Technology in Schools: What the Research Says

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By Metiri Group—Commissioned by Cisco Systems

Three decades after the first computer was introduced into school classrooms, educational technology remains surprisingly controversial. This paper provides a forum for informed use of technology in the context of emergent research from the learning sciences.

Today's schools cite a myriad of purposes for technology in schools, including improved teaching, leadership, and decision making, as well as the following student-focused purposes:

- Improving learning (e.g., higher standardized test scores)
- Increasing student engagement in learning
- Improving the economic viability of students (e.g., increasing students' abilities to succeed in a 21st century work environment through teaming, technology fluency, and high productivity)
- Increasing relevance and real-world application of academics
- Closing the digital divide by increasing technology literacy in all students
- Building 21st Century skills (e.g., critical thinking and sound reasoning, global awareness, communication skills, information and visual literacy, scientific reasoning, productivity, and creativity)

TECHNOLOGY IN SCHOOLS: A LOOK BACK

As the rate of penetration of the Internet rapidly increases in countries across the globe, and the investment in technological infrastructure in schools, teacher training, and software reaches into the billions, many are questioning its value.

The reality is that advocates have **over-promised** the ability of education to extract a learning return on technology investments in schools. The research studies now suggest that their error was not in citing the potential of technology to augment learning—for research now clearly indicates that the effective use of technology can result in higher levels of learning. This review of the past decade suggests four miscalculations on the part of educators:

- First, in being overly confident that they could easily accomplish the depth of school change required to realize the potential technology holds for learning—not an easy task
- Second, in their lack of effort in documenting the effect on student learning, teacher practices, and system efficiencies
- Third, in overestimating the time it would take to reach a sufficiency point for technology access
- Fourth, in underestimating the rate of change in technology, and the impact of such rapid, continuous change on staff time, budgeting, professional development, software upgrades, and curricular and lesson redesign

As a result, the real potential of technology for improving learning remains largely untapped in schools today.

Technology advocates suggest that just as technology is accelerating globalization, it will advance educational change. They contend that **what** students learn as well as **when** and **how** they learn will change. Pulitzer Prize winner Thomas Friedman, in his recent book *The World Is Flat*[i], talks about the critical role of education in today's knowledge economy. "As we push the frontiers of human knowledge, work at every level becomes more complex, requiring more pattern recognition and problem solving." He goes on to say, "on such a flat earth, the most important attribute you can have is creative imagination—the ability to be first on your block to figure out how all these enabling tools can be put together in new exciting ways to create products, communities, opportunities, and profits." That entrepreneurial spirit depends on a high-quality education system aligned to the realities of globalization and democratization of technology in this 21st century.

The contrarians, on the other hand, cite promises of school reform, increased achievement scores, and deepening of academic learning through technology that have gone unfulfilled. Larry Cuban, a professor at Stanford University, contends that although results such as those are important to note, they are not sufficient to warrant continued investment in technology. In his book, *Oversold and Underused*, he says, "The introduction of information technology into schools over the past two decades has achieved neither the transformation of teaching and learning nor the productivity gains that a reform coalition of corporate executives, public officials, parents, academics, and educators have sought." He suggests that educators step back to "critically examine reformers' assumptions about technology."

Serious attention to Cuban's recommendation for a critical reexamination of technology in schools should result in redirecting investments of technology funds to proven learning technology solutions. Conscientious educators, facing severe budget deficits, will need to examine the research to focus technology investments on solutions that address profound, critical challenges that schools face today. For example:

- Adolescents who are nonreaders or who struggle to read fluently, with comprehension
- Secondary schools that report dropout rates of more than 30 percent
- Large percentages of students failing basic algebra and other mathematics courses
- Achievement gaps based on race, socioeconomic status (SES), and gender

Lowell Monk of Wittenberg University, Springfield, Ohio, admonishes educators to pay attention to the importance of developing students' tacit and explicit knowledge. Nonaka and Takeuchi, experts in strategic planning, describe explicit knowledge[ii] as that which is easy to articulate and can be defined clearly; whereas tacit knowledge is rooted in a person's knowledge that is embedded in individual experience and action and is not easily articulated. They stress the importance of tacit knowledge to innovation, and suggest that the West focuses more on explicit than tacit knowledge in its schools[iii]. Monk contends that web-based information represents conceptual (explicit) knowledge, and that students can build experiential (tacit) knowledge only through real-world, off-line, tactile explorations and learning.

Cognitive scientists John Bransford and Ann Brown, editors of *How People Learn* (U.S. National Research Council), include technology as a means to building both tacit and explicit knowledge. They identify three key principles of learning:

- Students' preconceptions must be engaged in their learning.
- Learning with understanding requires a deep foundation of factual information and knowledge organized in the context of a schema or conceptual framework.
- Metacognition helps students take control of their own learning.

Researchers find that extracting the full learning return from a technology investment requires much more than the mere introduction of technology with software and web resources aligned with the curriculum. It requires the triangulation of content, sound principles of learning, and high-quality teaching—all of which must be aligned with assessment and accountability.

Technology plays three important roles in transforming schools into systems that employ these principles. First and foremost, it is a **learning tool** for more student-centric, relevant, rigorous learning. Second, it serves as a **data tool** for education to better understand and inform educational and instructional decision making. Third, it is an **enabling force** behind globalization, knowledge work, and entrepreneurship, and thus students must understand the role it plays in transforming political, social, cultural, civic, and economic systems around the world. The combination of the three presents much of the rationale for technology in schools today. According to Stanford Professor Larry Cuban,[iv] schools have not been able to produce such results through technology on a large scale.

FROM SPECULATION TO SCIENTIFIC RESEARCH

Reports from the British Educational Communications and Technology Agency (BECTA) in 2001 found that, "The historic research [related to Information and Communications Technology (ICT) in schools] is often on small samples, rarely controls out the effects of things other than ICT, and is rarely rigorous enough in its methodology or its search for explanations of findings to support the weight that has been put on it." The report goes on to say that research in the agency's recent publications "sets new standards of methodological decency in this area of research." In the United States the level of attention in educational research has also increased, in large part because of the rigorous research standard established by the Institute of Education Sciences.

A LOOK AT RESEARCH

Educators often use best practices, i.e., those widely adopted by experienced, respected educators, to inform their instructional decisions. In fact, as new theories, techniques, and strategies for learning are introduced and tested, the field depends on expert review and commentary to identify innovations that seem to be working. This phase of the scientific process is important in that it determines which innovations merit further, more rigorous study—and it shapes the research questions or hypotheses about such innovations. However, far too many educators discuss research and best practices without distinguishing between them. For the purposes of this paper, the following categories of research are defined:

- **Rigorous Research**: Rigorous research is defined as experimental or quasi-experimental design studies (i.e., use of treatment and control groups, preferably through randomization, and rigorous statistical design and analysis to test hypotheses).
- **Descriptive Studies**: Descriptive research studies provide historical insights as to what happened as a technology solution was implemented, how it was implemented, and why it was implemented. Although such studies might include qualitative research and/or pre- and poststatistics that reveal strong correlations, they do not provide definitive evidence of cause and effect.
- **Theoretical Underpinnings**: A significant body of research in the field of education addresses educational strategies (nontechnology) with respect to those that achieve positive results and those that do not. If a technology solution were grounded in educational theory deemed to be sound, then it would be logical to believe that the technology solution that embodies this theory would also produce positive results. It is not sufficient to simply articulate that alignment. For educators to be confident that a technology-based learning solution has theoretical underpinnings, evidence of the theoretical basis must be documented in white papers and/or formative research studies conducted during the development of the solution or software. **Note: Because the determination of theoretical underpinnings is specific to the particular software or learning solution, only the former two categories are used in this document to report findings across types of technology.**

Many of the studies currently available on the effect of educational technology on learning are correlational studies (i.e., descriptive studies). Such studies do not use treatment and control groups for comparisons; rather, they typically compare gain scores from pre- and posttests to expectant gains based on historical data. Although such studies suggest what is working, they do not control for confounds that may provide alternative explanations for results, and thus cannot be used with any confidence to discuss outcomes related to specific innovations.

One of the purposes of this publication is to provide educators with trend data about technological innovations that experts and research say are working—and to identify the "power" within these innovations, according to that research. Ultimately this work should inform school leaders who make the decisions about technology investments.

The report is not intended to be comprehensive, but rather representational. It highlights emergent research studies that indicate which technology does—and which does not—result in spikes in student learning.

WHAT THE RESEARCH SAYS

Contrary to popular belief, much is now known about the effect of technology on learning and teaching in primary and secondary schools. This paper looks at the critical areas of literacy, mathematics, science, and digital literacy, discussing variability of effect across types and configurations of technology as well as types of technology use—noting the importance of pedagogical approach. Beyond general trends, the report provides details about representative studies in each area, profiling the rigor, significance, and dangers of oversimplification of the findings. The overall findings indicate the general areas of learning that technology can be expected to significantly advance. The list of specific studies cited is not meant to be comprehensive, but rather indicative of the results possible when technology is coupled with appropriate pedagogy and implemented with fidelity.

Trends in research findings, organized around eight specific types or configurations of technologies (TECHtypes), follow. Because the findings varied considerably with regard to uses of all technologies, the organization is defined around categories of learning. Through advances of the cognitive sciences, much is now known about how people best learn. The following areas are all important aspects of a student's learning experiences. This paper analyzes research on educational technology and classifies results based on the following types of learning:

- **Automaticity** is the ability to effortlessly complete tasks without conscious thought to step-by-step processes.
- **Content expertise or knowledge** requires a deep foundation of factual knowledge that the student organizes within the context of a conceptual framework for effective retrieval.
- **Information processing and visualization** is the ability to interpret, evaluate, and use multimedia-based information in ways that advance thinking, decision making, and learning.
- **Higher-order thinking and sound reasoning** together represent the cognitive ability to analyze, compare, infer or interpret, evaluate, and synthesize, as applied to a range of academic domains and problem-solving contexts.
- **Authentic learning** is the ability to engage in academic pursuits that are characterized by relevancy, deep and rigorous academic inquiry, and knowledge production.

Following are the "spikes" noted in recent reviews of emergent research—that is, the technology uses that research indicates are producing significant results. The reader should be cautioned that many of the studies cited have not been replicated. Thus, although such studies provide sound information about **possible** effects, educators should be cautious about generalizing beyond the specific populations and contexts of such studies. Educators might consider piloting such technology solutions in their own schools prior to full-scale implementations—in essence, attempting to replicate the results on a small scale first, fine-tuning, and only then scaling the solution after it is shown to work in a different context. Single studies point educators in the right direction, providing sound indicators for potential successes, but until more definitive studies are conducted and replicated, educators must apply such limited findings with caution, adding to the knowledge base as they do so.

TECHtype: Television and Video

The visual medium is already a widely used instructional resource.[v] A great body of research shows that children can learn from viewing and interacting with video and television. Viewing video was once thought to be a passive process. Now, cognitive research has shown that viewers observe, interpret, and coordinate all the information in the video to make their own personal sense of what is being communicated.[vi] A new genre of television program has emerged, exemplified by *Blue's Clues*, designed specifically to engage young children based on social, emotional, and cognitive developmental levels. For example, the use of repetition is extensive within the weekly programming of Blue's Clues, an aspect that appeals to 5-year-olds but not to adults. Educational television and videos are used extensively in classrooms today.

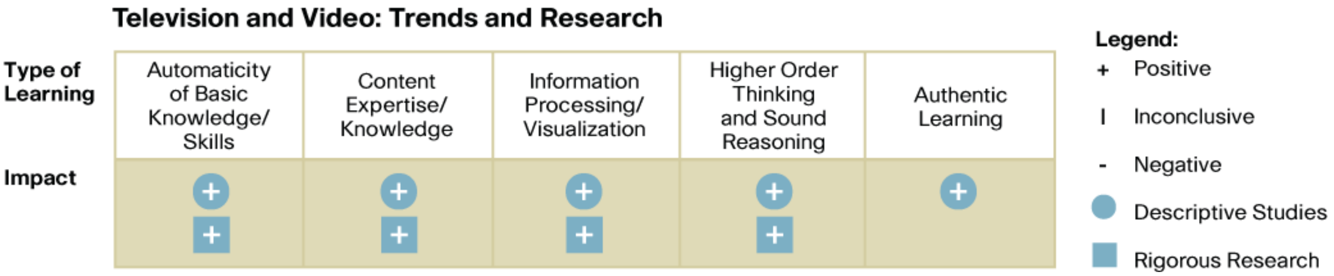
With the advent of digital media, vendors are now producing shorter segments called "learning objects" that are carefully coordinated to mandated curricula and can be flexibly integrated into instruction, e.g., virtual manipulatives in mathematics, historical segments for social studies, introductory segments to engage students, animations that teach processes or concepts, anchored multimedia segments for reading programs, and writing prompts. With the emerging use of video on handheld devices such as iPods, such use will only continue. Although evidence shows that children can learn facts and procedures from video and that viewing video can affect attitudes, we also know that interactions are complex among variables such as the frequency of viewing, the genre of video, the characteristics of the learner, the content of the video, and the context in which the video is viewed. Emergent research suggests that video can add rich context to students' learning experiences without increasing cognitive load on working memory, translating into increases in complex, higher-order thinking.

Representative Rigorous Research Studies (Not Intended to be Comprehensive):

- **Sesame Street**. Some of the earliest and most comprehensive examples of this research focus on the television program Sesame Street and its audience of preschool children.[vii] These studies show that viewing this program was positively associated with vocabulary and letter and number recognition.[viii] Children who watched more *Sesame Street* prior to entering school were rated by their teachers as better prepared for school (e.g., greater verbal and quantitative readiness, better attitudes toward school, and better relationships with their peers).[ix] In more recent studies, these effects were replicated with low SES children.[x] The effects of early experiences with *Sesame Street* persist over time, with 15- to 20-year-olds who watched it as preschoolers having significantly higher grades in high school English, math, and science. These students also had more positive academic self-esteem and a better attitude toward academics.[xi] Versions of Sesame Street adapted for children in other countries have produced similar results for children in Mexico, Portugal, and Turkey.[xii]
- **Jasper Woodbury**. School children in formal school settings also learn from new forms of television and video that enrich understanding. The research on a product by Vanderbilt University called Jasper Woodbury has shown that middle school students viewing a story in an interactive video format recall more information than those reading a text version of the story.[xiii] Based on evidence that even when students understand and remember content learned from video they may fail to apply it to situations in which it may be useful, Jasper was designed to connect mathematics content to problem-solving situations—a process that enhances transfer. Students taught with Jasper showed a small but insignificant improvement over control students on standardized tests, but performed better on word problems—and significantly better on subscores of planning problems than did students in control classrooms.

The **power of television and video for learning** lies in the use of multimedia to engage students visually, cognitively, emotionally, socially, and civically in facets of the academic content. Visual learning can result in increased engagement as well as increased complexity, depth, and breadth of experience to improve student academic performances. Results depend on the inclusion of **high-quality content** and **sound pedagogy**.

Figure 1.



Television and Video: Trends and Research

Type of Learning	Automaticity of Basic Knowledge/ Skills	Content Expertise/ Knowledge	Information Processing/ Visualization	Higher Order Thinking and Sound Reasoning	Authentic Learning
Impact	● + ■ +	● + ■ +	● + ■ +	● + ■ +	● +

Legend:
\+ Positive
I Inconclusive
\- Negative
● Descriptive Studies
■ Rigorous Research

TECHtype: Calculators

Historically, research results on the use of calculators in mathematics classes have been mixed. However, after the graphing calculator was introduced in the 1980s, results were increasingly more positive. A 1997 study conducted in England[xiv] reported that national policies differed considerably, with Denmark, Norway, Portugal, and Sweden adopting a centralized view that calculators should be an established component of the curriculum; England, Italy, Poland, and Spain leaving the decision up to individual schools and teachers; and Austria, former West Germany, and Switzerland not encouraging calculator use in secondary schools. In the United States, the National Council for Teachers of Mathematics credited the graphing calculator for "the emergence of a new classroom dynamic in which teachers and students become natural partners in developing mathematics ideas and solving mathematical problems," especially in algebra and higher mathematics.[xv] In general, the literature suggests that the use of calculators improved learning in three areas: understanding of graphical concepts, the ability to make meaningful connections between functions and their graphs, and enhanced spatial skills.[xvi] Recent meta-analysis indicates that, when calculators are an integral part of testing and instruction, students' operational and problem-solving skills improve, but further research is needed on the retention of mathematics skills and/or the transfer of skills when calculators are used.[xvii]

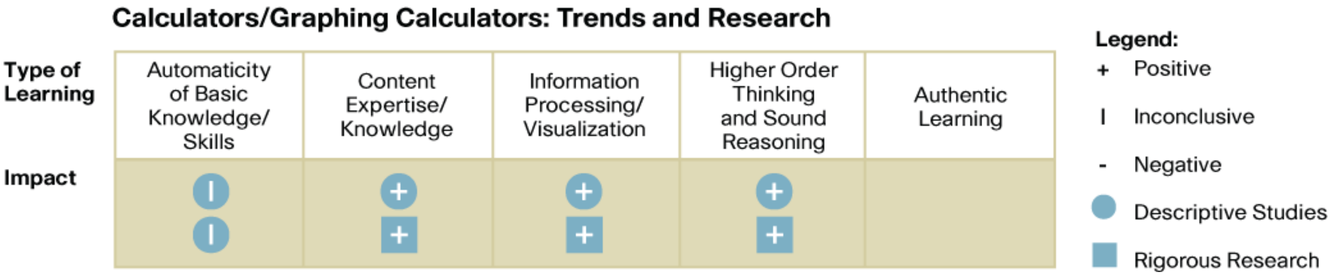
Representative Rigorous Research Studies (Not Intended to be Comprehensive):

In a large-scale study by the Educational Testing Service in the United States, college-bound juniors who were permitted to use calculators did significantly better on a test of items drawn from the SAT than students who were not. Questions for the exam were selected to be more sensitive to calculator effects than the actual SAT. Three out of four ethnic groups (Whites, African-Americans, and Asian-Americans) and both genders benefited equally from calculator use. Latinos benefited slightly more than the other groups.[xviii]

A 1998 study in the United States investigated the value of providing access to calculators and of providing instruction on how to use calculators (in addition to access) for increasing middle school students' math test scores. The study found that seventh and eighth-grade students using calculators outperformed students without calculators on a test of basic math skills, whether or not the students were instructed in how to use the calculators.[xix]

Studies suggest that the **power** of this technology for learning mathematics is unleashed when the tools are used **long-term** (more than nine weeks), are **integral to the instruction, not just computational tools**, and are used in both **instruction and assessment** activities. Research is positive on the effect of calculator use on algebra and advanced mathematics students' scores, mixed with respect to other aspects of mathematics, and slightly negative with respect to use by fourth-grade students.

Figure 2.



Calculators/Graphing Calculators: Trends and Research

Type of Learning	Automaticity of Basic Knowledge/ Skills	Content Expertise/ Knowledge	Information Processing/ Visualization	Higher Order Thinking and Sound Reasoning	Authentic Learning
Impact	● I ● I	● + ■ +	● + ■ +	● + ■ +	

Legend:

\+ Positive

I Inconclusive

\- Negative

● Descriptive Studies

■ Rigorous Research

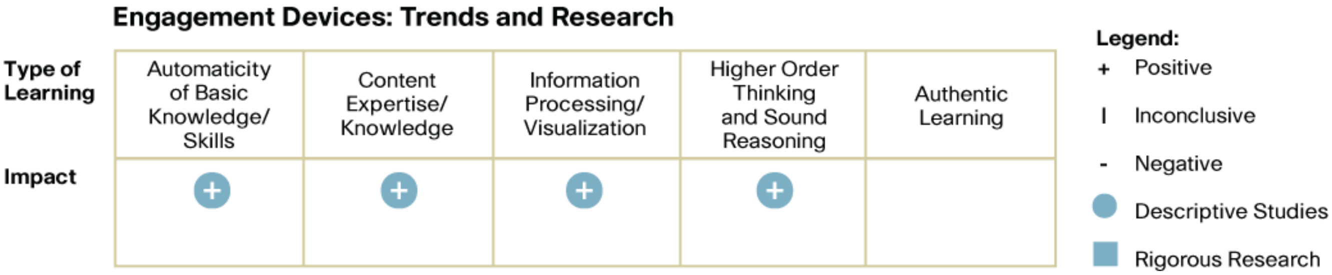
TECHtype: Engagement Devices

Interactive whiteboards. Still a relatively new technology, whiteboards appear to be considered valuable classroom learning tools by educators. Descriptive studies indicate three levels of whiteboard use: 1) to increase efficiency, enabling teachers to draw upon a variety of ICT-based resources; 2) to extend learning by using more engaging materials to explain concepts; and 3) to transform learning by providing learning styles stimulated by interaction with the whiteboard. The theoretical research base indicates that the increased visualization, increased interactivity with students, and the increased reflective dialog among students and teachers around this focal point should contribute to learning. A recent BECTA brief suggests that, although to date no research has been conducted on the effect of whiteboards on learning, there is evidence of good practice and positive outcomes across the curriculum.

Quick-response devices. Another relatively new technology appearing in classrooms today is the quick-response device. Serving as real-time windows into each child's understanding of concepts, these devices can provide a foundation for decision making based on data at a scale never before possible. The authors could locate no rigorous research conducted on the use of these devices to date. However, descriptive studies at the university level with online quizzes suggest that "online quiz questions provided scope for individual and group feedback, self-checking of responses, and comparison of their scores with peers," all leading to metacognitive focus on the topic.[xx]

Note: No rigorous research studies have been located on the two engagement devices referenced in this section.

Figure 3.



Engagement Devices: Trends and Research

Type of Learning	Automaticity of Basic Knowledge/ Skills	Content Expertise/ Knowledge	Information Processing/ Visualization	Higher Order Thinking and Sound Reasoning	Authentic Learning
Impact	+	+	+	+	

Legend:
+ Positive
I Inconclusive
- Negative
● Descriptive Studies
■ Rigorous Research

TECHtype: Portable ICT Devices

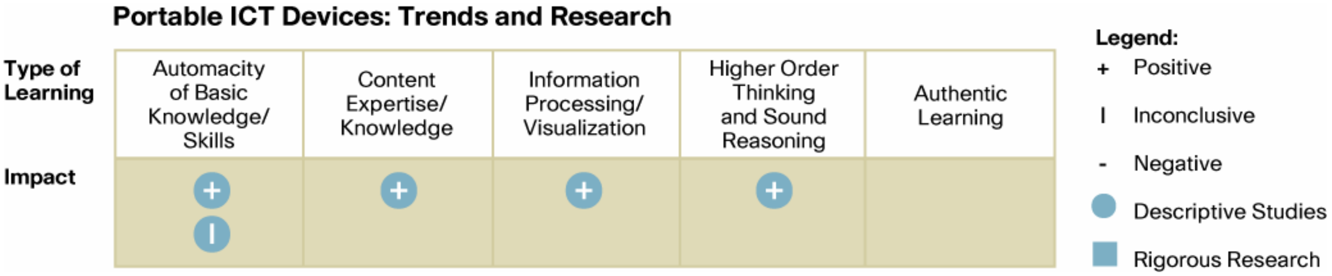
Handheld devices such as personal digital assistants (PDAs), tablet PCs, palmtop computers, and data-logging devices are increasingly available and affordable. Benefits identified in descriptive studies on such devices include accessibility, flexibility, and frequency of use, while concerns included small screen size, small size of keypad, and limited functions. Access in school tends to more fully engage students, and portability extends their learning beyond the school. Experts suggest that these personal devices can increase motivation, organizational skills, independent and active learning, and self-directed learning. Evidence also indicates that ownership of portable devices increases fluency and transparency for students' research of topics, access to resources, writing, reading, and production. Device functions and screen size have been of concern for the smaller devices. The authors could locate no rigorous studies conducted on the effect of these devices on learning. Although initial response by educators, students, and parents is reportedly positive, their effect in comparison to more conventional teaching or other technologies is not yet substantiated by rigorous research.

Representative Rigorous Research Studies (Not Intended to be Comprehensive):

A 2003 study of 1,274 first- and second-year (early elementary) students in Chile compared a treatment group that used handheld devices with games specifically designed to advance reading comprehension, spelling, and mathematical skills with control groups both in and outside the school. Results were mixed, indicating that after 30 hours of using the devices over a three-month period students showed significant improvements compared to the control groups outside the school, but no significant differences when compared to the in-school control group. The researchers did report on improvements in motivation and technology transfer.[xxi]

Descriptive studies indicate positive correlations between the use of educational games on PDAs and increases in reading comprehension, as well as improvements in performance in mathematics. There are some indications that gaming on PDAs engages students in **deep concentration and motivation**, providing a method for learning that is at least equivalent to traditional methods and that leads to high attention, concentration, and self-regulation of students' learning process.[xxii]

Figure 4.



Portable ICT Devices: Trends and Research

Type of Learning	Automaticity of Basic Knowledge/ Skills	Content Expertise/ Knowledge	Information Processing/ Visualization	Higher Order Thinking and Sound Reasoning	Authentic Learning
Impact	+ I	+	+	+	

Legend:
+ Positive
I Inconclusive
- Negative
● Descriptive Studies
■ Rigorous Research

TECHtype: Virtual Learning

The types of virtual learning range from supplementary to comprehensive, from synchronous to asynchronous, from audio to web-based or videoconferenced, as well as innovative hybrids thereof. In 2004, a synthesis of new research on K–12 online learning reported results across five major meta-analyses. The authors summarized multiple meta-analyses, reporting that on average students perform equally well or better academically in formal online learning situations as students under traditional instruction. Summaries also indicate that student achievement in courses using email and web-based virtual learning was slightly better than in courses using traditional instruction, while student achievement in courses with video-based virtual learning was either the same or slightly lower than traditional instruction. Emergent research on visualization and learning through multimedia and a summary report from England suggest that results will be determined somewhat by learner control, dialogue, learner support, and opportunities for direct learner involvement.[xxiii]

Representative Rigorous Research Studies (Not Intended to be Comprehensive):

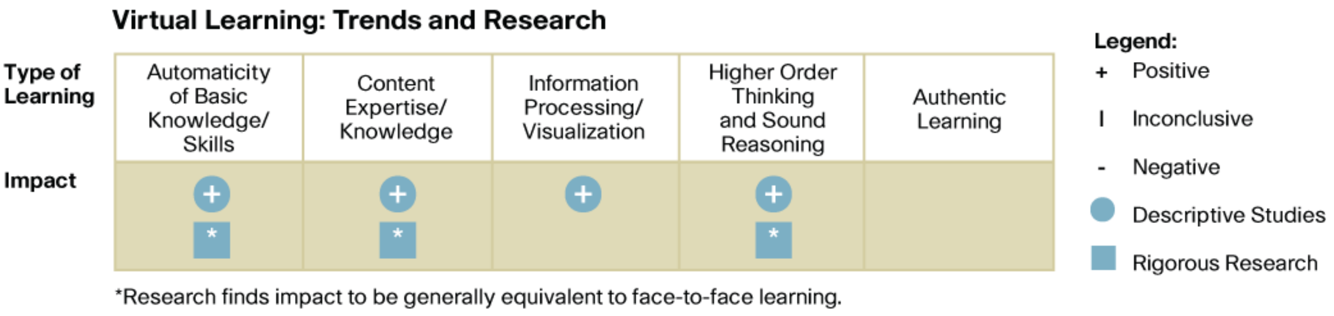
A recent U.S. meta-analysis on distance learning found a slightly positive effect in results when comparing learning through web-based virtual learning courses versus traditional schooling. However, that same analysis detected a slightly negative impact on student learning when videoconferencing was used as a delivery mechanism.[xxiv] A 2004 study compared 232 students of distance versus conventional teaching. This study included primary and secondary schools and institutions of higher education, that compared learning outcomes in online and through videoconferencing to conventional teaching. Researchers found no significant differences in either comparisons between conventional teaching and online learning, or conventional teaching and videoconferencing., The authors of the study also noted that, while online learners slightly outperformed traditional classroom students, they had lower class retention rates; and that students in conventional, face-to-face classrooms did outperform videoconferencing students, although the differences were not significant.

Note: The use of videoconferencing is relatively new to education, a fact that may explain the slightly negative learning results, for new users tend to replicate face-to-face learning through this media rather than capitalizing on the unique features of videoconferencing [e.g., close-ups of individuals to capture facial expressions and gestures; effective use of video clips, images, and animations; document cameras; bringing in experts for short segments from multiple locations; preparatory work with participants; etc.]).

In a study reported in 2006, the academic achievement in physics of high school students taking an online, hands-on Microcomputer Based Laboratory (MBL) unit on motion was compared to that of students in a more traditional MBL classroom setting with a teacher. The online students showed significant comprehension gains from pre- to posttest, paralleling those of the students in the control group. The authors suggest that the study indicates that students who do not have access to face-to-face courses in physics should consider the online MBL course.[xxv]

Virtual learning today is a breakeven proposition (i.e., gets the same results as face-to-face learning), while at the same time providing **flexibility** to its users. In general, researchers find that students in distance-learning situations perform as well as their counterparts in face-to-face, traditional schooling.

Figure 5.



Virtual Learning: Trends and Research

Type of Learning	Automaticity of Basic Knowledge/ Skills	Content Expertise/ Knowledge	Information Processing/ Visualization	Higher Order Thinking and Sound Reasoning	Authentic Learning
Impact	● + ■ *	● + ■ *	● +	● + ■ *	

Legend:
+ Positive
I Inconclusive
- Negative
● Descriptive Studies
■ Rigorous Research

*Research finds impact to be generally equivalent to face-to-face learning.

TECHtype: In-School Computing (Labs, In-Classroom Computers, and/or Computers Situated in Learning Environments such as Libraries)

Countless studies have been conducted on the effect of technology on Pre-K–12 learning over the past decades. The meta-analyses conducted over the last 20+ years consistently find that, across hundreds of studies, there is a significant, albeit small, positive gain in academic achievement by students who use computers, versus those who do not.[xxvi, xxvii, xxviii] Although educators should be encouraged by such findings, they should go on to ask deeper, more fine-grained questions related to their specific student populations, the learning trends in their schools, and their specific learning goals in order to take advantage of the technologies that register the highest gains or spikes in learning.

Although meta-analyses are useful in looking at overall trends, the real value lies in mining information from the studies that show significant spikes in learning. The following reviews provide overall summaries, but also include the “spike studies.”

Representative Rigorous Research Studies (Not Intended to be Comprehensive):

- **Simulations.** A review of research literature by BECTA[xxix] published in 2004 found that the use of simulations and modeling in the natural sciences resulted in increased learning and retention by students. This summary included both descriptive and experimental research findings. The experimental research findings suggest that the sequencing and scaffolding of learning using simulations and visual modeling positively affects learning. The following studies demonstrated positive results:
  - **Frog Dissection Simulation.** An experimental study was conducted in the United States with seventh-grade students involved in dissections of frogs in a life science course. Researchers found that students learned significantly more when only a dissection simulation was used, or when the simulation was used immediately prior to the actual dissection exercises in comparison to dissection only or dissection immediately followed by the simulation.[xxx]
  - **Microbiology Simulation.** A simulation program, “The Growth Curve of Microorganisms,” was used in a biology classroom to engage students in problem solving as they manipulated the three independent variables of a simulated experiment. Students who used the software significantly outperformed the control group on academic achievement in science (students from the treatment group were compared to students at similar cognitive levels in the control group). Girls in the experimental group achieved equally with boys from that group. The researchers suggest that this result may indicate that students with low reasoning skills can be assisted in computer-based simulations with problem solving that require high cognitive skills.[xxxi]

    The **power** behind the use of simulations in the life sciences is in the opportunity for students to explore “what-ifs” in ways that enable the student to **build schemas of understanding**. The visualization of processes and structures **reduces the cognitive load**, enabling even novice learners to understand academic complexities.
- **Productivity tools (e.g., word processors, spreadsheets, and databases)**. Research is emerging on the use of electronic productivity tools in support of academic learning. A meta-analyses conducted by Boston College on writing with word processors across the curriculum found that students using these electronic tools wrote significantly more, received earlier interventions by teachers, and wrote higher-quality work than students in comparison groups.[xxxii]
  - In the area of reading, several studies have shown that students who use word processors, versus those who use pen and paper, are more engaged and motivated in their writing, they write more, they receive earlier scaffolding and intervention by teachers, and they produce higher-quality work.[xxxiii] A caveat: the study found that students who learned to write using the computer but were tested using pencil and paper were at a distinct disadvantage, in that they were not able to demonstrate their writing skills.[xxxiv]

The **power** behind the use of writing using the word processor lies in the timeliness of **electronic communication** about the students’ work by teacher and peers, the ease of online writing and rewriting, the use of writing prompts, and the **ease of student revisions**.

- **Visualization tools** (e.g., concept or story maps, presentation software, graphics packages, and desktop publishers). Emergent research indicates that visuals can serve as a scaffold to deeper, more complex thinking, without causing cognitive overload. In other cases dynamic visualization tools enable students to explore cases and concepts:

    - **Semantic and concept maps**—also known as story maps, graphic organizers, and story webs—are visual and graphic representations of elements and the relationship(s) between these elements. As such, the generation of such concept maps offers an excellent opportunity for students to "visually think" about and visually represent stories, concepts, theories, and passages they have read. In doing so, they have the opportunity to represent similarities, differences, the direction of causality, hierarchical structures, flow processes, time sequences, etc. The National Reading Panel cites numerous research studies that link the use of concept maps to increases in reading comprehension.[xxxv]
    - **Dynamic geometry software**. Initially developed specifically for geometry exploration and modeling, Geometer's Sketchpad is a dynamic construction and exploration tool that can also be used to explore algebra, trigonometry, calculus, art, and science. Using dynamic visualization, students explore the mathematical properties of an object they have constructed in Sketchpad by dragging it with the mouse. One study has shown that geometric conjecture by students using Sketchpad significantly increased in comparison to a control group not using Sketchpad, but geometric knowledge and construction did not.[xxxvi] A study in Turkey used an experimental design where two software programs, Excel and Autograph, were used in experimental groups separately, and a control group took traditional instruction without using any technological tools. Classes were randomly assigned to one of the three groups. A national mathematics test assessed the students' performance. The experimental group using the dynamic geometry software (Autograph) scored significantly higher than both the control and Excel groups.[xxxvii]
    - **Web-Based Inquiry Science Education (WISE)**. Students explore thermodynamics in the context of the temperature of objects around them. After making predictions about the temperature of various objects, gathering data, and interacting with computer simulations, students create and electronically discuss principles to explain that data. After years of research and development, outcome measures indicated that students who used the visualization tools in the context of inquiry science learned significantly more than students in the control group.[xxxviii]
- **Cognitive tutors. Cognitive tutors are intelligent software preprogrammed to guide students' studies in academic areas, anticipating common misconceptions students have about the subject and teaching strategies to correct such misconceptions.**
    - **Cognitive Tutor Algebra.** This paper reported on a large-scale experiment conducted in the Moore, Oklahoma, Independent School District during the 2000–2001 school year in which students were randomly assigned to either the Cognitive Tutor Algebra 1 program or a traditional Algebra 1 course. Overall, students taking Cognitive Tutor Algebra 1 did significantly better than their counterparts on the Educational Testing Service (ETS) Algebra End-of-Year Assessment. The strongest advantage for Cognitive Tutor was found among those teachers whose traditional students performed least well. A survey of student attitudes indicated that Cognitive Tutor students were significantly more confident of their mathematical ability than students in traditional classes, though both sets of students were less confident than eighth-grade honors students taking traditional Algebra 1 classes.[xxxix]
    - **Project LISTEN.** Project LISTEN is software developed at Carnegie Mellon that listens to children's reading and responds. This pilot study explored the potential for the 2004 Project LISTEN Reading Tutor (RT) computer program to help English language learners in grades 2–4 improve their reading skills. In a crossover experimental design that took place over two months, 34 students were randomly assigned to work with the RT program or the sustained silent reading (SSR)/control program for one month, and then switched groups the following month. Analyses of the findings from this crossover experimental design study revealed that the RT group demonstrated significant gains over the SSR group on measures of fluency and timed sight word recognition. However, no significant differences were found between RT and SSR groups for untimed sight words and reading comprehension.[xl]

The power of cognitive tutor programs is in their anticipation of common misconceptions students bring to the learning of specific concepts, and the intelligent feedback provided to students by the tutor that leads to correction of such misconceptions.

- **Computer Assisted Instruction (CAI) and/or drill and practice.** In general, CAI in the content areas offers small, significant advantages to learning with computers over learning in more traditional ways. However, new generations of software based on neuroscience report promising findings.
    - A meta-analysis conducted at the University of Amsterdam regarding the teaching of English and Dutch revealed an advantage to learning to read with computers in students aged 5–12 in comparison to students in more conventional learning situations. The effect was larger with English than Dutch.[xli]
    - A BECTA study in England comparing the academic achievement of elementary students who received CAI as a supplement to the traditional program versus students who received traditional instruction only showed better achievement among the CAI students.[xlii]
    - In the United States a recent meta-analysis across 42 studies showed significant positive results with the use of virtual learning technology in primary and secondary schools, and a very small negative behavioral impact. Results were consistent across grade levels and subject areas (with the exception of foreign language, for which virtual learning was not effective), with slightly increased effects for those programs that combine an individualized approach with traditional classroom instruction.
    - The effectiveness of reading intervention software at the middle school level was analyzed across studies by a U.S. educational laboratory. Results indicate that reading comprehension can be improved significantly through the strategic use of computer software.[xliii]
    - A meta-analysis conducted across studies related to science from 1970 to 1999 revealed the largest degree of effectiveness for subtopics to be in physics. The largest impact, by type of use in science, was for simulations, with tutorials a close second. Also interesting is the increase in degree of effectiveness as the student-to-computer ratio decreases. While the effectiveness for a 1 to 1 ratio reached the significant level (e.g., an effect size of 0.37), a 3 to 1 ratio in science classes, overall dropped below the significant level (e.g., an effect size on average of 0.1). The impact of computer use was reported to be higher when the computer was used as a supplement rather than a substitute.[xliv]
    - An example of the new genre of CAI is represented by the product, FastForword. Fast ForWord products take a brain-based approach to preparing students for reading by developing oral comprehension and other skills required for successful reading. Technology based products use exercises that help students understand, process, and use language more effectively. A special feature of the software is its ability to adapt to each student's skill level and rate of progress. As a student moves through an exercise, the level of difficulty gradually increases and modified speech sounds gradually change to natural speech sounds. Research finds that, when used in the prescribed manner, the software literally retrains the child's brain through visual/auditory processing and oral language training.

The **power of CAI** was in the provision of **supplementary activities** to strengthen learning and skill levels through provision **of immediate feedback.**

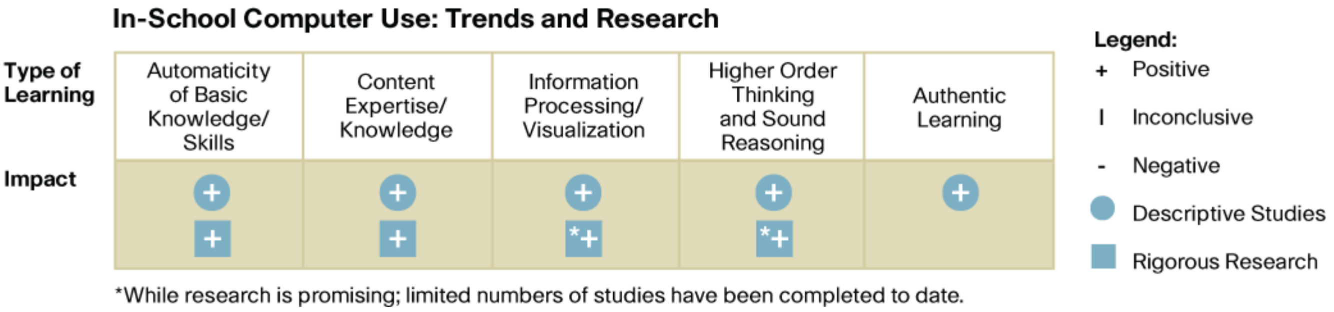
- **Communications.** Educators are finding that reflective dialog augments learning. Social networking accelerates learning and is facilitated by technology. Students are highly motivated to communicate via technology be it text messaging, email, instant messaging, talking, or videoconferencing. Social networking via technology can connect students to a broad range of interactivity that sharpens and extends thinking and piques intellectual curiosity. Research on computer-supported collaborative learning (CSCL) is only now emerging.
    - A study in Canada on knowledge construction through CSCL (in this case augmented by the CSILE environment) has been shown to increase higher-order social interaction, collaborative knowledge building, and deep understanding of concepts.[xlv]

- **Educational gaming.** In general, the research on educational gaming finds that the use of computer games in educational settings has a positive effect on academic achievement (reading comprehension, algebra, and decoding), on attitudes toward learning, and on self-concept, in comparison to traditional instruction. Studies have found that games offer immediate feedback, increase active learner participation, reinforce knowledge, and influence attitudinal changes.[xlvi] Educational gaming favors the development of complex thinking skills and problem solving, planning, and self-regulated learning.[xlvii] Furthermore, the studies show that the impact of the game on learning depends on the degree of interaction between the user and the system.

  The **power** behind games is in the **concentrated attention** of the user to an environment that continuously **reinforces knowledge, scaffolds learning**, provides leveled, appropriate challenges, and provides **context to the learning of content.**

Decades of studies indicate that school implementations result in mixed reviews (e.g., dependent of the type of software, the content area, the context, the pedagogy, and student factors). Positive results indicate that it is **possible** to achieve significant gains through the In-School Computing TECHtype, provided sound pedagogy and high-quality content are implemented with fidelity.

Figure 6.



In-School Computer Use: Trends and Research

Type of Learning	Automaticity of Basic Knowledge/ Skills	Content Expertise/ Knowledge	Information Processing/ Visualization	Higher Order Thinking and Sound Reasoning	Authentic Learning
Impact	● + ■ +	● + ■ +	● + ■ *+	● + ■ *+	● +

Legend:
+ Positive
I Inconclusive
- Negative
● Descriptive Studies
■ Rigorous Research

*While research is promising; limited numbers of studies have been completed to date.

TECHtype: 1:1 Ratio of Computers to Students

The four major goals set for 1:1 learning initiatives include: improved academic achievement, digital equity, economic development, and the enhancement of teaching. In the United States alone, the states of Maine, Texas, New Hampshire, and Michigan have invested in broad-scale 1:1 laptop initiatives at middle and high school levels. In addition, hundreds of public and private schools are investing in the model. Descriptive studies report that such deployments **increase student engagement in learning** and **shift instructional practices of teachers** to more collaborative, small-group work that is more student-centered and problem-based—and more demanding of higher-order thinking skills. Preliminary studies indicate that **24-hour access trumps in-school laptop learning in engagement of students in high-quality writing**.[xlviii] The few rigorous research studies on the 1:1model that have been completed to date report **positive academic learning results in comparison to those of control groups, educators should be cautious about generalizing to larger populations until researchers have replicated the findings with broader populations over sustained periods of time**.

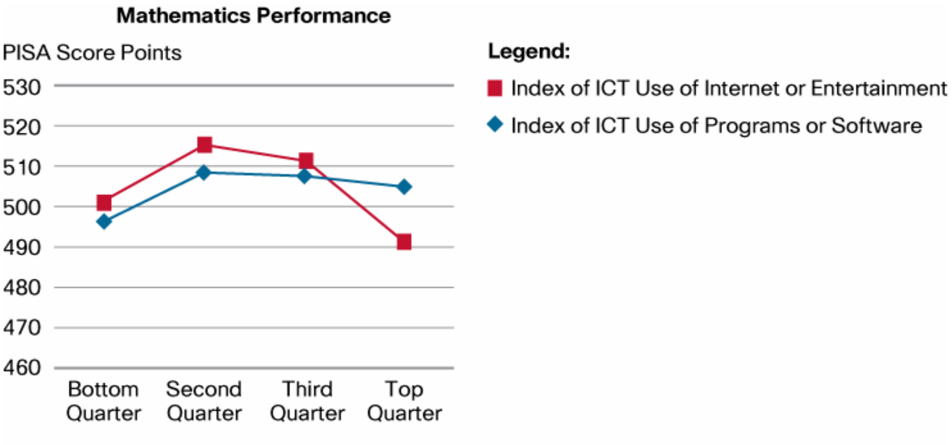
Representative Rigorous Research Studies (Not Intended to be Comprehensive):

- A 2003 California study with relatively high SES middle school students found that compared to a control group, the laptop students significantly outscored students in conventional classrooms in the areas of mathematics and language arts.[xlix]
- A study in a single public school in Massachusetts compared upper elementary classrooms with 4:1, 2:1, and 1:1 ratios of students to computers. The researchers found advantages to the latter, with higher incidence of computer use at home for academic purposes among laptop students and less large group instruction in 1: 1 learning environments.[l]
- A study in Germany of 1:1 learning found that laptop students made greater gains than students in a comparison group in technology literacy (e.g., productivity tools; skill in using the Internet; and knowledge of hardware, software, and operating system).[li]

Note: While studies are being conducted on 1:1 computing, it is instructive to note that 1:1 laptop computing is not synonymous with ubiquitous computing (i.e., the transparent use of technologies you need, when you need them). The author speculates that 1:1 computing may simply be a transitional stage toward ubiquity—for the laptops, while smaller and lighter than ever before, are still cumbersome to carry.

The Organization of Economic Cooperation and Development (OECD) released a report in 2003, *Are Students Ready for a Technology Rich World*, which reports on trends in student computer use and academic achievement. The following chart indicates that students with the highest mathematics scores fall in the **moderate/midrange** of frequency of computer use for Internet and entertainment and for programs and software.

Figure 7. Comparisons of Frequency of Student Computer Use to Mathematics Achievement

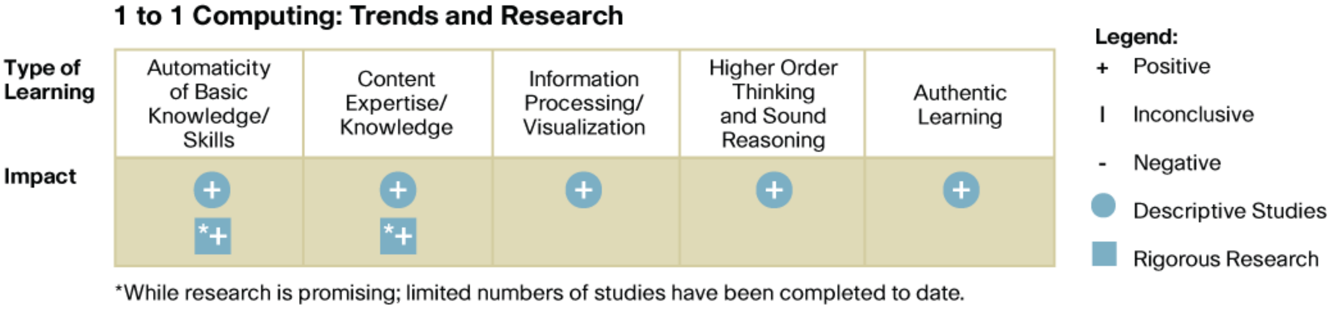


*Source: OECD PISA 2003 database, Tables 4.5, 4.6 and 4.7

Source: OECD 2003 report, *Are Students Ready for a Technology Rich World*

The **power** in each of the situations described in the studies on 1:1 computing seems to lie in the **availability of the personal device** to the student for learning both in school and beyond the school day, coupled with increased productivity. More research is needed to determine exactly what combination of technology, content, and pedagogy maximizes the effect of learning in a 1:1 environment.

Figure 8.



1 to 1 Computing: Trends and Research

Type of Learning	Automaticity of Basic Knowledge/ Skills	Content Expertise/ Knowledge	Information Processing/ Visualization	Higher Order Thinking and Sound Reasoning	Authentic Learning
Impact	●+ ■*+	●+ ■*+	●+	●+	●+

Legend:
+ Positive
I Inconclusive
- Negative
● Descriptive Studies
■ Rigorous Research

*While research is promising; limited numbers of studies have been completed to date.

SUMMARY

This publication is intended to provide the reader insights into emergent research findings on the effect of technology on learning. Although it is not comprehensive, it provides general trends in use and effect for a range of current technologies used in schools across the globe to help educators invest wisely in educational technology.

The following chart shows trends and research findings related to educational technology across various types of learning. A "+" under the Descriptive Study column indicates that qualitative or correlational studies are promising. A "+" under the Rigorous Research column indicates at least one rigorous, experimental, or quasi-experimental design study shows positive results. A "-" indicates flat or negative results, and mixed or inconclusive results are so noted. A blank cell indicates that the authors have located no studies on that topic.

Table 1.

LEARNtype	**Automaticity of Basic Knowledge and Skills**		**Content Expertise and Knowledge**		**Information Processing and Visualization**		**Higher-Order Thinking and Sound Reasoning**		**Authentic Learning**	
TECHtype										
	Descriptive Studies	Rigorous Research	Descriptive Studies	Rigorous Research	Descriptive Studies	Rigorous Research	Descriptive Studies	Rigorous Research	Descriptive Studies	Rigorous Research
Television or Video	+	+	+	+	+	+	+	+	+	
Calculators or Graphing Calculators	Mixed Results		+	+	+	+	+	+		
Engagement Devices	+		+		+		+			
Portable ICT Devices	+	Inconclusive	+		+		+			
Virtual Learning	+	**	+	**	+		+	**	+	
In-School Computer Use	+	+	+	+	+	+	+	+	+	
1:1 Computing	+	+	+	+	+		+		+	

**Research finds effect of virtual courses to be generally equivalent to face-to-face learning.

The reader should be cautioned that, although single studies with positive results are encouraging, such results could not be generalized beyond specific student populations and contexts within the studies. Educators are encouraged to pilot such solutions and research the effect locally prior to full-scale implementation.

The research on the effect of technology in learning is emerging. **Overall, across all uses in all content areas, technology does provide a small, but significant, increase in learning when implemented with fidelity**. While this statistic is encouraging, the real value lies to research lies in the identification of those technology interventions that get sufficiently positive results to warrant the investment. Most educators are looking for the value proposition that will significantly advance learning, teaching, and school system efficiencies. Taking advantage of these leverage points requires serious review of specific research studies that specifically address the needs and challenges of specific schools ***and serious attention paid to leadership development, professional development for teachers, school culture, curricular redesign, and teacher preparation***.

The reasons cited for this lack of progress vary considerably over time and locale. For many educators, the lack of access to reliable, up-to-date technology is a major barrier to effective use. In schools with sufficient access (e.g., 1:1 environments, schools with laptops on carts, schools with low student-to-computer ratios), the barriers to effective use are lack of: vision, access to research, leadership, teacher proficiency in integrating technology in learning, professional development, school culture, and/or resources. Gains in learning can be accomplished in a variety of classroom configurations. Challenges for schools include:

- The amount of student access required to achieve gains in learning varies considerably by type of use. For example, an intervention such as FastForword requires high levels of use for a short period of time in order to maximize learning gains; student writing on word processors is highly facilitated by 1:1 access during the writing, editing, and production process; and Cognitive Tutor Algebra requires that each student dedicate two days each week working individually for a class period on a web-enabled computer. On the other hand, whole class interventions, such as the Jasper Woodbury mathematics series, requires a teacher at a demonstration station to facilitate learning. The challenge for schools is in ensuring adequacy of access and availability of the technology in configurations that fluctuate with teachers' lessons and students' needs.
- Identifying the technology-based interventions that have the potential to bring about higher levels of student achievement is another challenge that schools face. Despite the decades of use of technology in elementary and secondary schools, the number of rigorous research studies is small, the quality of the studies varies considerably, and the level of funding for such research is low in most countries.
- The fidelity of technology integration in schools varies tremendously. Unfortunately, such fidelity is often neither tracked nor reported in research studies, translating into research findings for specific interventions that vary considerably across sites, with such variations left unexplained. For example, there is definitive research on the positive gains in reading accomplished through high-fidelity use of Waterford Early Learning with at-risk students, yet a larger urban school system that invested significant funding in that same intervention has not been able to replicate those gains, partly because of poor fidelity.

The indicators for success are not solely dependent on the level of student access, but rather on the nature of student and teacher use and the fidelity of the implementation. **Such fidelity of implementation in a school, in turn, is determined by leadership, teacher proficiency, professional development, fit with curriculum, school culture, pedagogical approaches—and to some degree on levels and types of technology access**.

For additional sources of research, refer to the following resources:

- The British Educational Communications and Technology Agency: http://www.becta.org.uk/
- The What Works Clearinghouse by the U.S. Department of Education: http://www.w-w-c.org
- The International Society for Education's Center for Applied Research in Educational Technology (CARET) web site: http://caret.iste.org/
- The Journal of Technology, Learning, and Assessment (JTLA) at Boston College: http://www.bc.edu/research/intasc/jtla.html
- The Organisation for Economic Co-operation and Development (OECD; this organization brings together countries sharing the principles of the market economy): http://www.oecd.org
- Metiri Group's Technology Solutions That Work: www.metiri.com

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