions work best with students of what learning styles and under what conditions), and ultimately how these models can be replicated. Government can help address education needs by both targeting government R&D to fill the gaps in private research and allowing for-profit entities to further access R&D grants. Education technology developers operate at the cutting edge of research and work closely with educators to understand and respond to their needs. As a result, companies are often in the best position to identify research gaps, respond in partnership with practitioners, translate findings to software, and ensure these resulting technologies are made available**.**

CONCLUSION

Education stakeholders have collected a growing body of experience and research over the last two-plus decades about what technologies are needed in education and what purposes they serve, what works and what does not work, and why the varied impact. We know that technology serves many purposes, and that even within a certain category, design and quality will vary from application to application. We also know that the promises of technology's impact has perhaps been overstated over the years, in large part due to education's slow systemic pace of effective adoption.

Perhaps most importantly, we know that the predominant traditional methods are not adequate. The National Math Panel has been appointed to better understand and make recommendations on promising and effective models for math curriculum and instruction. I would encourage you to include technology in both categories. And I would encourage you to examine the research yourselves as well as to include educational technology as worthy of further study and consideration.

Further, we would urge that the Math Panel's findings and recommendations focus toward broad principles and practices of effective math instruction and curriculum, rather than toward identifying specific interventions, programs and products. To the degree you do look at specific interventions, we encourage you to look foremost at the underlying reasons for effectiveness in a manner that can more broadly inform educators as well as developers. We believe your most appropriate role and greatest impact will come not from giving educators the fish (i.e., a list of interventions and products), but by sharing with them the knowledge you gained and teaching them to fish themselves. Only then can we keep up with ever-changing instructional programs and practices in the face of evolving research and technologies.

Finally, I'll end with a comment from now former Secretary of Education Dr. Rod Paige in his introduction to the Visions 2020 Report about the future of education: "Indeed, education is the only business still debating the usefulness of technology. Schools remain unchanged for the most part despite numerous reforms and increased investments in computers and networks. The way we organize schools and provide instruction is essentially the same as it was when our Founding Fathers went to school. Put another way, we still educate our students based on an agricultural timetable, in an industrial setting, but tell students they live in a digital age."

SIIA and our member companies stand ready as both contributors to and customers of the work of your National Math Panel. We thank you for your work, and we stand ready to both provide further assistance, including a collection of relevant research, as well as to incorporate your findings into the development and implementation of educational technologies to improve our students' understanding of math.

Thank you.

Appendix

2000 Research Report on the Effectiveness of Technology in Schools

(*Selected Chapters*)

About This Report

In 1990, the Software Publishers Association (SPA) published its first "Report on the Effectiveness of Microcomputers in Schools." (SPA and IIA merged in 1999 to become the Software & Information Industry Association.) In that report, numerous research studies supporting the use of technology as a valuable tool for learning were described. These studies indicated that the use of technology as a learning tool could make a measurable difference in student (1) achievement, (2) attitudes and (3) interaction with educators and other students. The evidence suggested that positive effects of technology were dependent upon the subject area, characteristics of the student population, the teacher's role, student grouping decisions, the design of the software and the level of access to technology. Since then, research documenting the effectiveness of educational technology has continued to grow and become more detailed.

This report, commissioned by the Software & Information Industry Association (SIIA) and conducted by an independent educational technology consulting firm, Interactive Educational Systems Design Inc. (IESD), summarizes educational technology research from the late 1980s through 2000. This report is based on 311 research reviews and reports on original research projects, from both published and unpublished sources. Of these 311 studies, 135 were published in professional journals and 56 were doctoral dissertations. The 311 studies were chosen from an original set of
more than 3,500.

The report is divided into three sections:

- Effects of technology on student achievement
- Effects of technology on student self-concept and attitude about learning
- Effects of technology on interactions involving educators and students in the learning environment

Conclusions

Technology is making a significant positive impact on education. The findings of greatest importance in the research reviewed for this report include the following.

General

- The specific student population, the software design, the educator's role, how the students are grouped, the preparedness of the educator and the level of student access to the technology influence the level of effectiveness of educational technology.
- Educators are an essential element in the effectiveness of technology.
- Software is effective because it allows individual learner traits and multiple pathways to learning (e.g., text, graphics, speech) to be taken into consideration when software is being designed and used.
- Effectiveness of educational technology depends on a match between the goals of instruction, characteristics of the learners, the design of the software and technology implementation decisions made by educators.
- Students of teachers with more than 10 hours of training significantly outperformed students of teachers with 5 or fewer training hours.

Positive Effects of Technology on Student Achievement

Educational technology has demonstrated a significant positive effect on achievement. Positive effects have been found for all major subject areas, in preschool through higher education and for both regular education and special needs students. More specifically:

- Large-scale, statewide implementations of educational technology (in West Virginia and Idaho) have been correlated to gains in standardized test scores.
- In studies focusing on reading and language arts, technology has been shown to provide a learning advantage in the areas of phonological awareness (awareness of the structure of sounds in a language), vocabulary development, reading comprehension and spelling. Furthermore, there is evidence that students who use word processing software in combination with carefully sequenced instruction in the writing process or writing tools with built-in guidance in the writing process improve their writing significantly more than students without access to such tools, as do students who write to a real audience via the Internet or e-mail.
- Technology has been used effectively to support mathematics curricula that focus on problem solving and hands-on, constructivist, experiential activities. Students participating in such technology-supported learning experiences have demonstrated superior conceptual understanding of targeted math topics than students receiving traditional instruction.
- Studies focusing on science education suggest the benefits of simulations, microcomputerbased laboratories, video to anchor instruction to real-world problems, and software that targets students' misconceptions.
- A learning advantage has been found when students have developed multimedia presentations on social studies topics.
- Kindergartners who have used technology have benefited in areas such as improved conceptual knowledge, reading vocabulary, reading comprehension, and creativity.
- Educational technology has significant positive effects on achievement for special needs populations. Speech recognition is an especially valuable compensatory tool for the learning disabled.
- Interactive video is especially effective when the skills and concepts to be learned have a visual component and when the software incorporates a research-based instructional design.
- Use of online telecommunication for collaboration across classrooms in different geographic locations can improve academic skills.

- Using the Internet to provide college students with supplementary instructional resources can benefit their academic performance.
- Use of distance learning has been shown to be as effective as instruction that takes place locally.

Positive Effects of Technology on Student Motivation and Self-Concept

- Educational technology has been found to have positive effects on student attitudes toward learning and on student self-concept. Students felt more successful in school, were more motivated to learn and had increased self-confidence and self-esteem when using computer-based instruction. The evidence of these effects is the strongest for: Language arts and writing instruction; Mathematics instruction; Science instruction; Telecommunication technology, including the Internet; Video technology.
- Educational technology has significant positive effects on student attitudes for special need populations.

Effects of the Teacher's Role and Instructional Decisions

- The teacher's role is of primary importance in creating an effective, technology-based learning environment—an environment that is characterized by careful planning and frequent interaction among students and the teacher.
- Teacher professional development and decisions about how computers are to be used in instruction may matter more than how often technology is used.
- Students trained in collaborative learning on computer in small groups had higher student achievement, higher self-esteem and better attitudes toward learning than students working individually. The positive effects of collaborative learning were especially pronounced for low ability students and for female students.
- Expanding student responsibilities through a learner-as-multimedia-designer environment can positively impact student attitudes.
- Decisions about the choice of medium when assessing student performance should reflect students' experience writing on the computer. Testing students by having them write by hand has been shown to result in an underestimation of their writing abilities if they are accustomed to writing on computer. However, multiple choice tests administered via computer and using pencil and paper have been shown to yield similar results.

Effects of Specific Software Design Features

Specific software design elements have been shown to have a positive impact on student achievement and on student motivation and self-concept. Several research-based suggestions follow.

- Offering students some control over the amount and sequence of instruction, including options for student review of material, can result in higher achievement and better student attitudes toward learning than having the software control all instructional decisions. However, low-achieving students and students with little prior content knowledge are likely to require more structure and instructional guidance than other students are. When students have a high need to learn, this may nullify the impact of the level of learner control.

- In tutorial and practice software, programs with feedback providing knowledge of correct responses were found to be superior to programs that require students to keep answering until they achieve a correct response. Furthermore, feedback that identifies *why* a response is wrong was found to be more effective than feedback that only identifies *what* was wrong.
- Software that includes embedded cognitive strategies provides students with a learning advantage. Helpful cognitive strategies include: Repetition and rehearsal of content; Specific note-taking techniques; Paraphrasing; Outlining; Cognitive mapping or diagramming; Drawing analogies and inferences; Generating illustrative examples; Having students explain their steps in solving problems; Specific techniques for reading in the content areas; Using pictorial information.
- Students can benefit academically from software with embedded conceptual change strategies — sequences of instruction that move students from their faulty preconceptions to a more accurate understanding of the concepts involved.
- Instructional scaffolding—gradually decreasing the level of help available and/or gradually increasing the complexity of the task—can be effective in improving student achievement.
- Animation and video can enhance learning when the skills or concepts to be learned involve motion or action.
- Animation accompanied by spoken narration is generally superior to animation accompanied by explanatory text. When including narration, additional extraneous audio (e.g., music, sound effects) should be avoided.
- Still graphics can enhance learning when the concepts or skills to be learned have a visual component but do not involve motion or action.
- Content-related graphics (both static and animated) and video can help improve student attitudes and motivation in mathematics and science.
- Students using hypermedia software can benefit from an interface that includes a navigation map that shows the links among the various screens of information and the hierarchical structure of the information. It is also advisable to make the entire hyperspace to which students will eventually have access fully transparent while limiting their access to what is currently instructionally appropriate.
- Foreign language students can benefit from presentation of video segments with captioning (i.e., subtitles in the target language) and from access to native language translation when reading text-and-graphics dialogues in the target language. These design features are likely to make a difference for ESL students as well.
- Recent research additionally suggests possible benefits from inclusion of the following software design characteristics (subject to further exploration and confirmation): Providing sufficient practice; Stating objectives; Advanced organizers in simulations; Pedagogical agents that communicate with a human voice in a personalized dialogue with the student; Graphs in mathematics instruction; Multiple representations of concepts; Dynamic visualization of abstract concepts; Motivational contexts, such as story, game, and fantasy elements; Multiple window presentation options (overlapping vs. tiled windows).

Effectiveness of Interactions Involving Educators and Students in the Learning Environment

- Introducing technology into the learning environment has been shown to make learning more individualized and student-centered, to encourage cooperative learning and to stimulate increased teacher-student interaction. Technology has been used successfully to support constructivist, inquiry-based and project-based instructional methods.

- Specific characteristics of the learning environment help to maximize the benefits of educational technology:
    - District-level involvement and the leadership of a school-level computer coordinator are key factors in developing a school environment conducive to effective use of technology.
    - Educators are more effective after receiving extensive training in the integration of technology with the curriculum.
    - Exemplary computer-using educators benefit from a social network of other computer-using educators at their school.
    - Exemplary computer-using educators typically have smaller class sizes and more funds available for software acquisition.
    - Educators should carefully plan, and actively participate in, learning activities that incorporate tool software. Before students use database software independently, they should be given search strategy training.
    - Educators should offer students self-directed learning experiences and activities that encourage self-expression.
    - Students benefit from personal interaction among class members.

- Courses for which computer-based networks were used increased student-student and student-teacher interaction increased student-teacher interaction with lower-performing students, and did not decrease the traditional forms of communication used. Many students who seldom participated in face-to-face class discussions become more active participants online.
- Classroom connectivity to the Internet was found to be the best predictor of teachers' professional use of the Internet. Furthermore, classroom connectivity in general and, more specifically, connectivity with four or more computers were found to be important factors in predicting whether teachers directed student research involving the Internet.
- When upper elementary students use the Internet to conduct research, they tend to spend more of their time browsing rather than conducting carefully planned searches. Teachers are advised to provide a variety of support, possibly including "natural language" search engines, guided practice in conducting searches, broadly defined research tasks, and instruction in identifying and using relevant source material. These findings may apply to older students with limited Internet research experience as well.
- Small group collaboration on the computer is especially effective when students have received training in the collaborative process. However, there are trade-offs in deciding whether students should work individually or collaboratively:
    - Students who worked in groups were found to interact more with their fellow students (including cognitive and positive social interactions), to use more appropriate learning strategies, and to persevere more on assigned instructional tasks.
    - Students who worked individually at the computer were found to spend more time actually engaged with the software and to complete their tasks more quickly, but they needed more help from the teacher.
- Greater student cooperation, sharing and helping behaviors has been shown to occur when students use computer-based learning in which students compete against the computer rather than against each other.
- University and inservice teacher training provides educators with greater comfort in using computers, an increased desire to use computers and an understanding of how to integrate software into the classroom curriculum.

- Preservice teachers have successfully used communication technologies such as email, news groups, and listserv mailing lists to exchange ideas on instructional issues. Preservice teachers who do this over several weeks have been shown to make greater gains in self-efficacy and confidence in their teaching abilities than teachers without access to such tools.
- Positive changes in the learning environment brought about by technology are more evolutionary than revolutionary. These changes occur over a period of years, as educators become more experienced with technology. Long-time computer-using teachers tend to make changes in the learning environment generally related to a constructivist teaching approach.

This report provides software developers and publishers with research that will enable them to improve educational technology so that it continues to have a significant positive impact on student achievement, self-concept and motivation and on the interactions in the learning environment for students of all ages, capabilities, socio-economic backgrounds and areas of interest. The research reviewed in this report aims to help educators make effectual educational decisions as they incorporate technology-based learning experiences into the curriculum, increase student achievement and motivation in a variety of subject areas and consider advantageous software design characteristics when selecting software.

MATHEMATICS

Several studies compared instruction in mathematics using technology to instruction using traditional methods.

Elliott and Hall (1997) found that the use of computer-based mathematics activities enhanced mathematical achievement among at-risk four-year-olds. Children were placed into one of three groups, two of which used computer-based mathematics software. Children in the third group participated in a range of typical discovery-oriented preschool mathematics activities off-computer, together with computer activities in other areas. **Students in both groups that used computerbased math activities had significantly higher posttest scores on the Test of Early Mathematical Ability—TEMA 2.**

Raghavan, Sartoris and Glaser (1997) reported positive impacts on student learning from the first two units of the Model-based Analysis of Reasoning in Science (MARS) middle school curriculum. These units, which focus on area and volume, include models (area tiles and volume cubes) that students manipulate on the computer screen to replicate, compare and construct two and three-dimensional figures. Performance of sixth grade students who completed the units was compared with that of eighth grade students who had studied perimeter, area and volume in both sixth and seventh grade and had reviewed geometry concepts at the beginning of eighth grade Algebra I. The researchers found that **although both groups performed about the same in simple application questions, the sixth grade students (who had completed the MARS units) significantly out-performed the eighth graders on questions requiring problem, data and concept analysis, resulting in a significantly better overall score** . To evaluate long-term retention, some of the MARS students were also retested in December of their eighth grade year. **Even after two years, the MARS students significantly out-performed other eighth grade students in Algebra I**, with a mean score of 13.4 out of 25 compared with 7.9 out of 25 for the non-MARS students.

Researchers from Leicester University (Underwood, Cavendish, Dowling, Fogelman and Lawson, 1996) found that students using mathematics software in an Integrated Learning System (ILS) at schools throughout the United Kingdom showed significant learning gains, compared to students not using the software. The study included students between the ages of eight and thirteen. Those in primary schools performed significantly better in the areas of addition, subtraction, multiplication and extensions. Students at the secondary level showed significant gains in the areas of operations and diagrams.

Three studies were designed so that instructional time for the experimental and control groups was approximately the same. Stone (1996) compared second grade students who had used several mathematics and reading software programs since kindergarten with students in a nearby school who did not use the software. Both schools followed the same Board of Education-approved course of study. However, students who had used the software scored significantly higher in mathematics problem-solving on a standardized test. In another study by Fletcher, Hawley and Piele (1990), third and fifth graders received either CAI (*Milliken Math Sequences*) or traditional math instruction for 71 days. At both grade levels, students receiving CAI scored significantly higher than students receiving traditional instruction on a test of basic math skills, as well as on an assessment of computer literacy. CAI was rated as having greater cost utility. Reglin (1989-1990) focused on a seminar on mathematics skills, in preparation for an exam required for admission to teacher education programs. One group of students received nine hours of classroom instruction and nine hours of computer-assisted instruction (CAI); the other group received 18 hours of classroom instruction. Students in the classroom instruction-plus-CAI group showed significantly higher achievement gains than the students in the classroom instruction-only group. **Since these studies were controlled for time spent on instruction, their results suggest that the computer experience, not merely time-on-task, account for the differences in student achievement.**

Two studies by researchers at the Stevens Institute of Technology (Jurkat, Skov, Friedman, Pinkham and McGinley, unpublished paper) demonstrated the positive effects of commercially-available high school mathematics software on retention (i.e., performance on a delayed posttest). In one study, each student received instruction for two geometry topics, one with supplemental software and one without. One group used software for the first topic and the other group used software for the second topic. For retention, student performance was significantly better when instruction included software. In the other study, two groups of students were compared. One received instruction that included supplemental software and the other group did not use software. Once again, the group using software demonstrated significantly better retention (70 percent better) than the group who did not use software. **The researchers point to the technology experience of the teachers in the computer-mediated treatments as a critical factor.** They note that the educators "had been part of a computer-mediated education development project for more than two years."

Funkhouser and Djang (1993) found that high school algebra and geometry students who used commercially available problem-solving software scored significantly higher on tests of mathematics content than a comparable group of students who did not use the software. The students using the software also made significant gains in problem-solving ability.

Mac Iver, Balfanz and Plank (1999) found significant improvement in knowledge and application of math procedures by Philadelphia seventh graders who participated in CATAMA, "a combination of computer-assisted instruction and structured cooperative learning." In place of an elective class, students spent one class period a day for 10 weeks working in pairs on a tailored lesson sequence covering "a broad spectrum of proficiencies in math computation, math concepts, word problems, geometry, algebra, and thinking skills." Performance of CATAMA students on the end-of-year Stanford 9 Mathematics Procedures test was compared to that of non-CATAMA students whose performance had been similar on the previous year's test. **Researchers found that "mathematics procedures achievement scale scores were much higher for typical CATAMA participants than for students in the comparison sample."** This translated into an 11-point difference in the end-of-year national percentile rankings: 54th percentile for CATAMA students, 43rd percentile for the comparison group. Mac Iver, Balfanz and Plank also noted one particularly practical benefit of these results for students from a school that comprises over 85% low-income families and over 50% non-native English speakers: *Many of the special admission high schools in Philadelphia...require a student to score at [85th local] percentile or above at the end of the seventh-grade year in order to be considered for admission as a ninth-grader.* ***Eighteen of 48 CATAMA participants reached the 85th citywide percentile on their mathematics procedures test as opposed to only 7 of the 48 matched students from the comparison sample.***

Tucson Unified School District #1 (1994) reported positive results for "an integrated curriculum revolving around the use of a networked business computer system." The computer network gave teachers and their seventh grade students access to a variety of commercially available tool and reference software products. **For two consecutive years, students involved in this innovative curriculum demonstrated significantly greater improvement in mathematics basic skills than comparison students receiving traditional instruction did. Furthermore, the computer-using students had a lower average number of absences and a lower rate of withdrawal from school.**

Koedinger and Sueker (1996) found that **college students using the Practical Algebra Tutor (PAT), an intelligent computer tutor that presents skills "in the context of authentic, realistic problem-solving tasks," scored significantly higher in a performance assessment of algebraic problem-solving, qualitative reasoning and the ability to communicate effectively about mathematics than students who did not use PAT**. Scores on the departmental final exam did not differ significantly for the two groups, demonstrating that time spent using PAT "did not detract from the...acquisition of the algebraic manipulation skills targeted" by the final examination. This is good news for schools seeking to incorporate both performance-based assessment and traditional testing in their student evaluation program.

In a related study, Koedinger, Anderson, Hadley and Mark (1997) compared performance of ninth grade students using PAT in 20 nontraditional classrooms with that of two other groups using a more traditional curriculum: five standard ninth grade algebra classes, and two "Scholar" academic track algebra classes. Students using PAT worked in cooperative teams on a National Council of Teachers of Mathematics (NCTM) Standards-oriented problem-solving curriculum, where teachers were freed to provide more individualized help to students. **On two standardized tests with basic skills objectives, PAT students scored as well or better than the standard algebra classes (significantly higher on one test), even though this was not a primary focus of the curriculum.**

On two NCTM-oriented tests, they "significantly and substantially" out-performed the standard classes and equaled or exceeded the Scholars classes. This included one test of students' abilities to translate between verbal descriptions, graphs, and symbolic equations, where students using PAT scored significantly higher than the Scholars students did. This set of findings attests to the potential for using technology in a problem-solving curriculum without sacrificing basic skills.

In a study by Alexander (1993), college algebra students who used software designed "to aid in the instruction of functions using concrete visualization" plus a graphing calculator significantly outperformed students receiving conventional instruction in their "understanding of the concept of functions...and in mathematical modeling." **The results in this study suggest the power of the computer to provide concrete visual support for the learning of abstract concepts.**

O'Callaghan (1998) found that students using technology in a constructivist college algebra class "achieved a better overall understanding of functions and were better at the components of modeling, interpreting, and translating" among symbols, tables and graphs than students in two traditional algebra classes. Students in a Computer-Intensive Algebra (CIA) course completed activities that typically required them "to solve problems, often with the help of computer tools (e.g., symbol-manipulation programs), and to describe their methods of solution." **Results demonstrated that CIA students had a significantly deeper conceptual understanding of algebra.**

Gerretson (1998) compared the geometry performance of two groups of preservice elementary teachers enrolled in a mathematics methods course. Both groups completed hands-on, experiential activities designed to help them develop a deeper understanding of the concept of similar geometric figures. The control group used manipulatives and traditional tools such as a protractor and ruler, together with a mechanical device for drawing similar figures. The experimental group used *Geometer's Sketchpad* software. **Results showed that students using the software performed significantly better on a posttest measuring understanding of the concept of similarity.** The researcher attributed this difference to the fact that students using the software were able to generate multiple examples of similar polygons quickly and easily, while students in the control group were limited to a smaller number of examples they could construct using handheld tools.

Two studies by the Cognition and Technology Group at Vanderbilt University (1991) explored the effectiveness of *The Adventures of Jasper Woodbury*, a video series focusing on mathematical problem-solving. *[The video series is] designed to promote problem posing, problem-solving, reasoning and effective communication. Each adventure is a 15-20 minute story. At the end of each story, the major character (or group of characters) is faced with a challenge that the students in the classroom must solve before they are allowed to see how the movie characters solved the challenge.* **Students in Jasper classes out-performed students receiving traditional math instruction in solving one-step, two-step and multi-step word problems.** Jasper students demonstrated greater skill in planning for problem-solving and generating "the subgoals necessary to achieve a larger goal." Jasper is a good example of software that engages students in the construction of their own knowledge and that anchors instruction in the context of meaningful, real-world problems. Fortunately, the results demonstrated that "**spending time on Jasper did not negatively affect performance on standardized tests**." (Jasper students performed marginally better than the control students, but this difference was not statistically different.)

A subsequent Vanderbilt study (Barron, Vye, Zech, Schwartz, Bransford, Goldman, Pellegrino, Morris, Garrison, and Kantor, 1995) suggests that supplementing Jasper videos with technology based thinking tools and follow-up activities help students to apply what they've learned to new problem situations. The supplementary software focuses on four different parts of the problem solving process. *Smart Lab...provides feedback to students about decisions they have made in the course of their work... Roving Reporter...[provides interviews with] various students in the learning*

community [who speak] about the problem-solving they have been doing...to showcase student reasoning and provide an opportunity...to react to various ideas. Toolbox...provides ideas for visual representations (e.g., timelines, graphs) that can be conceived of as "tools" for thinking, problem-solving and communicating. The Challenge...[gives] students a new problem-solving challenge...[and prompts them to] revise their work based on feedback they had just received.
On a new problem scenario that required application of the mathematical skills they used during the original Jasper problem, students who used these supplementary tools demonstrated significantly greater problem-solving skill than Jasper-only students did.

A study by Shyu (1997) found that use of the *Encore Vacation* videodisc as part of an anchored instructional program led to similar improvement in problem-solving skills among Taiwanese fifth grade students. Students watched the story segments linearly, then took a pretest designed to test their abilities in problem identification, problem formulation, generation of subgoals and execution of an appropriate solution. Students then watched the individual video segments again and worked cooperatively over eight class periods to solve mostly mathematical problems based on information from the videodisc. After completing the instruction, **students performed significantly better on a posttest of problem-solving skills. These results were consistent across high-, mid- and lowability groups in mathematics and science, demonstrating that videodisc-based anchored instruction can be an effective tool for teaching problem-solving across both cultures and ability levels.**

Researchers at the Educational Testing Service Policy Information Center (1998) raised an important caveat with respect to student achievement and the use of educational technology in mathematics: teacher professional development and decisions about how computers are used in instruction may matter more than how often technology is used. In their analysis of National Assessment of Educational Progress of 1996 (NAEP) data for 6,227 fourth-graders, they found that mathematics achievement was related to using computers for "learning games" (a category that likely includes activities that promote higher-order thinking skills) and to teacher professional development in the use of computers. In their analysis of NAEP data for 7,146 eighthgraders, they found that mathematics achievement was related to teacher professional development in the use of computers in general and in their use to teach higher-order thinking skills. However, at this grade level, "the use of computers to teach lower-order thinking skills was negatively related to academic achievement." At both grade levels, sheer frequency of use of computers in schools was negatively related to mathematics achievement. Because there was no detailed correlation between type of software and frequency of use, it is impossible to say whether this finding applies to use of computers generally or if it simply reflects ineffective, time-consuming use of computers to teach lower-level skills. It should be noted that the NAEP mathematics assessment was designed to align with the NCTM *Curriculum and Evaluation Standards for School Mathematics* (1996) and therefore focused on striking a balance among conceptual understanding, procedural knowledge and problem-solving. Given the extensive changes in mathematics instruction over the past several years, it is possible that much of the software used by the students in the study was directed toward more traditional goals and methods and therefore may not correlate well to current *NCTM Standards*.