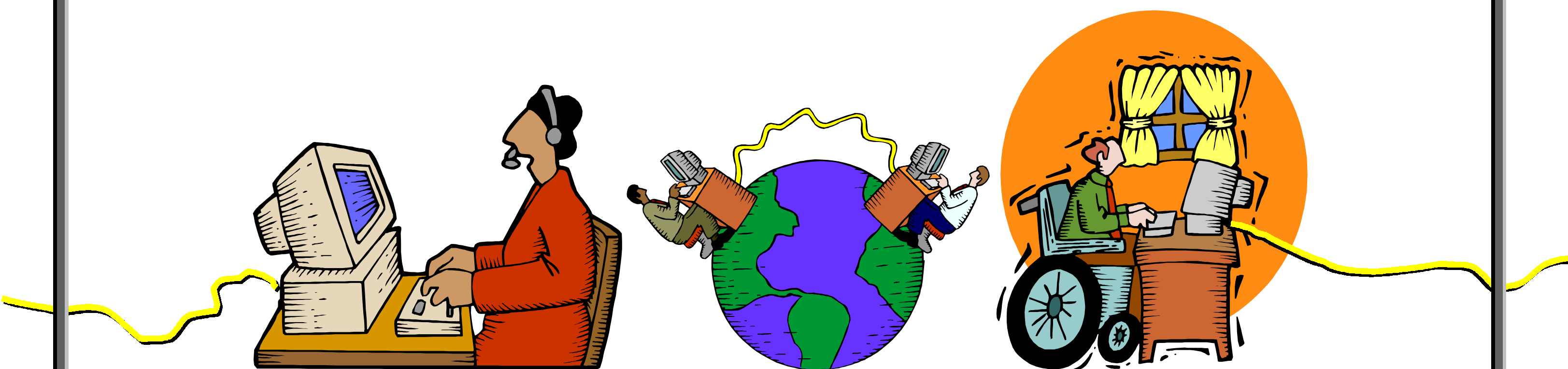
TECHFORCE 2010

Envisioning the Technological Workforce of the Future



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1.0 Introduction

In an era of increasing international economic competition, the quality of America's elementary and secondary schools could determine whether our children hold highly compensated, high-skill jobs that add significant value within the integrated global economy of the twenty-first century or compete with workers in developing countries for the provision of commodity products and low-value-added services at wage rates comparable to those received by third world laborers. Moreover, it is widely believed that workers in the next century will require not just a larger set of facts or a larger repertoire of specific skills, but the capacity to readily acquire new knowledge, to solve new problems, and to employ creativity and critical thinking in the design of new approaches to existing problems.

While a number of different approaches have been suggested for the improvement of K-12 education in the United States, one common element of many such plans has been the more extensive and more effective utilization of computer, networking, and other technologies in support of a broad program of systemic and curricular reform. During a period in which technology has fundamentally transformed America's offices, factories, and retail establishments, however, its impact within our nation's classrooms has generally been quite modest.[1]

--Report to the President on the Use of Technology to Strengthen K-12 Education in the United States (March 1997)

"A technology revolution is about to sweep America's classrooms…
Call them the schools for the New Economy. Over the next 5 to 10 years, the same technologies that have forced corporations to remake themselves for e-commerce hold the potential to similarly transform U.S. education."[2]

--BusinessWeek, Wired Schools (September 25, 2000)

In the 1998-99 school year, 90.4 percent of schools had Internet access in at least one location in their school building; 84 percent of all public K-12 schools had LANs and 64 percent had WANs.

As the excerpts above illustrate, the availability of technology and its and level of adoption by K-12 education is accelerating at an unprecedented pace. In just three years, we have witnessed dramatic changes from isolated, dial-up Internet access at one or two locations within a school building to comprehensive networking initiatives designed to put every classroom in a school district on the 'Net. In the 1998-99 school year, 90.4 percent of schools had Internet access in at least one location in their school building; 84 percent of all public K-12 schools had LANs and 64 percent had WANs.[3] With these rapid and ubiquitous developments, educators, policymakers, employers, parents, and other stakeholders must question the impact of this pervasive technology use on students' education, their study and work habits, their extracurricular activities, and their expectations about the world and their place in it.

Seymour Papert, professor at the Massachusetts Institute of Technology's Media Laboratory and an early advocate of the use of computers as teaching tools, said, "The world is changing so fast that the concept of schools teaching people what they need to know is no longer viable. We're moving into a time when people need to know how to learn things they weren't taught in school. Second, we now have the technology to let kids learn better. This will not just allow them to learn the same things better; it will teach kids to learn radical new things at all ages."[4]

Given this unprecedented acceleration and adoption of technology, in all its forms, among most sectors of society,[5] and with special focus on K-12 education, the guiding questions we have attempted to investigate in this white paper are:

- ***What will be the impact of this pervasive, dynamic, and evolving use of technology among the target profile[6] of middle and high school students who will be candidates for the NIMA analyst positions in the year 2010?***
- ***How will the educational system, in its current form, prepare future workers to deal with the complex, multi-dimensional problems to be encountered by such analysts?***
- ***And what related trends will impact upon these issues in the next 10 years?***

In researching these questions, we considered:

- Current conditions and future trends for school and home computer and Internet access and use

- The fierce and accelerating competition among employers for skilled IT workers

- The effects of national initiatives such as the federal E-Rate program[7] to increase the pool of students from non-traditional or disadvantaged populations capable of filling such positions

- Science and mathematics achievement among U.S. students and its impact on the pool of qualified candidates for TechForce 2010 workers

- National, state, and local science and mathematics education standards and school reform programs calling for increased attention to student engagement in: critical thinking; problem-solving; analysis, collaboration, synthesis and presentation of ideas; and authentic uses of technology in instruction

- Issues related to teacher preparation and use of technology, including stated instructional objectives; quality/preparation of the teacher pool; projected teacher shortages; and federal initiatives to promote meaningful integration of technology among colleges of teacher education

- Effects of the "Information Age Culture," a growing trend among the target age group, in which digital gadgetry is pervasive and integral to human behavior, on work habits, social behaviors, and career expectations

- Related factors impacting student achievement and capabilities, such as increased parent involvement through technology use; standardized "paper-and-pencil" student testing methods vs. computer-supported assessments capable of measuring more complex tasks and reasoning capabilities; and the availability of previously inaccessible content and "homework help" through distance learning courses or Web-based collaboration.

This white paper, TechForce 2010, is organized in eight major sections:

1.0 Introduction

2.0 Computer and Internet Access in Schools

3.0 Teacher and Student Use of Computers and the Internet

4.0 Home Computer and Internet Access and Use

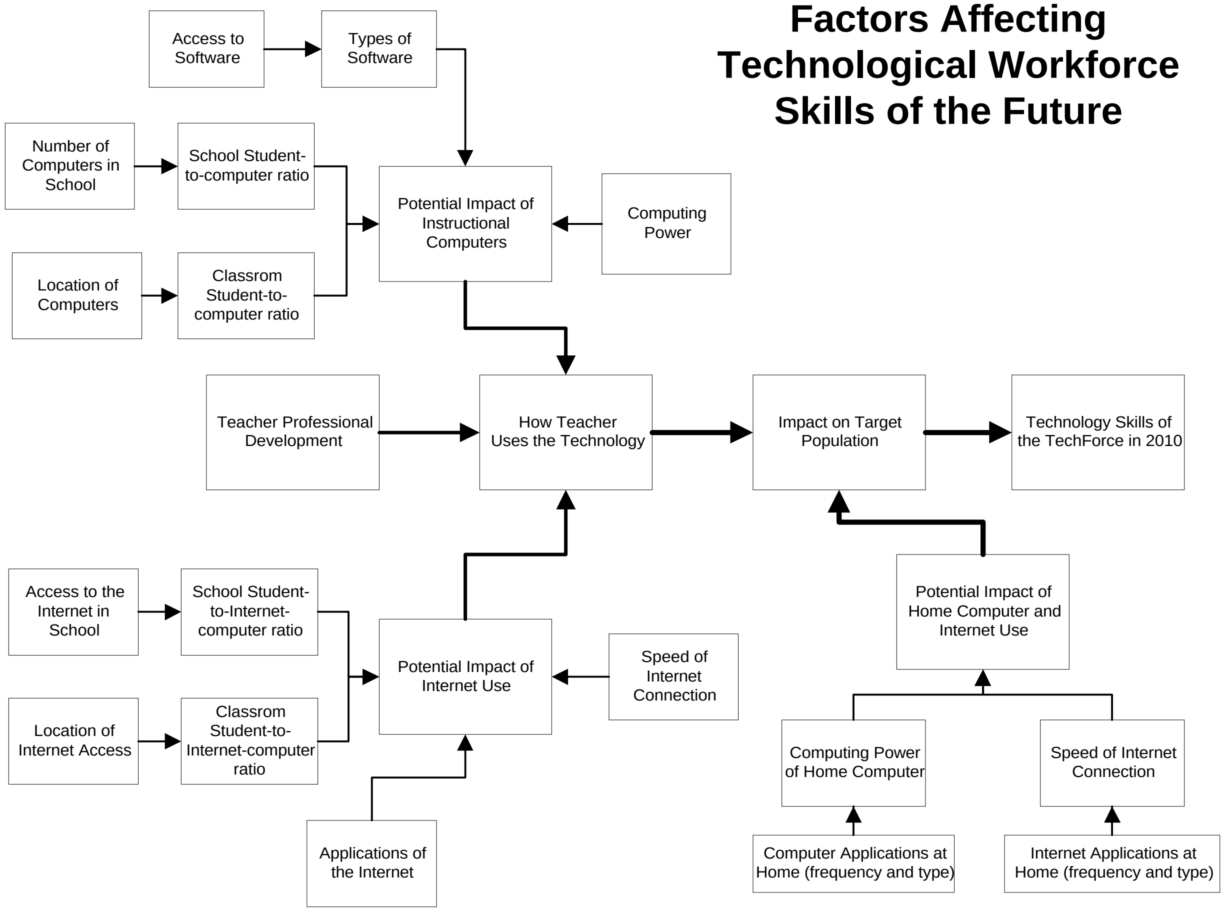
5.0 Cognitive Implications of Technology Use and Current Educational Practices

6.0 Other Factors Influencing the Capabilities and the Composition of the Techforce of 2010

7.0 Summary and Projections

8.0 Related and Supplemental Resources

Factors Affecting Technological Workforce Skills of the Future



2.0 Computer and Internet Access

To understand the technical capabilities of the workforce of 2010 we must first investigate the role that technology is playing in the lives of present day middle and high school students who fit the target population profile[8]. To facilitate this complex investigation we will focus on two of the most significant technologies that are present today in the lives of these students. These are: (1) personal computers; and (2) the Internet. When investigating how these two technologies are impacting on the target population we must begin by answering two primary questions:

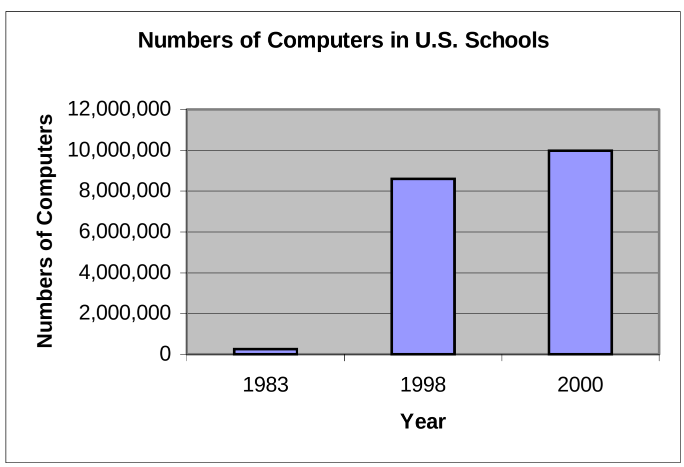
- What type of access do students have to these technologies?
- How (what applications) are they being used?

Once we answer these questions, we can then discuss the impact the technologies are having, and subsequently, the implications of this impact for the workforce of 2010.

2.1 Instructional Computers

Since the early 1980's personal computer use in the United States has been growing at a rapid and accelerating rate. To understand how personal computers are impacting on the lives of the target population we must investigate how these students are being exposed to them. At the surface it appears that this is simply an issue of how much access the target population has to instructional computers and how they are being used. In reality, the issue of access is quite complex. In order to make accurate predictions of how computer use will impact the workforce of 2010, we must first investigate all of the nuances associated with the subject of computer access. These include: number of students per computer; age of computers; location of computers; and access to software and the Internet. Once we have clarified these issues, we will have the necessary knowledge to construct a model on which we can base our predictions.

2.2 School Access to Instructional Computers



To begin our investigation into the issue of access we can start at the simplest level, by looking at how many computers are present in schools today and what associated trends have existed in the past. School systems in the United States have varied in their approaches to purchasing and using computers in instruction. In 1983, when data was first collected, the student to computer ratio was 168 to 1 in 1983. Based on estimates, it dropped to 6 to 1 in 1998, and to 4 or 5 to 1 in the 1999-2000 school year.[9] Because of falling costs and increased state and federal funding, this pattern of growth is expected to accelerate over the next few years. If this ratio is realized, it may well mark an important benchmark set by the

President's Committee of Advisors on Science and Technology. This committee has called for a computer to student ratio of approximately 4 or 5 to 1 for effective utilization by students.

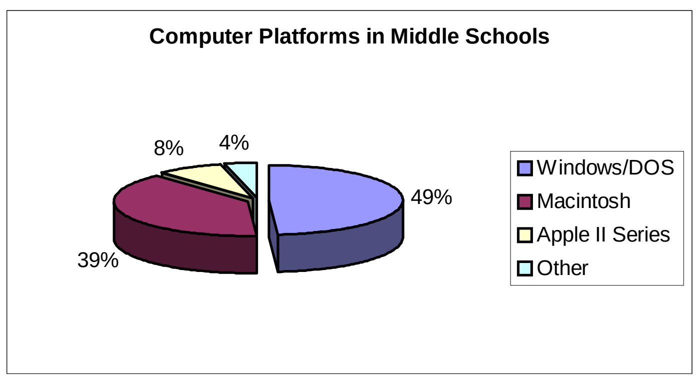
In fact, if we consider current data on the target population, we find that they may have already reached this desired ratio. Among this group, the reported student to computer ratio is 5 to 1.[10] Given current trends, this number is expected to drop even lower over the coming years and thus will be an important indicator to follow. From these general numbers, we can see that significant progress has been made over the past two decades. Clearly, we are at a point where the number of computers in schools has finally reached a level that has the potential to significantly impact on students and the learning process. But these numbers only tell us part of the story. In order to really understand what impact this access will have, we must take a closer look at several additional factors that are central to this issue.

Schools within our target population reported a student to instructional computer ratio of only five to one. Given current trends, this number is expected to drop even lower over the coming years and thus will be an important indicator to follow.

2.3 Types and Age of Instructional Computers in Schools

In the previous section, we answered the simplest question associated with the issue of computer access, that being how many computers are available to students in schools. This answer is only the first step in creating our model, as it has not told us specifically what types of computers are accessible. Because of the rapid changes that are taking place in the computer industry, answering this additional question is critical to understanding the role that computers play in the lives of the target population.

As the following figure indicates, as of 1998, there were nearly equal numbers of Windows-based and Macintosh-based computers in our nation's schools, with Windows machines holding a slight majority. In addition, we know that of the nearly 8 million computers in U.S. schools in 1998, roughly half the computers in middle and high schools today are less than five years old and could be considered modern computers.[11] Although this seems to be a relatively small percentage, it is a significant increase since 1992 when the IEA study, Computers in American Schools, concluded that the computers in U.S. schools were largely obsolete and outdated.[12] **Even with this increase over the past decade, researchers continue to find "major deficiencies" in computing power due to the fact that "much of the technology equipment currently in schools and classrooms is from an earlier generation."**[13]

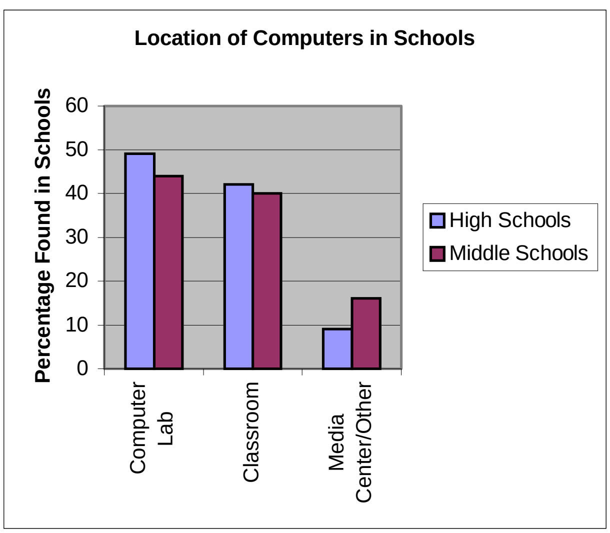


Given the 6 to 1 student to computer ratio in 1998 and the fact that half the computers in schools could be considered modern, we find a resulting student to modern computer ratio in 1998 of 12 to 1. This ratio appears too high to allow for effective use of computers, and thus may mean that there are not enough modern computers in schools to have an impact on students. That said, we must keep in mind that these are general numbers for the all of the K-12 schools in the U.S. and not just for the target population. Since this target population most likely attends suburban schools in affluent communities, it could be assumed that this ratio is slightly lower. For example, in 1998 in the target profile schools, the number of students per instructional computer with Internet access in 1998 was 10 to 1,[14] and the ratio of students to instructional computers was 5 to 1.[15] In looking at short-term trends, we also know that the ratio of students to Internet ready computers in the target group dropped to 7 to 1 in 1999.[16] Assuming that most computers with Internet access could be classified as modern, we can see that the student to modern computer ratio seems to be lower for our target population than the general student population. In addition, it appears that this ratio of students to modern instructional computers among our target population is quickly falling and could reach levels that would result in significant student impact in the next year.

2.4 Location of Instructional Computers

"The mere presence of computers in a school building does not mean that teachers and students…will be able to utilize [them] effectively for learning."[17] Therefore, in order to develop an understanding of how computers are impacting on the lives of our target population, we must investigate not only how many computers are present in their schools but, more importantly, where these computers are located.

As the figure below indicates, nearly half the computers in all schools in 1998 were located in computer labs and half were distributed in classrooms.[18] Among the target group, 42% of teachers had only one computer in the classroom, and 13% had no computer in the classroom at all. This means that in almost half of the target classrooms, the student to classroom computer ratio (assuming a class size of 25), could be as high as 25 to one. Even with five computers in the classroom, the student to classroom computer ratio drops to 5 to 1, which is at the borderline ratio necessary for significant impact. This underscores the fact that the general school student to computer ratios detailed previously do not reflect actual classroom ratios. Given that "the sequestration of a school's computers within a computer lab makes it more difficult to use these tools…as an integral part of various elements of the curriculum"[19] the actual student to classroom computer ratio is clearly important.



Since 1992 there has been a "noteworthy" shift towards more computers in the classroom, with a 10% overall increase in classroom computers across grade levels.[20] That said, during the period 1992 to 1998 the number of instructional computers has risen from 3.5 million to 8.6 million, an increase of more than 150%. This leads to the conclusion that, although schools are investing in more computers, they are not necessarily placing them in actual classrooms. **Therefore, the student to classroom computer ratio will be an important benchmark to follow for the next decade, as it will provide an indicator of the impact that computers are having on students.**

2.5 Access To Instructional Software

Software is equally as important as hardware when it comes to the impact that computers can have on students and the learning process.[21] Thus, we must consider what types of software are accessible by our target population in building our model on which we will base future predictions.

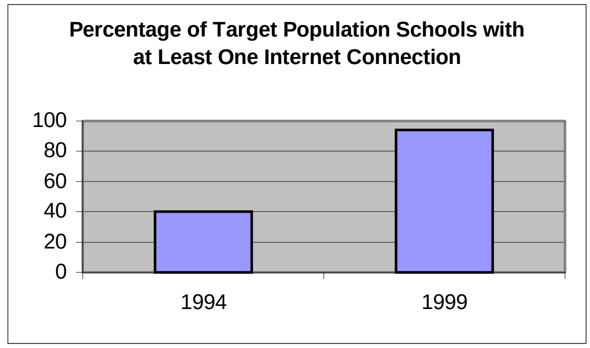
When we look at the types of software available on the computers in schools we find that word processing, spreadsheets, database, drawing/paint software, desktop publishing and Internet software are all relatively common. **Word processing, spreadsheet, and database software are the most common types, with over 80% of the instructional computers in a school having access to these types of programs in both middle schools and high schools.[22] After these general software packages, we find that reference CD-ROMs, paint programs, presentation software, and Internet software are also found on at least half of the instructional computers in schools.** In contrast, basic subject-specific programs (e.g. math and English skill practice software) are found on fewer then 25% of the computers in middle and high schools, while these same subject-specific programs are found on more than half of the computers in elementary schools.

2.6 The Internet

“The Internet is arguably the most rapidly spreading communication technology in history."[23] Over the past decade the number of schools with access to the Internet has grown from only a handful of schools to more than 90%. With penetration of this scale, the Internet clearly has had an impact on middle school and high school students in our target population. The Internet, therefore, is equally as important for us to investigate its impact on our target population as the impact of instructional computers. As with computers, the question of how the Internet will impact on the lives of our target population is not simple. We will start from the same basic reference point of access to the technology, but will quickly find that some of the same issues we discussed with computers will arise in our findings about the Internet. **Our investigation will be made even more challenging by the simple fact that the Internet is so new that trends and patterns are only just beginning to emerge. Although we can use these initial data points in our analysis, it will be important to follow this technology closely over the next five years to better understand its impact on our target population.**

2.7 School Access to the Internet

The percentage of schools with Internet access has grown at nearly exponential rates since 1994 when data was first collected. In that year, only 40% of schools in the target population reported having at least one Internet connection in the school. By 1999, this number had jumped to 94% among the same population.[24] **This has resulted in a student to instructional computer with Internet access ratio of 7 to 1 for our target population.** This is close to the current student to instructional computer ratio of 5 to 1 and demonstrates the high saturation level that the Internet has reached in our target population schools.



2.8 Types of Internet Access

As anyone who has surfed the Web using a regular dial-up connection as well as a high-speed connection knows, the speed of the connection makes a significant difference in how the Internet can be used. Research has confirmed that teachers with high-speed access have a higher perceived value of the Internet and use it more frequently with students than those who only have simple modem-based access.[25]

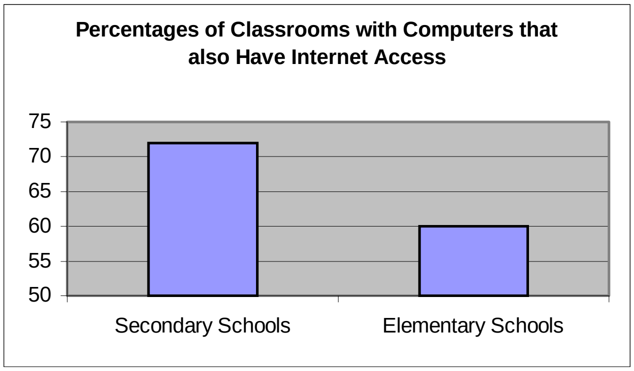
As with access in general, the speed of access has also increased rapidly over the past few years. In 1996, of those schools that were connected to the Internet, 74% of them used a dial-up connection through a modem.[26] This number dropped dramatically over the following years and reached 14% by the fall of 1999.[27] In contrast, 63% of schools now use a dedicated high-speed connection. Among our target population, 72% utilize a high-speed Internet connection and only 7% use a dial-up modem connection. These numbers appear to be roughly the same for middle school and high school populations with high schools having a slightly higher percentage of direct connections and fewer dial-up connections than middle schools.[28] The trend here appears fairly clear: schools are quickly connecting their computer networks to the Internet through high-speed, dedicated connections. If this trend continues, we might expect our target population to be using high-speed connections almost exclusively in the near future.

Among our target population schools, 72% utilize a high-speed Internet connection and only 7% use a dial-up modem connection.

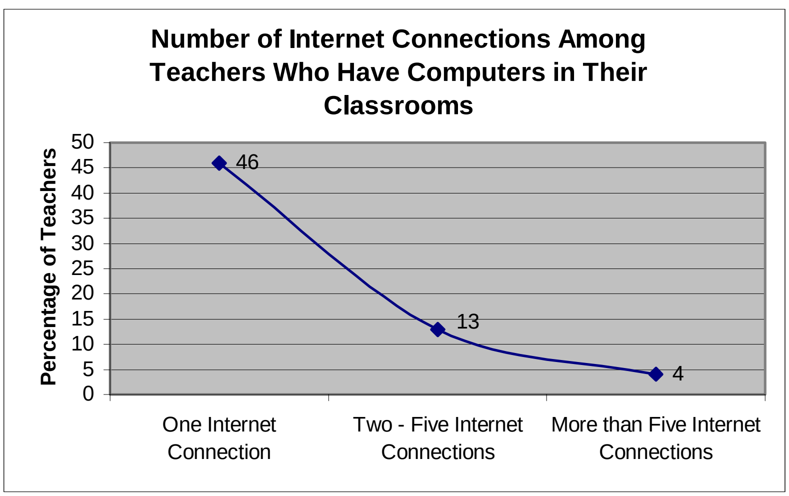
2.9 Location of Internet Access

As with instructional computers, the location of Internet access plays a critical role in the impact it will have on the target population. "Teachers (are) more likely to use the Internet in their classroom than elsewhere in the school, and they are more like to use it to a large extent in their classrooms than elsewhere in the school (20% compared with 10%)."[29] We have already seen that more than 90% of the schools in the United States reported having some connection to the Internet in the school building. **In 1999, among teachers who reported having computers in the classroom, 64% said that they also had Internet access in their classrooms.**

Interestingly, this number is significantly higher for secondary schools, where 72% of those teachers who had classroom computers also reported having Internet access, than elementary schools where only 60% of teachers with a classroom computer reported having the Internet. It is also important to note that these numbers do not change much for our target population. In these schools, 67% of the teachers who had classroom computers reported also having Internet access.[30] It is also important to note here that these numbers only reflect percentages among those educators who had computers in their classroom. (The assumption is that that those teachers who did not have computers in their classroom also did not have Internet access.) **Given that in 1999, 13% of the teachers who work with our target population reported not having any computers in their classrooms,[31] we can conclude that almost half of the classrooms among our target population do not have any Internet connections.**



Recent data shows that of the teachers reporting only one Internet connection in their classroom, only 6% indicated that they use the Internet often. This percentage is dramatically smaller than for those teachers with more than 5 Internet capable computers in their classroom, among whom 33% reported using the Internet often.[32] Clearly the student to classroom Internet computer ratio will be important in understanding how much impact classroom Internet access might have on students. Therefore, we must investigate how many of the classroom computers, among those teachers who have them, are actually connected to the Internet. Again in 1999, among teachers who reported having computers in the classroom, 46% reported having only one Internet connection. Among that same population of teachers, 13% reported having 2-5 computers and only 4% reported having more than five Internet ready computers.[33] Although these numbers were not specifically for our target population but rather for a general school population, they do provide some important insights into the classroom connectivity status of U.S. schools. Based on this data, we can see that the student to classroom Internet computer ratio remain fairly high. Assuming an average class size of 25 students, the majority of classrooms have a ratio of 25 to 1. This ratio is inadequate for any substantial impact to be made on student learning. **Given the pattern of rapid Internet growth in schools over the past six years and significant federal funding programs aimed at increasing classroom access, it appears likely that this student to classroom Internet computer ratio could drop significantly over the next three to five years.**

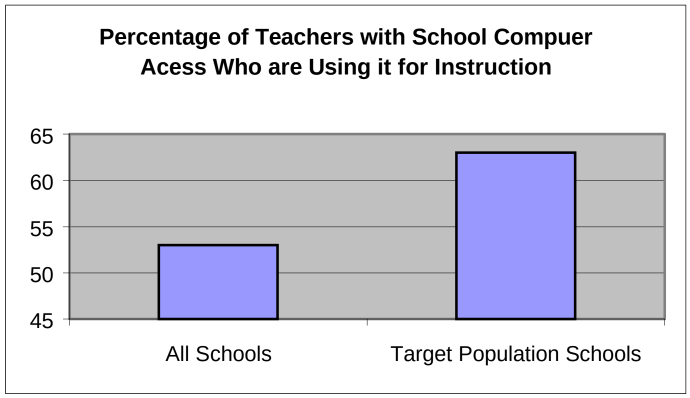


3.0 Teacher and Student Use of Computers and the Internet

Now that we have developed a clearer picture of access, we need to investigate how teachers and students are utilizing this access. Even if every classroom among our target population had access to modern computers for each student (which they do not), the impact of this access would depend on two variables: the frequency of use and how it was used. To complete our analysis of this complex question, we need to consider these two variables and how they will affect our target population.

3.1 Frequency of Computer Use

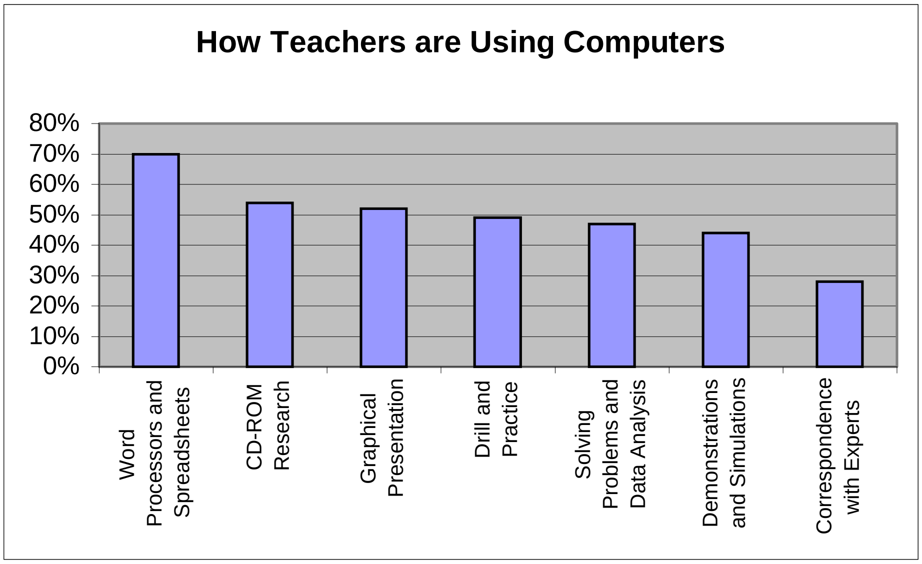
To begin, we will look at the frequency of use. In 1999, among those teachers who had computer access in their schools (but not necessarily in their classroom), only 53% reported using the computer (or Internet) for instructional purposes.[34] This seems to support the conclusion that having access to computers does not necessarily mean that they will be used. Interestingly, 78% of these same teachers reported using the computers to create instructional materials.[35] This may imply that teachers are not yet comfortable using computers directly with their students even though they are proficient using them on their own.



If we take a closer look at the data for our target population, we find that teacher use increases. In 1999, 63% of teachers who had access to computers and who were working in target population schools reported using computers (or the Internet) for instruction during class time. This means that as many as one third of the teachers with computer access did not use this access. It is important to realize that this could be due to the previously stated issue of computer location. If teachers only have access to computers outside their classroom, then they may find it impossible to use them during class time.

3.2 Types of Computer Use (Applications)

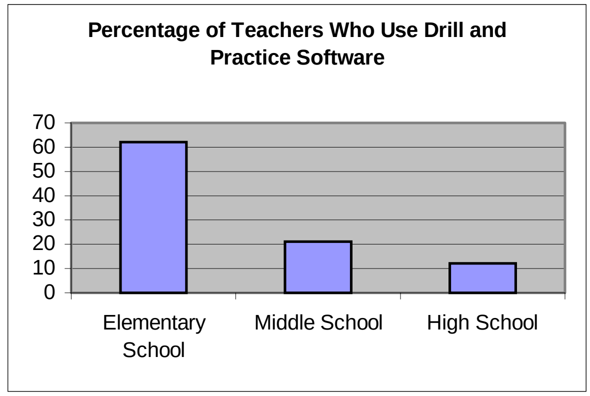
Now we need to take a look at the more complex issue of how the technology is being used. This is a critical question as the answer will shed light on how the technology is shaping the knowledge and abilities of the target population. If we again examine our target population in 1999, we find that 70% of those with computer access report using word processors and spreadsheets.[36] Among this same population, 49% of the teachers reported using instructional computers for tutorial or drill and practice applications; 47% for solving problems and data analysis; 54% for CD-ROM research; 52% for graphical presentation; 44% for demonstrations/simulations; and only 28% for correspondence with experts.[37] We can go a level deeper by looking at the extent to which each application is used. Unfortunately, data on this level is only available for the general teacher population who have access to computers and not specifically for our target population. Given this limitation, of the teachers reporting use of word processors and spreadsheets, one-third indicate they used them to a small extent; a third reported moderate use, and a third reported a large extent of use. Interestingly, among the same general teacher population, almost half reported using instructional computers for problem solving and data analysis to only a small extent. Similarly, more than half reported using computers to only a small extent for graphical presentations as well as simulations.[38]



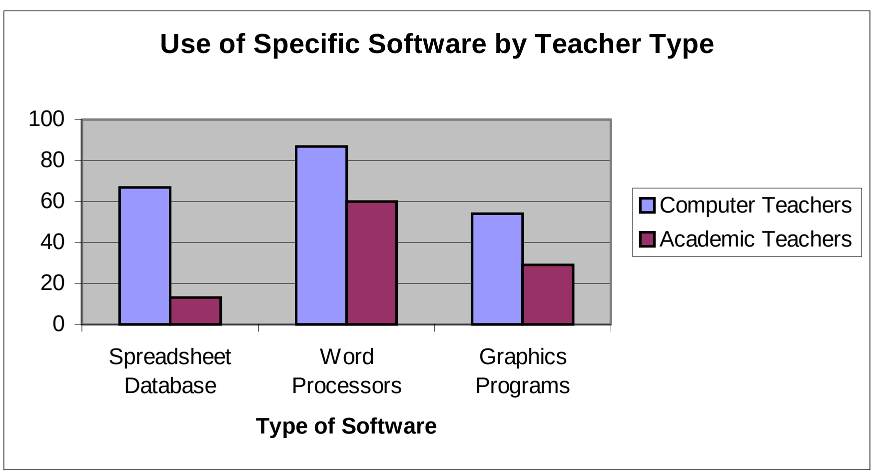
This data from 1999 paints an important picture of how teachers in our target population are using their computers. It appears to show that having access to instructional technology, such as computers, does not necessarily mean that it will be used with students. Of those teachers who do use computers for instruction during class time, the vast majority use them for basic applications such as word processing and spreadsheets. Even among this group, only a third report using these two applications to a large extent. If we then look at how other computer applications are used, such as programs that deal with problem solving and data analysis, we find that although as many as half the teachers use them, they do so only to a small extent.

Of those teachers who do use computers for instruction during class time, the vast majority use them for basic applications such as word processing and spreadsheets.

This points to an important difference in the type of software that is being used by students today. Many educators categorize software in two general types: tutorial software, sometimes called "drill and practice" software and tool software. Tutorial software is usually aimed at increasing students' abilities in specific basic skills such as mathematics or English and is software-driven, as opposed to student-driven. Tool software, including "productivity tools" such as spreadsheets and word processing software, as well as some subject-specific software like Geometer's Sketchpad, for example, is much more flexible and open-ended in its applications in instructional settings and tends to provide students with enhanced capabilities for learning. These capabilities, if applied correctly, can allow for more in-depth analysis and investigation of a range of different subjects. Word processors, spreadsheets, presentation software, and graphical analysis programs are all examples of tool software. The research indicates that on the elementary level there is a propensity toward both tutorial software as well as tool software. For example, on these grade levels, 66% of teachers reported student use of word processing software, but 62% also reported use of "skill practice games." The proportions change significantly when we look at middle school and high schools. Only 21% of middle school teachers and 12% of high school teachers in general reported student use of "skill practice games" in 1998.[39] This is an important shift from the 1980's and early 1990's when "the primary uses of computer technology in schools involved students practicing basic math and language arts skills."[40]



Before leaving this topic, we must investigate further the context in which students are using this software. We have just seen that there is a growing shift in middle schools and high schools toward the use of tool software over basic tutorial software. But is this shift taking place in all classrooms and subjects? The data indicates the answer is no. "More math teachers use skill practice games than any other type of computer software" including spreadsheets, databases, and CD-ROMs.[41] This fact points to the more general issue of integration of software applications into traditional subject-area curricula. Not surprisingly, there is a significant difference in software use between computer classes and other subjects. For example, in 1998, 67% of computer teachers reported student use of spreadsheets and databases; 87% reported student use of word processors; and 54% reported use of graphics programs. In contrast, only 13% of mathematics teachers reported student use of spreadsheets and databases; 60% of English teachers reported use of word processors; and 29% of fine arts teachers indicated student use of graphics programs. It appears that although educators are beginning to use tool



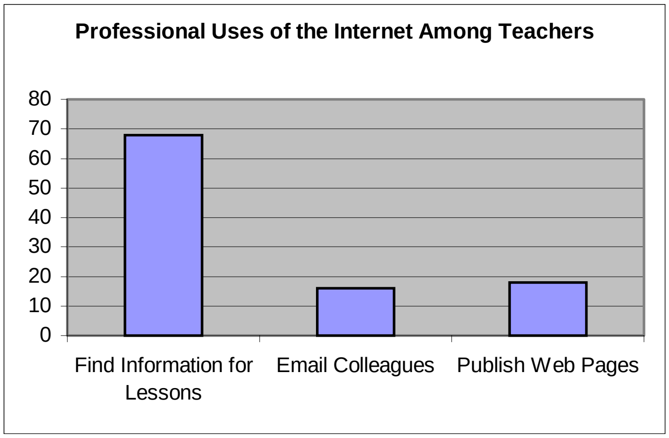
applications more frequently than skill practice software, they have not yet reached the point where this use is fully integrated into traditional core subject areas.

Why is this classification of instructional software important? The answer lies in the impact that its use has on student abilities. Drill and practice software has been in use in schools for almost two decades and has been shown to be an effective tool for increasing basic skills, such as basic math or reading abilities.[42] Although this is an important and useful application of instructional technology it falls short when it comes to the development of higher-order thinking and reasoning abilities. Since these abilities are key elements in problem solving and critical thinking we must look to other applications if increasing these capabilities is desired. This is partly the role of tool software. Recent studies have shown that appropriate use of this category of software can increase students' abilities to solve problems and think critically. Most notably, in a meta-analysis that examined the impact of technology on student learning, researchers found increased teacher-student interaction, cooperative learning, and, most important, problem-solving and inquiry capabilities among students who were using technology.[43] They also found that certain technologies could facilitate access to a range of resources and then help students to store, reshape, and analyze this information. It also enabled students to become hypothesis-testers, with the result that the knowledge that was acquired could be used more effectively.[44] Could any application of technology lead to these results? The answers appears to be no. Researchers Statham and Torell cited one essential condition for this type of student learning to take place: **Computers should be used less for drill-and-practice in the classroom and more as open-ended thinking tools and content resources**.[45]

"Many of those who support increased incorporation of computer-related activities into academic coursework argue that student engagement in doing schoolwork is improved and even carries over to times of the day when direct teacher supervision is absent."[46] More importantly, according to the National Center for Education Statistics (NCES), "it is the way that computers are used to change and enhance curriculum that represents the most important factor in determining whether or not computers have an impact on achievement."[47] It therefore is not surprising to find that one of the new National Educational Technology Standards for Teachers calls for them to "implement curriculum plans that include methods and strategies for applying technology to maximize student learning."[48] These findings call for moving beyond teaching basic technology skills and the use of software tools in isolated computer classes towards a more integrated approach where these skills and tools are incorporated into regular classroom instruction. If this shift occurs we would expect to see an increase in student motivation and achievement as a result of the integration of technology and instructional content.

3.3 School Use of the Internet

As one might expect, as access to the Internet has increased, so has teacher use of the technology. Between 1997 and 1998 the percentage of secondary teachers who used the Internet at work rose from 28% to 43%.[49] In 1999, of those teachers with Internet in their classrooms, 88% indicated that they used it. This percentage is then broken down by frequency of use with 37% using it to a small extent, 30% using it to a moderate extent, and 20% using it to a large extent.[50]



In 1998, a majority (68%) of teachers reported using the Internet for professional applications, such as to "find information resources for their lessons," but these same teachers reported very little professional use of the Internet to email their colleagues (16%) or publish Web pages (18%).[51] Additional data from 1999 seems to indicate that these last two professional uses are increasing, particularly among schools serving the target population.[52]

Possibly the more important issue is how students are using the Internet in schools. **"Just as information-gathering for lesson preparation is the most common use of the Internet by teachers, teachers have students use the Internet for "research," or information-gathering, more than for any other purpose."**[53] Surprisingly, this type of information-gathering activity has become the third most common use of school computers in general. Clearly, educators currently see this application of the technology as its most important use. Besides using the Internet for research, students, to a lesser degree, are also using the Internet for other applications such as email, collaborative projects and publishing work online. Overall, only 7% of the teachers had students email at least three times per year and even smaller percentages had students involved in collaborative projects or Web publishing.[54] Interestingly, we find that these numbers are significantly higher in classes that are dedicated to computer instruction, yet much lower in classrooms that deal with core subjects. For example, 12% of high school and middle school computer teachers had students involved in Internet-based collaborative projects, whereas only 4% of mathematics teachers on the same grade levels had students engaged in these activities.[55] This difference points to the fact that although teachers are using the Internet, much of this work is not integrated into the core subjects.

Overall, only 7% of the teachers had students email at least three times per year and even smaller percentages had students involved in collaborative projects or Web publishing.

3.4 Advanced Student Technology Applications

To paint a clearer picture of the extent to which modern technology is currently and can potentially impact upon students—their learning habits and behaviors, their ability to acquire, process, and understand data, their proclivities for collaboration, and their understanding of important concepts—we now look at several examples of advanced technology applications in middle and high schools. Although these types of applications have not yet penetrated large numbers of schools throughout the U.S., they help to illustrate the ways in which students: (1) interact with the technology; (2) communicate, through the technology, with other students, experts, and use real data and information; (3) and the effects of this intensive technology use on their study and work habits and their learning. The future impact on the science learning of students who experience contact with and use of real time data from collaborative projects, sensors and scientific laboratories will be significant.

3.4.1 The CoVis Project

Funded by the National Science Foundation, with industry partners including Sun Microsystems and Ameritech, the Learning through Collaborative Visualization Project or CoVis, linked 50 U.S. middle and high schools in an advanced and technology-intensive inquiry of atmospheric and environmental sciences.[56] At the heart of CoVis are scientific visualization software programs (the Weather Visualizer, the Greenhouse Effect Visualizer, and the Climate Watcher), customized to a school learning environment. Through CoVis, students also used: desktop videoconferencing; shared software environments for remote, realtime collaboration; access to resources of the Internet; and a multimedia scientist's notebook. These technological tools were employed through close collaboration with teachers, in pursuit of improved pedagogical and project-enhanced science learning. CoVis was envisioned as the "development of scientific understanding which is mediated by scientific visualization tools in a collaborative context."[57]

In research on the CoVis project, three advantages were found in using scientific visualization for high school science education:[58]

(1) The ability to conduct direct investigations in areas to which students had previously had only indirect access (e.g. laboratory simulations or "tornadoes in a bottle" as compared to real data from actual events)
(2) Inquiry using scientific visualizations can link students with the authentic practice of science and facilitate their interpretations of the results emerging from scientific research
(3) Understanding of the uses of visualization is becoming an increasingly important skill both for practicing scientists and for informed citizens. It impacts a broad range of disciplines from mathematics to information processing to finance.

One challenge for CoVis designers has been to create age-appropriate visualization tools with supplemental resources necessary for effective interpretation (e.g., the background and implicit understandings scientists routinely apply in interpreting data). Through close collaboration with subject-matter experts and scientists, as well as participating teachers, CoVis developed tools which demonstrate that "appropriate scientific visualization tools used in a collaborative environment that includes students, teachers, and scientific experts, can enable students to perform meaningful investigation of the same sorts of scientific questions being asked by leading edge researchers.[59]

The Weather Visualizer is a unified set of tools for examining current weather conditions throughout North America. Using the Weather Visualizer, students are able to view the following:

- Satellite images of the U.S. in the visible and infrared spectrums
- Customized weather maps displaying clouds, temperature, pressure, wind direction, wind speed, dew point, weather symbols, visibility, radar, severe weather watches, fronts, isobars, isotherms, isodrosotherms, and names of reporting stations, as well as wind speed at five different altitudes.
- Six-panel preconstructed visualizations displaying temperature, pressure, wind, speed, wind direction, dew point, and moisture convergence for North America.
- Textual reports providing local conditions and local and state forecasts for all reporting stations.

3.4.2 The EdGrid Project

We have noted how the world of scientific and technological R&D can be brought into classrooms through use of Internet technology. Students will increasingly be able to sit side by side with scientists and engineers as they gain new insights into nature and as they create new artifacts that meet the needs of humankind. This proximity to scientists and engineers is enabled by information technologies that transfer data as well as text, voice and images in support of student communications with experts and mentors. Students in their early years of education will not only be in touch with the frontiers of discovery and invention but will be exposed to the human and cultural aspects of these domains.

In addition to experimentation and the gathering of data, scientists and engineers utilize simulations, modeling and tools for visualization of complex phenomena and systems. The Internet can also make these tools and techniques available in classrooms. Simulations and modeling are particularly important in the field of meteorology, in the exploration of fusion and in the design of new airplanes. In many cases these professional tools can be adapted or modified for classroom use.

An important program that is developing applications of simulation, modeling and visualization tools for use in classrooms, as well as in teacher training, is EdGrid. A consortium based at the National Center for Supercomputer Applications (NCSA) located at the University of Illinois is engaged in numerous projects. Some examples include: a project at the University of Illinois to help teachers use visualization tools; the NCSA Biology Student Workshop project, which is developing opportunities for students to use computational tools to manipulate information from molecular biology databases; and an SRI International project on development of modeling tools for use in teacher education programs.[60]

While it will be several years before use of high tech resources such as these become widespread, they are now entering innovative programs such as the Maryland Virtual High School. It may be that the target population for this TechForce 2010 study may be able to take advantage of these computation-intensive aids to science education more quickly than the general population through access to such online resources.

3.4.3 Internet-Enabled, Real World Problem-Solving

The following excerpt of a 1997 article, "*Web Adventures in K-12 Science*"[61] published with permission of TECHNOS Press of the Agency for Instructional Technology (AIT), describes some of the real world problems today's middle and high school students are tackling as a result of Internet-based resources and creative teaching. Focusing on unique and compelling applications of the Internet, these types of lesson activities engage students in doing real science; collaborating with students and experts around the world; communicating personal, cultural, geographic, and project-related information; evaluating, analyzing and synthesizing "messy" real world data; and utilizing multi-disciplinary approaches to solve problems.

You can find many of the curriculum activities developed by the Center for Improved Engineering and Science Education at Stevens Institute of Technology at our Web site *(http:// kl2science.stevens-tech.edu).* Here we give a few examples that illustrate some of the concepts presented.

A Water Quality Collaborative

Three years ago, students in eighth-grade science classes in Jersey City learned about ecosystems by reading a textbook. Today they visit a local freshwater pond to collect samples. Next, using new equipment, they analyze the samples under microscopes. Then, on the Internet, they establish communication with classes in Japan, South Africa, and England that are conducting similar investigations. After making predictions about whether the same organisms that populate Jersey City's ponds will be found in the foreign sites, they are able to observe, through pictures posted on their farflung partners' Web pages, that the very same creatures do indeed exist in all four sites.

Remote Scanning Electron Microscopes

Powerful optical and electron microscopes at universities and research centers are available. for classroom use via the Internet. Electron microscopes make images accessible in classrooms with magnifications that previously were available only to research scientists.

At Stevens we are developing a microscope initiative as a prototype of what can be accomplished through remote access to these scientific instruments. We provide students with opportunities to submit samples of airborne particulate matter from their schools for electron microscope analysis. These samples are processed by graduate students who are in contact with the submitting high school via CU-SeeMe Internet two-way video.

In their classrooms, students are able to see how the electron microscope operates and get direct access to the resulting images. By reviewing images with magnifications of 3,000x to 10,000x and comparing them with reference images, students have been able to identify chalk particles. This activity not only helps students understand concepts of size and scale but also is directly relevant in terms of understanding the new Environmental Protection Agency air-quality standards, which call for control of particles as tiny as 2.5 microns.

Data from Ships at Sea

Hundreds of ships in the world's oceans regularly report their precise locations along with basic information about weather and sea conditions. The data can easily be obtained from a database maintained by the National Oceanographic and Atmospheric Administration, which updates the information several times each day. While the volume of information can be overwhelming, it provides an exciting way for students to engage in vicarious travel.

Pretending they are frightened stowaways on a ship who happen to have access to laptop computers and cellular telephones, fifth-grade students try to determine the location of the port to which their ship is bound, using sequential reports of location and Internet resources to calculate the speed and direction of the ship. With this information, students can determine the ship's arrival at a port city, where they can call their parents to pick them up.

This type of activity allows students to apply facts, such as the equation for the speed of an object, to real-life situations, giving them a context for learning that other technologies can't supply. Most students find the activity engaging.

We have now arranged for students to be in direct email contact with senior staff members of major cargo vessels. This new dimension gives students the chance not only to communicate directly with professionals in the shipping industry but also to have their work checked and to engage in scientific conversations about weather conditions. The response from both the students and the officers on board the vessels has been quite positive, and we hope to expand this project schoolwide.

We use an extension of this unit with seventh- and eighth-grade stowaways who decide to stay on board a ship and accept work assignments. They become the captain's Internet weather advisers, tracking the progress of the ship and monitoring weather conditions from real-time satellite sources to determine whether the ship needs to change course.

Email to South Africa

While we direct our efforts at science topics, we have found that using the Web often leads naturally into other learning areas as students exchange email about themselves, their culture, and current events. A notable exchange took place with two separate student groups in South Africa, one that wanted to achieve a common culture for South Africa and another that advocated the preservation of native traditions.

Such an educational experience would have been hard to implement in any other fashion. It stimulated so much dialogue that the Jersey City teacher had to ask her students to curtail the exchanges!

3.4.4 Multi-Disciplinary Impact

As these examples illustrate, the work of scientists and students using authentic tools is inherently multidisciplinary. These technology-rich projects and lessons demonstrate that students must draw on their mathematical understanding to conduct data analysis and make forecasts; use social studies and geography to locate collaborating partners or events that are being studied; employ communications, language arts, and written and oral presentation skills as they communicate with experts and peers around the world and present their findings; and often practice foreign language skills as they communicate with others around the globe. The inexorable push toward use of authentic problems and tools for K-12 education necessitates a multidisciplinary approach to instruction, and, in turn, expects students to use all their skills, knowledge, and background, to solve these real world problems.

3.5 Factors In Teacher Use of Instructional Computers and the Internet

In order to understand future trends in uses of instructional computers, we need to understand the current factors behind their use by teachers. We have seen that use of instructional computers by teachers working in the target population schools has not reached maximum levels and that use of software differs widely. If we can develop an understanding of why this is the case, we can then factor in the other trends we have noted and make some predictions about future uses.

3.5.1 Access

"Teachers who don't use software or Web sites for instruction are more likely to cite a lack of classroom computers than any other reason."[62] As we have stated already, having access to computers in the classroom is central to their use by students and teachers. We have also seen that at present, only about half of the computers in schools are located in classrooms. Although this may be slightly higher for our target population, it is still most likely a significant factor in the present level of use of instructional software by teachers. Since 1992 we have seen a steady trend towards placing more computers in classrooms.[63] Given the assumption that our target population schools are based in affluent communities, we may be able to conclude that, in addition, the number of computers in these schools will increase dramatically over the next decade. As this happens, schools will reach the point where they cannot allocate more space for computer use in labs and will then begin to place computers into classrooms at a much faster rate than at present. The result is expected to be a dramatic increase in the use of the computers for instructional purposes by teachers.

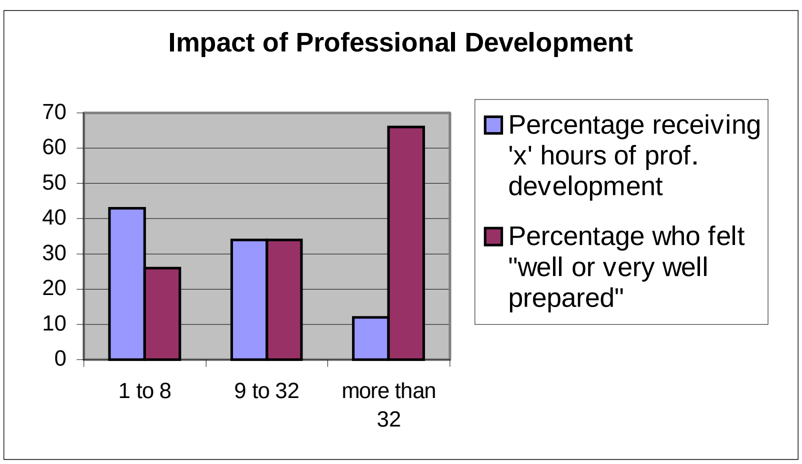
3.5.2 Support

Of those teachers who reported not having a technology coordinator in their school building, 39% indicated it was a "great barrier" to their use of the technology.[64] Overall, 80% of teachers without technical support in their school building reported it was a barrier to at least some extent. **In addition, "technology leaders need to be cognizant of the fact that technology support is not simply technical support"[65] but also includes instructional integration support.** Of teachers without technology coordinators in their school, 33% indicated that a "lack of support regarding ways to integrate technology into the curriculum" was also a "great barrier" to their use of the technology.[66] **This is a very new issue that has only recently surfaced in the data. It is clear that over time, schools must find ways to address this issue if they want to ensure that the technology is used and used effectively.**

3.5.3 Professional Development

In 1999, only "10% of teachers reported feeling ‘very well prepared’ to use computers and the Internet for classroom instruction" (23% reported feeling ‘well prepared’).[67] This lack of teacher preparedness clearly has significant meaning when we look at how they are using the technology with students. For example, of those teachers who indicated that they were "somewhat" prepared to use problem-solving or data analysis activities with their students, only 47% of them actually assigned students this type of work. Of those teachers who didn't feel prepared at all, only 14% assigned students these same types of activities.[68] As one might expect, teachers with more technology training are much more likely to feel "better prepared" to integrate technology in classroom lessons than teachers with less training or no training. In addition, training on "integrating technology into the curriculum" seems to have a greater impact on teachers than "basic technology skills" training when it comes to whether they use software and how much they rely on it.[69] This points to the critical need for teachers to receive professional development, particularly in the area of technology integration, so that they can learn how to use the technology effectively.

A growing concern in the United States is the significant number of new teachers who will need to be hired over the next several years as a large portion of the teaching force enters into retirement. This raises the question of how prepared new educators will be to use instructional technologies when they enter the classroom. Although one might expect that schools of education would be addressing this issue, there are strong indicators that they have done little to deal with the situation. In a report to Congress in 1995, titled *Teachers and Technology: Making the Connection*, the Office of Technology Assessment (OTA) indicated that "despite the importance of technology in teacher education, it is not central to the teacher preparation experience in most colleges of education…[and]…most new teachers graduate from teacher preparation institutions with limited knowledge of the ways technology can be used in their professional practice."[70] Although five years have passed since this report was released, many recent studies "suggest that little progress has been made."[71] Given the massive explosion of Web technologies that have taken place in this same time period one can assume that schools of education now face an extremely challenging task in preparing future generations of educators.



Before concluding, it is important to recognize an emerging issue related to Web-based technologies and their use in the classroom. The World Wide Web has only recently surfaced as an educational tool, but school systems and educational organizations have already spent millions of dollars to wire schools and classrooms. Of concern is the fact that of those teachers that use Web sites for instruction, only 9% of teachers say it is a "primary resource" while a large majority, 88%, use it simply as a "supplementary resource."[72] Related to this is the fact that teachers have students use the Internet for research or information gathering more than for any other purpose. This trend, which is similar to that of computers over the past 10 years, in which educators use Web-based technology as an add-on rather than an integral part of the instructional process, will diminish the impact that Web technologies can have on student learning and behavior in the near term. Colleges of education and those providing professional development opportunities for today's educators must learn from past experiences with computers. As educational leaders they must ensure that teachers understand how to use the Web as more than just a large library, but as a tool that can engage students in meaningful learning experiences.

Over the next decade it will be important to track developments in these three areas of access, support and professional development as they will be predictors of how effective educators will be in their use of instructional technology.

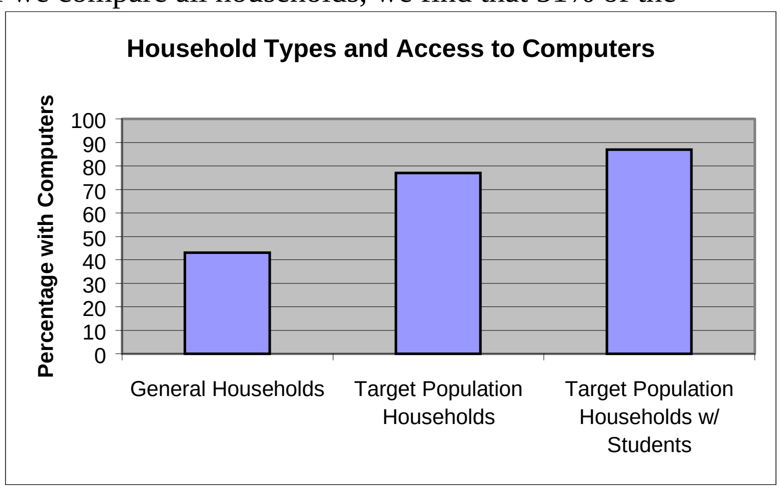
4.0 Home Computer and Internet Access and Use

We have taken a close look at how students access and use computers and the Internet at school and the trends associated with these topics. To complete the picture of how technology is impacting the lives of our target population, we must now investigate how students access and use computers and the Internet at home.

4.1 Home Computer Access and Use

Among our target population we would expect to find a significant number of students who enjoy access to computers at home. In some cases, these students may have better access to more powerful computers at home than they do in their schools and classrooms.

As we did with schools, we begin by examining the numbers of computers found at home. In 1997, 43% of the total population in the United States had computers.[73] If we assume that the household income for our target population is $75,000 and above, then we find that the percentage rises significantly to 77%,[74] also in 1997. If we now look at students (ages 3 to 17) who live in households with a family income of $75,000 and above, we find that 87% of them had a computer at home.[75] Interestingly, if we compare all households, we find that 51% of the households with children had computers, but only 31% of the households without children had them.[76] **This data, in combination with the previous numbers, indicates that parents recognize the importance of having a computer at home if they have a student in the house.** Clearly, among our target population, we can see that the vast majority of these students already have a computer at home.

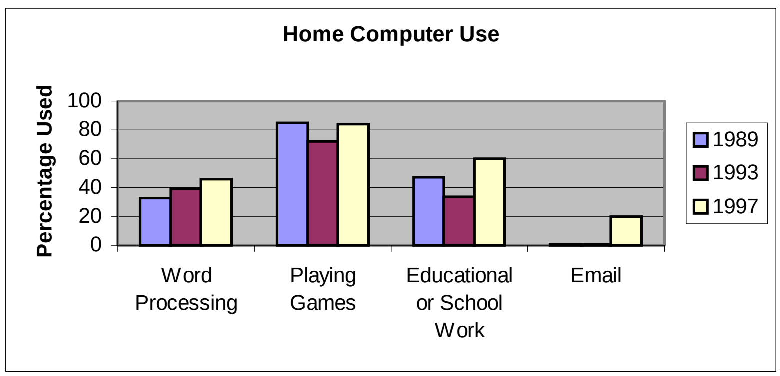


This household percentage also marks a high point in a historical trend that has seen a steady increase in home computer access over the past decade. Starting in 1984, when data was first collected, we find only 22% of households in our target group had a computer. In 1989, this percentage increased to 44%, in 1993 it was 60%,[77] in 1997 it was 76%,[78] and finally in 1998 it jumped to 80%.[79] Based on this trend, we might expect as much as 90% of the target population households to have computers within the next two years. With this level of penetration, home computer use is expected to have a tremendous impact on the target population.

As we saw with school computer access, it is important to look at how modern computers are when we are investigating the impact they will have on students. **In 1997, more than half of the home computers reported were purchased within the last year and more than 83% were purchased within the past three years.**[80] This means that, among the target population, the majority of home computers could be considered modern. It also means that even if home computers were not upgraded since 1997, that more than half would only be two to three years old and thus still be considered modern.

To complete this picture of home computer use, we need to look at how often students used their home computer and for what applications. In 1997, approximately 45% of all students used a computer at home with only a slight difference between middle school and high school students. If we consider only households in our target group, then we find that this number rises dramatically to 74%. Among students in these households, 22% reported using their computer six to seven times a week; 36% reported using it two to three days per week; and 20% reported using it one day or less per week.[81] As a comparison, in 1996, 41% of eighth graders in our target group indicated that they watched an average of one to two hours of television per day.[82] This implies that although students are using computers at home frequently, they spend similar amounts of time watching television.

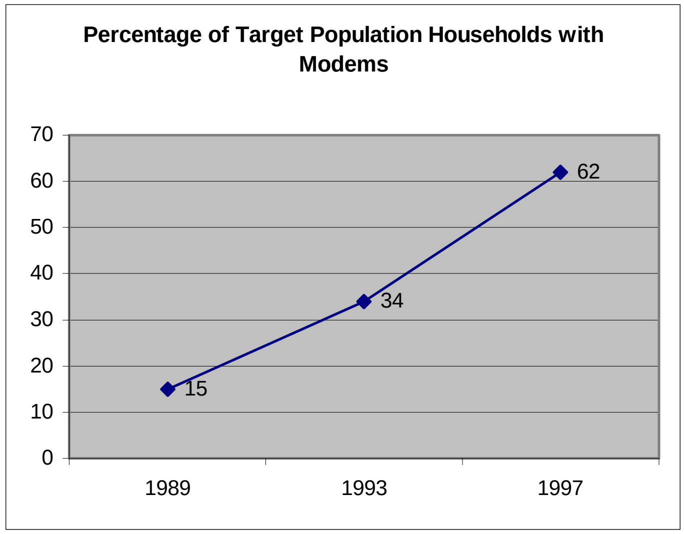
Finally, we need to look at how students are using home computers. In 1989, students from our target population used their home computer extensively for playing games (85% reported this use).[83] Word processing was just emerging as an important use of the home computer, with 33% of the students in our target population reporting using such tools. These same students were also beginning to use their computers for schoolwork (47%).[84] Although in 1989 bulletin boards were used by 3% of the students in our target population, email was only used by 1% of the same population. By 1993, game use by our target population had dropped slightly to 72%, but use of the computer for communication and schoolwork remained relatively unchanged.[85] Students were also starting to use their home computers to run educational programs (34%) but at a level far below that of playing games (72%). In the same year, there was also a small increase in the use of word processors, with 39% of the students in our target population reporting use of this software at home.[86] Then in 1997 several important shifts took place in how home computers were being used. The use of educational programs rose dramatically with 96% of our target households reporting their use. Although game playing also rose slightly (84%), so did the use of computers for schoolwork (60%) and word processing (46%). Not surprisingly, in 1997, we also saw a significant increase in the use of electronic mail with slightly more than 20% of the target student population reporting use of their home computer for this purpose.[87]



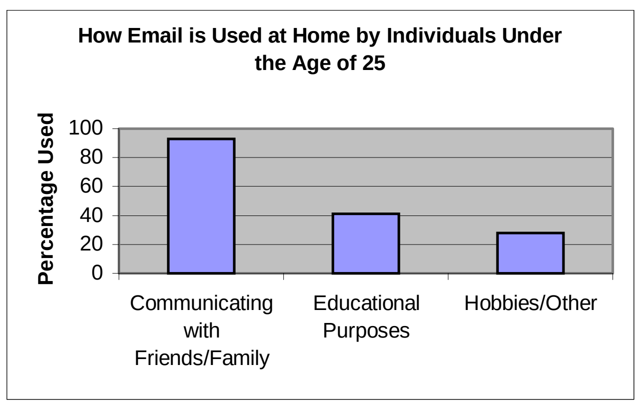
In a relatively short time span between 1993 and 1997 we saw a dramatic change in how students were using their home computers. Whereas computers had previously been primarily used for playing games, they are now more often used for educational purposes.

All of this data seems to be pointing towards an important trend in home computer use by students in our target population**. In a relatively short time span between 1993 and 1997 we saw a dramatic change in how students were using their home computers. Whereas they previously had been primarily used for playing games, they are now more often used for educational purposes.** In addition, we saw an equally important rise in the use of computers as a communications tool with the application of email. If these trends continue, we would expect to find almost all of the target population homes using computers for a wide range of applications, including educational and communications.

4.2 Home Internet Access and Use



"The Internet has rapidly become a critical, not optional, tool for many people in their day-to-day activities."[88] As a result, we have seen a rapid increase in the number of homes that now have access to the Internet. Although data specifically on home Internet access and use was not collected until 1997, there is some information available prior to that year which is useful in discussing trends. In 1989, in households of our target population, we find that only 15% had modems. This number rose to 34% in 1993 and then almost doubled four years later to 62% in 1997.[89] Not surprisingly, email use rose from only 10% in 1994 among the same households, to 44% in 1998. In that same year (1998) 60% of the target population households reported having access to the Internet.[90]



If we now look at how the Internet is used at home, we find that among target population households, the most common use of the Internet is for email (79%). Information searching is also a relatively common use of the technology with 60% of the target population households reporting this use.[91] If we then consider how email is used, we find that for those under the age of 25, 93% reported using it to communicate with friends and family. Among this same age group, 41% reported using email for educational purposes, and 28% reported using it for hobbies or other special interests.[92]

This acceleration in home use of Internet and email is expected to reach nearly saturation levels within the next few years among students in our target population households. Coupled with the demonstrated growth in educational uses of computer software and Internet applications in school by students and teachers, this data points to an immersion in technology by our target population never before seen or even anticipated.

5.0 Cognitive Implications of Technology Use and Current Educational Practice

After considering the dramatic increases in computer availability and Internet access and use in schools and in homes, and the current statistics on software applications used for educational purposes, the next area to consider in addressing our core questions is the demonstrated impact on student learning, student behavior, and student outcomes resulting from this technology use.

Until recently, research on technology's impact has focused on learning "from" technology (instructional TV, integrated learning systems, computer-based tutorial software), as opposed to learning "with" technology (databases, spreadsheets, semantic networks, expert systems, communications software such as teleconferencing programs, on-line collaborative knowledge construction environments, multimedia/hypermedia construction software, and computer programming languages).[93] But, according to the North Central Regional Educational Laboratory, "(Education) **(r)esearchers are now beginning to meet the more complicated research task of investigating the impact of technology use in meeting these new expectations for what students should learn. They are examining students' ability to understand complex phenomena, analyze and synthesize multiple sources of information, and build representations of their own knowledge. This model of integrated technology-supported learning emphasizes the ability to access, interpret, and synthesize information instead of rote memorization and the acquisition of isolated skills."[94]**

It should also be noted that an assessment of technology's impact on students must consider:

(1) The diverse array of technology available and its varied applications by teachers and students

(2) Standardized tests, the most common measure of student achievement, have limited applicability when measuring students' thinking skills

(3) Schools and classrooms are complex, social environments in which a variety of factors combine to influence student achievement and student behavior

Available recent research combined with vignettes and anecdotal evidence from purposeful, early-adopter educators and high-end technology-using students help to paint a picture of the impact on students of tool technologies that promote cognitive challenge. **Here, we seek to elucidate the impact of technology, not *only* on student achievement, (measured largely by standardized tests, which, many educators believe have limited value in assessing student thinking processes),[95] but on the ways in and extent to which they engage in subject-matter investigations; their study and research habits; their ability to utilize a variety of media and sources to analyze and solve complex and multi-dimensional problems; and their reasoning, critical thinking, and ability to present rational, cogent arguments.**

5.1 Context and Trends in the U.S. Educational System

It is not possible to discuss the effects of technology on students without looking more broadly at the U.S. educational system as a whole. Unlike our international counterparts, the U.S. educational system is highly decentralized, with 15,959 individual school districts,[96] each responsible for its own curriculum and policies. One effect of this macrostructure of nearly 16,000 independent units relevant to our study is that there exists a wide diversity in the achievement, instructional practice, and technology infrastructure throughout the U.S., and even within the same counties of a given state. Therefore, formulating a profile of a "typical" middle or high school student's technology use is not possible; a typical student in a high poverty, urban school and a typical student in an affluent suburb would have widely divergent educational experiences and access to/proficiency with technological tools. (A later section in this report will describe federal efforts to close the technology gap between wealthy and poor students.)

Another effect of the decentralization of the U.S. educational system is the comparatively low achievement of U.S. students in general in science and mathematics, as compared to their international counterparts.[97] It must be noted that while today a large majority of the students who are high-end technology users are also those that excel in science and mathematics, the inexorable push toward "radical simplicity"[98] among makers of computers and other digital devices will broaden the representation of high-end technology-using students. **It is clear, however, that a strong foundation in science and mathematics will be critical to solving the complex problems demanded by NIMA and other similar employers in 2010 and beyond.**[99]

With this important recognition, policymakers and the education community at the national, state, and local levels have adopted demanding new curriculum standards and frameworks that emphasize more rigorous content knowledge, depth of understanding, engagement in hands-on activities, and authentic uses of technology to solve problems, communicate, and collaborate. Major players such as the National Science Foundation and the U.S. Department of Education have made investments in the billions of dollars to provide incentives for states and school systems to meet these higher standards. The American Association for the Advancement of Science (AAAS)'s Project 2061, which has been a leader in the push to promote adoption of challenging standards by states, defines *10 Benchmarks for Science Literacy*[100] that include science and mathematics concepts that are critical for effective schooling and productive citizenship, as well as recommendations for technology, engineering, and "Habits of Mind." In this latter section, AAAS enumerates the following tenets:

- Students' ability and inclination to solve problems effectively depend on their having certain knowledge, skills, and attitudes.
- Quantitative, communication, manual, and critical-response skills are essential for problem solving, but they are also part of what constitutes science literacy more generally…
- Learning to solve problems in a variety of subject-matter contexts, if supplemented on occasion by explicit reflection on that experience, may result in the development of a generalized problem-solving ability that can be applied in new contexts; such transfer is

unlikely to happen if either varied problem-solving experiences or reflection on problem solving is missing.

- The problem of rote learning is primarily a pedagogical one that applies to skills as well as knowledge, and it is not solved simply by stating learning goals in one way instead of another.

Further to the complex picture of educational practice is the range of pedagogical styles employed by teachers in the classroom. While most teachers would be considered eclectic, choosing from a large repertoire of instructional strategies as the situation warrants, educators and researchers most often identify two overarching approaches to teaching under which a variety of practices and beliefs may be classified. These include[101]:

- <u>Traditional Transmission Instruction</u> is based on a theory of learning that suggests that students will learn facts, concepts, and understandings by absorbing the content of their teacher's explanations or by reading explanations from a text and answering related questions. Skills (procedural knowledge) are mastered through guided and repetitive practice of each skill in a sequence, in a systematic and highly prescribed fashion, and done largely independent of complex applications in which those skills might play some role.

- <u>Constructivist-Compatible Instruction</u> is based on a theory of learning that suggests that understanding arises only through prolonged engagement of the learning in relating new ideas and explanations to the learner's own prior beliefs. A corollary of that assertion is that the capacity to employ procedural knowledge (skills) comes only from experience in working with concrete problems that provide experience in deciding how and when to call upon each of a diverse set of skills.

The key differences between these two approaches include:

a) the theory of student learning that undergirds instructional practice – i.e., the differenceb etween learning through reception of facts and repetitive practice of discrete skills versus learning through effortful integration of new ideas with those previously believed;
b) the role of teacher and student – i.e., the traditional didactic approach in which the teacher is the leader of an organized and highly prescribed set of activities defines the transmission model vs. the teacher-as-facilitator of student-designed learning;
c) social structures for learning which in constructivist classrooms include debates between students, cooperative group projects, and other activities involving the articulation of students' own ideas in concrete contexts vs. more individual learning structures based on reading and listening.

Since the 1983 publication of "*A Nation at Risk*"[102] many national reports on education, including the 1991 SCANS Report,[103] have proposed many education reform efforts involving changes in school curricula, teachers' instructional strategies, and organizational arrangements within schools and districts, that are consistent with constructivist beliefs. In constructivist-compatible classrooms, one would generally find one or more of the following behaviors:[104]

projects; groupwork; problem-solving; reflective thought through writing; tables that engage students in meaningful thinking.

5.2 Overview of Educational Research on Technology's Impact

A wealth of research exists on the effects of technology on student achievement; however, much of it defines student learning as the retention of basic skills and content information whose increase is measured by standardized tests. Large-scale, statewide implementations of educational technology have been correlated to gains in standardized test scores in Idaho and West Virginia. West Virginia attributes a rise from 33rd to 11th on student scores in national achievement tests over seven years, largely attributable to its technology program,[105] and 11 percent of the increase in mathematics and language arts to computer interventions.

However, in measuring student achievement, educational researchers are more broadly calling for the adoption of new evaluation methods that take into account the complexity of the school environment, the role of the teacher, and other factors integral to the outcome. In summarizing various educational researchers' analyses of the challenges to such evaluation, Heinecke and Milman state: "broad-based technological reforms, those that attempt multiple changes in a school… are more difficult to measure in terms of outcomes…(E)fforts to trace the effects of these projects must take into account measuring effects in dynamic situations where many variables cannot be controlled and where interventions and outcomes have not been well defined for measurement…(T)he complex environments in which technology projects are embedded make inference of causal relations between project activities and outcomes tenuous.[106]

For the purposes of this white paper, our investigations have focused more narrowly on the effects of tool and multimedia technology applications whose use engages students in critical analysis, problem-solving, and meaningful tasks.[107] Available research falls broadly into two categories:

1) summaries of large-scale studies on educational technology's impact, including data on teacher objectives for student learning with the use of technology; and
2) case studies on units of the educational system for defined technology applications with unique goals.

Supplementing this data is anecdotal evidence of:

- d) pioneering and thoughtful educators who have shared their insights;
- e) high-end technology using students who can be viewed as predictors of future, more widespread, use patterns.

5.3 Research Findings on Technology's Impact on Cognitively Challenging Tasks and Higher Order Thinking Skills

A 1999 Report from SRI International's Center for Technology and Learning analyzed the effects of a project that used multimedia as a key component of project-based learning. Significant changes in classroom practices were observed between technology-using classrooms (TUC) and non-technology-using classrooms (NTUC):

- The level of engagement in long-term projects was greater in TUC than NTUC.
- Students in TUC tended to construct products as part of their learning more than NTUC.
- Students in TUC became more likely to work in small groups on collaborative activities than students in NTUC.
- Over time, students in the multimedia classrooms were more likely to be engaged in "higher-level cognitive activities…such as deciding on the structure of a presentation; creating multiple representations, models, and analogies; arguing about or evaluating information; thinking about one's audience; and revising or editing work"[108]

In 1999 the Millken Exchange on Educational Technology compiled an analysis of the five largest-scale studies of education technology to date and two smaller-scale studies that are useful in demonstrating educational technology's impact on students.[109] These studies looked both at tutorial technology applications, as well as productivity or tool software. While the full report is instructive in reviewing the broad uses of technology both for basic skills as well as higher-order thinking skills, this section will look specifically at two studies that focused on the latter types of technology applications.

The Apple Classrooms of Tomorrow (ACOT) study and the Computer-Supported Intentional Learning Environment (CSILE) studies are illuminating. ACOT, which tracked five school sites across the country, sought to encourage instructional innovation and emphasize the potential of computers to support student initiative, engagement in long-term projects, access to multiple resources, and cooperative learning. The ACOT experience appears to result in new learning experiences requiring higher-level reasoning and problem solving. **It showed a positive impact on changing instructional environments from less "teacher stand up lectures" to more cooperative group work.** The research showed no differences between ACOT participants and the control group on standardized tests in vocabulary, reading comprehension, mathematics and work-study.[110]

CSILE, the most widely studied set of computer-based activities in schools today, focused on the social and collaborative aspects of computer use by entire classrooms of students over an eight-year period. Its evaluation findings[111] include:

- CSILE students surpassed those in control classrooms on measures of depth of understanding, reflection, and also on standardized reading, language, and vocabulary tests.
- CSILE maximizes student reflection and encourages progressive thought, taking multiple perspectives, and independent thinking

The 1998 Teaching Learning & Computing National Survey (TLC)[112] compiled extensive data from a representative sample of 4,100 U.S. teachers in Grades 4-12, with a purposive sample of high-end technology users. Several papers published from this study focused on teachers' objectives for technology use by students, and the types of classroom environments and student tasks that resulted from those objectives. TLC looked at frequency of project activities, subjects in which projects were taught, technology applications used, and a variety of other relationships. Among the leading objectives for students[113] (in descending order) were:

- Expression in writing
- Finding out about ideas
- Remediation of skills
- Analyze information
- Communicate electronically
- Learn to work collaboratively
- Present information to an audience

It was found that positive relationships exist between the degree of cognitive challenge and the frequency of software use, the variety of software use, and teachers' professional use of the computer.[114]

The TLC also analyzed the classroom environment and teachers' emphasis on more constructivist-compatible learning behaviors, including:[115]

- Projects, in which students employ a variety of skills and engage in a diverse set of tasks to accomplish a goal that, even if only implicitly, involves developing their understanding of important content
- Group work, where student tasks involve interdependencies with other students and, in particular, where the discourse with other students is facilitated
- Problem-solving tasks, where the procedural knowledge present for solving a problem is not algorithmic but requires thinking, evaluating, decision-making, and planning, and where the definition of the problems themselves may be the responsibility of the student
- Reflective thought through writing
- A variety of other tasks that engage students in meaningful thinking, including making conjectures, eliciting students' opinions, having them work on issues related to their own experiences, and arguing various points of view

While this survey was not designed to measure student outcomes, it did demonstrate a high correlation between teachers' philosophies about teaching and learning (constructivist vs. transmission model) and their creation of learning environments that did or did not engage students in the activities listed above.

5.4 Teacher and Student Perspectives: Anecdotal Evidence as Predictors of More Widespread Use Patterns

To supplement this emerging profile of technology-using students, our investigations turned to the insights of pioneering teachers and of high-end technology using students as predictors of future, more widespread patterns. These teachers are known to the authors as thoughtful educators whose degree of technology integration puts them in an elite category among U.S. educators. Their perspectives confirmed and augmented the research findings:

- A high school physics teacher in an affluent New Jersey suburb contends that using the Web to study vectors (using real time data to track real flights in U.S. skies and "live" wind speed data) results in two significant differences than the students who use more traditional approaches to this topic: greater ownership of the "problem" resulting in more persistence and more lively collaboration, and more probing questions among the students themselves.[116]

- A computer lab teacher in a large, low-achieving inner city New Jersey school system identifies greater student motivation from Web-based real world data and information and improvement in students' interest in subject matter, their critical thinking and thorough analysis of Web-based information.[117]

- Expanding the boundaries of the solution and helping students to think about the concept of "best" vs. "right" answer is another effect that several teachers noted when engaging students in Web-based activities.[118] Students understand that the textbook isn't the only source of information and understand that the world is a complicated place with many competing, conflicting, and contradictory sources of information.

- Improved written and verbal communication, more organized, cogent presentations, and greater attention to detail were student outcomes also cited by several teachers.[119]

It is noteworthy that, while the teachers interviewed reflected on and could distinguish a difference among their students in "with and without Web access," the students interviewed[120] could not recall "life before the Web." **Among the target group of students interviewed, including middle and high school students, and newly-arrived college freshmen, all perceived technology to be such an integral part of their education, their social habits, and their life that they could only comment on their current behavior patterns, and not the issue of "how their behavior has changed as a result of the Web." This is a logical, though not self-evident, finding, and has important implications for this study.** It points to the pervasiveness, rapid adoption, and degree of reliance on collaborative tools for social and educational applications of the target group, and their comfort with communicating and working remotely.

Five of six students interviewed used "chat" three or more times a week to socialize. All had used Web search to research information for a school project. One had engaged in online collaboration, creating a PowerPoint presentation and a research paper on the topic of epidemiology, with two students in a distant city. All used a variety of software applications, including Web page development tools, and most were self-taught.

When asked to describe an ideal work environment, students responded:

- "Lots of high tech toys."
- "The ability to use my engineering education."
- "Being able to work with other people, in person and online."
- "Compensation is a key."
- "The ability to be creative, do research, write, use the Web and other tools."

With prompts, they commented on the desirability of flexibility in telecommuting, working remotely from distant locations, and "flex time" scheduling.

5.5 Calls for and Responses to Comprehensive Research Initiatives on Educational Technology's Impact on Teaching and Learning

The March 1997 *Report to the President to Strengthen K-12 Education in the United States* by the President's Committee of Advisors on Science and Technology recommended an increase to $1.5 billion annually "to initiate a large-scale program of rigorous, systematic research on education in general and educational technology in particular."[121]

Similarly, the CEO Forum's 1997 *STaR Report*, in its "Year 1 Recommendations and Challenges," urged universities, policy makers, research institutions and the private sector to "work together to define and develop state-of-the-art measurement tools that will enable a realistic assessment of the effect of technology integration on the process of teaching and learning."[122]

The federal government has begun to respond to these calls for increased attention to research on the impact of technology. Through a new agency called IERI (the Interagency Educational Research Initiative) the U.S. Department of Education, the National Science Foundation, and the National Institute of Child Health and Human Development have committed $88 million over the next two years to improve preK-12 student learning and achievement in reading, mathematics, and science by supporting rigorous, interdisciplinary research on large-scale implementations of promising educational practices and technologies in complex and varied learning environments.[123] One of the most recent (October, 2000) awards is aimed at expanding the research base on the impact of Web-based applications on student achievement and thinking skills. This award[124] is a $490,714 grant to Stevens Institute of Technology's Center for Improved Engineering and Science Education (CIESE) and Yale University's Drs. Robert Sternberg and Elena Grigorenko, authors of "Teaching Triarchically Improves School Achievement" and "What Does It Mean to Be Smart" and creators of the Triarchic Theory of Intelligence. In this model, intelligence has three domains: practical, analytical, and creative. This project will assess the impact on student learning of four conditions: (1) triarchically-enhanced Web-based curriculum materials; (2) non-triarcically enhanced Web-based materials; (3) triarchically-enhanced textbook materials; and (4) non-triarchically-enhanced textbook materials. **The outcome of this 18-month study will inform policymakers and educators about how the use of enriched Web-based curriculum materials improve student achievement and critical thinking abilities, and should lead to additional research in this area.**

6.0 Other Factors Influencing the Capabilities and the Composition of the Techforce of 2010

As we have seen, the capabilities of the workforce in 2010 will depend on many factors. Key prerequisites for effective work in high technology environments for many years to come will be proficiency with the two most significant technologies of the Information Age: computers and the Internet. This report has focused on these influential and pervasive technologies in terms of the their availability and use in school environments and in homes, as well as the cognitive implications that this use of technology has on middle and high school students' ability to think critically, find and synthesize multiple sources of data, and to deal with complex, multi-dimensional problems.

In completing our profile, there are several other factors we must consider:

- Students' educational background, specifically in science and mathematics
- Effects of the "Information Age Culture," in which digital gadgetry is pervasive and integral to human behavior
- Effects of efforts to close the "Digital Divide" to increase opportunities for technology use by disadvantaged and underrepresented groups
- Teacher workforce trends
- Expected increases in parent involvement in education via technology

6.1 Educational Background

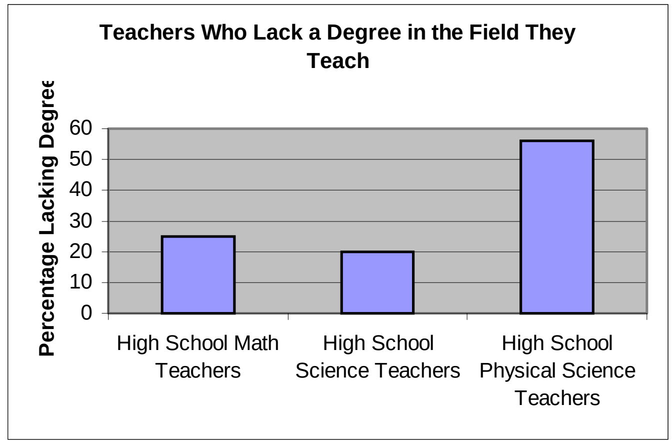
Since the day that Sputnik first circled the earth in 1957, there has been grave concern in the United States about the adequacy of mathematics and science education in our K-12 schools. The most recent articulation of this concern is the September 27, 2000 report of the *National Committee on Mathematics and Science Teaching for the 21st Century*, chaired by Senator John Glenn.

Entitled, "Before It's Too Late," this report summarizes a wealth of data that has been accumulating in recent years about the comparative weakness of U.S. students in science and mathematics achievement against international counterparts. Most notable of these analyses is the "Third International Mathematics and Science Study," or TIMSS report, and the "National Assessment of Educational Progress," or NAEP, which is also known as the "Nation's Report Card."

The most striking result of the TIMSS study was the U.S.'s lowest standing in mathematics and the second-to-lowest ranking in physics in a careful comparison involving 20 countries.

The NAEP studies show that less than one-third of U.S. students are proficient in science and mathematics, with data from similar comparisons showing equally dismal ratings for nearly 30 years.

The Glenn report emphasizes that the low levels of achievement of U.S. students in mathematics and science is closely correlated with inadequacies in the teaching profession. More than one in four high school mathematics teachers and nearly one in five high school science teachers lack even a minor in their main teaching field. The situation is worst in physical science, where 56% of students are taking courses by out-of-field teachers.[125]



This inadequate preparation results in a small pool of students who go on to study mathematics, engineering and information science. In 1995-96, 34.6% of all bachelor's and 44% of all master's degrees in the United States were earned by nonresident aliens.[126] The overall lack of teacher preparation in science and mathematics results in low levels of student performance (both in terms of international comparisons and by our own national standards) and, in turn, further inadequate preparation of mathematics and science teachers. These grim statistics are not expected to improve quickly, even with the most enlightened and vigorous national policies. In fact, it will be difficult to cope with these challenges since two-thirds of the nation's three million teachers are expected to retire during the coming decade.[127]

Given the limited number of students with strong science and mathematics backgrounds and the fierce and accelerating competition for their services, it is expected that extensive training of new workers will be required to fully meet the needs of the workforce in 2010. It is also likely that recruitment will need to be pursued among populations that go beyond the target group that is specified in this report. The target population described earlier in this white paper is an elite group with the best access to technology as well as the best access to qualified teachers and rigorous educational programs. This population will be inundated with attractive job offers. **To meet the hiring goals that motivate this study, there will likely be a need to expand the target group. In reaching out to a broader socio-economic population, there will be concomitant additional needs for on-the-job training programs in both subject matter and on the use of the needed technologies.**

6.2 E-Rate and Educational Technology Trends

In 1996 Congress established a dramatic new program aimed at increasing access to telecommunications services for needy schools and libraries. The E-Rate program, as it has become known, began implementation in 1998. Established as part of Public Law 104-104, the Telecommunications Act of 1996, the Universal Service Fund for Schools and Libraries provides discounts on the cost of telecommunications services and equipment to all public and private schools and libraries. Eligible services range from basic local and long distance phone services and Internet access services, to the acquisition and installation of equipment to provide network wiring within school and library buildings. Computer hardware and software, staff training, and electrical upgrades are not covered, however. Discounts range from 20 percent to 90 percent, depending upon economic need and rural location. Rural and urban schools with upwards of 75% of their students on federal free and reduced lunch programs are eligible for the maximum

90% discounts. All schools are eligible for at least a 20% discount with this discount rising significantly for schools that have more than 1% lunch program participation becoming eligible for 40% discounts in urban areas and 50% discounts in rural locations.

The first two rounds of implementation that took place from January 1998 through June 2000 had allocations that totaled $3.91 billion. The requested amount for July 2000 through June 2001 is $4.72 billion. About 80% of these discounts are being awarded to public schools with low-income schools being the predominant recipients.

A detailed analysis of the E-Rate program was prepared for the U. S. Department of Education by the Urban Institute of Washington D.C.[128] **The report states that the allocated funding is having a tremendous impact on urban schools with low income populations.** In order to grasp the magnitude of these E-Rate discounts, let us suppose that $5 billion was directed toward the nation's poorest students. Since there are about 50 million students, with about 20% of the nation's children living in poverty, we know that there about 10 million very poor students. Hence, an allocation of $5 billion for the technology infrastructure in schools of the very poor amounts to funding of $500 per child. It is easily seen that a continuation of the E-Rate program will greatly facilitate the computerization and wiring of schools for the poorest segment of American society.

Many other factors are required if there is to be effective utilization of this technology in disadvantaged schools, including teacher training and informed educational leadership. Even with the formidable hurdles that such utilization will encounter, it is highly significant that at least comprehensive acquisition of computer technology and connectivity will take place, even in the lowest income level schools. This assumption is based on the continuation of the E-Rate or similar programs.

Assuming that efforts will be needed to expand the pool of high technology workers in 2010 in order to meet hiring objectives, a strategy of jumpstarting educational improvement for lower income students can be envisioned through use of school-based Internet technology. While it is not likely that significant progress will be made in upgrading mathematics and science education in large numbers of lower income regions during the next five years, it will be possible to reach selected students through online and Internet-based interactive video courses. Today we see that a number of states are introducing virtual high schools. If meaningful courses were widely available via the Internet in 2002, those educational resources could have a significant impact on students from all socio-economic levels who will graduate from college in 2010.

While the Digital Divide is rapidly being closed in schools and libraries around the country, the differences in home use between rich and poor continue to be a major impediment to the educational advancement of low-income students. A 1999 U. S. Department of Commerce study entitled, "Falling Through the Net: Defining the Digital Divide," published by the National Telecommunications and Information Administration, reports that **households with incomes of $75,000 are 20 times more likely to have access to the Internet than those with lower levels, and nine times more likely to have a computer at home.**[129] It is noteworthy that even at the lower levels, urban households are twice as likely to have Internet access as rural households.

6.3 Information Age Culture

A third factor that goes beyond familiarity with computers and the Internet that is crucial for Workforce 2010 readiness is that of affective behavior in an Information Age environment. A short hand for this factor is "IA Culture."

IA Culture relates to the use of pervasive and ubiquitous information technologies that include but are not limited to computers and the Internet. For example, personal digital assistant devices, digital phones, digital cameras, digital music, digital video, digital fax, digital productivity tools, etc., all are all artifacts whose use is creating a new Information Age Culture.

A characteristic of these devices is that high-level computer skills are not required for their use. For example, current versions of Web TV make the Internet accessible for individuals who are not computer literate. Many elderly members of our society in their 80's and 90's are comfortable using a Web TV but would not go near a computer. A great deal of corporate investment is now going into next generations of Web TV in order to make Internet access no more complex than turning on a television set.

Another example of IA Culture is the specialized device that allows downloading of MP3 files from Napster for easy access to digital music. While Napster may not endure, some version of digital music file transfer is almost certain to be part of our future. This is likely to be the case for video and books as well.

At a recent conference in Washington, D. C. sponsored by Secretary of Education Riley, the Chairman and CEO of 3COM, Eric Benhamou, spoke about efforts in Silicon Valley to expedite the creation of the new information technology culture. He said that his highest priority was the development of devices that manifested the concept of "radical simplicity." This phrase was intended to communicate unimagined and unprecedented ease in the use of an information technology capability. Mr. Benhamou gave some examples of devices that manifested "radical simplicity." One that is close to being perfected is the Internet Radio. Such a radio for home use will have three ranges: AM, FM and IM, which stands for Internet Modulation. Through the IM range, users will be able to access the 5,000 Internet radio stations that are currently available with the same ease that allows one to tune into Saturday afternoon Metropolitan Opera broadcasts or a Yankees game.

Another example of an information technology utility is TIVO. This is a computer that serves as an intelligent video recording device that can store video on a hard disk after the user has had an interaction through an extremely friendly interface.

As the technologies of the telephone, computer, fax, video and Internet increasingly fuse into unified devices, new modes of behavior will become common. These will include the use of digital cameras, scanners, e-book specialized reading devices, unified voice mail/email systems, etc. Individuals will be adapting to varying levels of use of these related and interconnected technologies. Today, we see that almost every Wall Street professional is carrying a personal digital assistant device to take notes, keep schedules, hold addresses and telephone numbers, and sometimes to send and receive email.

Personal utility software facilitates the location of restaurants and parking lots, the identification of movies and television programs of interest and guidance in travel. The advances in software development go hand in hand with the processing capabilities of these emerging artifacts in the realization of these new examples of "radical simplicity."

There are multiple implications of "radical simplicity" that need to be considered with respect to planning for Techforce 2010. One is the extent to which individuals are comfortable with and readily adapt to an ever-changing IA Culture. It is likely that specialized devices and personal productivity tools will play an important role in the workplace of TechForce 2010 employees. Secondly, it may be that some of these information utilities will eliminate the need to be computer and Internet literate, since they may create new modes of access to information and new methods of manipulating data that do not require a significant learning experience. Another consideration is that it may be possible and necessary for those who create the 2010 workplace to customize personal productivity tools for specialized functions that are needed in executing a particular job activity.

6.4 Teacher Workforce Trends

Many indicators, as discussed in previous sections, point to the acceleration of technology that is integral to the educational process. The trend in the composition and skills of the teacher workforce in the next 10 years is no exception. There are three trends relevant to our investigation:

1. The projected retirement of nearly 2/3 of the nation's teacher force[130]
2. The greater professional use of the Internet by teachers under 30 and the relative value placed on the Internet as essential for classroom use[131] as compared to more veteran teachers
3. Increased emphasis by the federal government and major national organizations such as NCATE, the accreditation bureau for teacher education colleges, on preparing tomorrow's teachers to use technology[132]
4. The richer variety of exemplary lessons and more robust course offerings via the Web and through distance education

Although schools face a difficult challenge in filling science and mathematics positions in the next decade, it is likely that new teachers entering the teaching force will be substantially better prepared to use technology effectively with their students. Research indicates that teachers under 30 value more highly and use more frequently the Internet in their own professional collaborations and in the classroom.[133] The trend will be intensified, as a result of federal programs such as the PT3 grants, or Preparing Tomorrow's Teachers to Use Technology, which has committed $128 million in FY 2000 to promote the meaningful integration of technology among teacher education colleges. Likewise, organizations such as NCATE, the Standard of Excellence in Teacher Preparation, are vigorously adopting new requirements for colleges of teacher education for the use of technology in content and methods coursework. These developments portend more widespread and more meaningful uses of technology in classrooms all around the country.

6.5 Parent Involvement

Countless studies confirm the impact of parent involvement on student achievement. Roosevelt-Edison Charter School, Colorado Springs, Colorado, reports that parent volunteerism has skyrocketed 1,000% as a result of placing computers in nearly all 650 student homes. Teachers post homework on the Internet and send messages, and parents debate important issues related to school governance and their children's education.[134] The Buddy Project of Indiana and the Union City Online! (NJ) project, both focusing on home use of computers and telecommunications technologies, have reported similar effects.

As home access to the Internet continues to accelerate and schools become more adept at using telecommunications technology effectively to communicate with stakeholders, this trend will have important consequences for parental involvement in children's education.

7.0 Summary and Projections

In compiling a profile of students who will be candidates for the NIMA analyst positions in the Year 2010, we have reviewed a variety of issues and trends. We have seen a dramatic increase in computer ownership and Internet access in the U.S., both in schools and in homes, over the past two decades and particularly in the past five years. We have learned that access does not necessarily result in meaningful use by students, and much depends upon the location of the hardware, access to a range of software, types of Internet access, and teachers' proficiencies and objectives for software use.

We have researched how these technology resources are being used by teachers with students and have documented a trend toward more use of productivity or tool software and Internet applications that engage students in higher-order thinking, critical analysis, multiple representations of information, group work, online collaboration, and technology-supported creation of presentations. Research and anecdotal evidence indicate that *purposeful and effective* use of multimedia technologies and Internet applications does have a positive impact on: student engagement in long-term projects; critical thinking skills; creation of products; group work and collaboration; persistence on problem-solving; student reflection; and writing.

Related factors such as the "Digital Divide," the Information Age Culture, and the composition of the future teacher workforce will also impact upon the skills, capabilities, and expectations of the Techforce of 2010. These trends and initiatives point to an accelerating proliferation and dependency upon technology for educational, personal, and social applications.

Now that we have developed a comprehensive model of computer and Internet use by students in our target population, the impact of this use, and the related issues and trends that are projected for the next decade, we now venture some predictions about the technology environment in education during the next 10 years and the workforce of 2010:

- The number of modern computers in schools and classrooms will continue to rise and push student to computer ratios to lower levels than are presently found in schools. This will finally provide students with a level of access to computers that will result in significant impact. As a result, most students will be able to easily perform basic computer operations, have proficiency with a variety of productivity and communications technologies, and will be able to learn new technological skills quickly.

- Students' and parents' home use of computers and the Internet will continue to increase. Although both will remain tools for entertainment and socialization, they will increasingly become vital resources for a range of other applications, such as school work, jobs, and learning in general. Workers of the future will be used to being immersed in technology-rich environments, both at home and at work. They will expect to have many of the same capabilities at home as they do in the office and will utilize this home access for work-related activities.

- Teachers, through improved professional development opportunities, will become more comfortable using technology in general. Specifically, they will become more skilled at integrating technology into their instructional practice. One result will be an increased use of productivity or tool applications such as word processing, spreadsheets, graphical analysis and presentation software. Fully integrated use of these tools will have a significant impact on students and the skills that they will bring to the future workforce. Workers of the future will want a range of easy-to-use, yet flexible, computer-based tools to assist them in their jobs.

- The Internet will continue to grow as a mainstream technology, both at school and at home. High speed Internet access will soon be the norm rather than the exception and thus will radically affect the types of applications that can be easily pursued. With this high-speed access, more teachers will view the Internet as a critical tool in their instructional toolkit.

- Due to critical teacher shortages in science and mathematics and the relative low achievement in science and mathematics achievement by U.S. students as compared to international counterparts, there will be fierce competition for the pool of students with advanced science and mathematics coursework. It is likely the NIMA and other employers must be prepared to do significant on-the-job training of new employees and to expand its target pool of potential employees to those who have been traditionally underrepresented in such fields.

- Initiatives such as the federal E-Rate program, the trend toward "radical simplicity," and the proliferation of digital devices for specialized functions integral to human activity will all increase the availability, proficiency, and overall reliance upon technology of many sectors of our society.

- Because of increased federal, state, and local emphasis on teacher professional development on the integration of the Internet into core subjects, educators will rely more extensively on email to communicate with colleagues, on Web publishing to publish their own as well as their students' work, and will engage in collaborative projects with partners around the world, as well as other compelling uses of the technology. These types of activities will have a profound impact on how students work and how they view the rest of the world. Working collaboratively with partners in distant locations will become the norm, rather than the exception. Gone will be the need for frequent face-to-face meetings. Because of these experiences, workers in 2010 will feel comfortable collaborating at a distance using a range of technologies. Many will expect more freedom in where and when they engage in work as the technology will allow them to connect from any place at any time.

8.0 Related and Supplemental Resources

8.1 The Workplace of Tomorrow

This white paper has examined the present state and future trends of educational technology and the impact its use will have on the skills of the future workforce. Interconnected to this topic is the obvious issue of what the workplace of tomorrow will look like and how the skills of the future workforce will be utilized. The recent report titled, *Futurework: Trends and Challenges for Work in the 21st Century,*[135] which was developed by the U.S. Department of Labor, does an excellent job of providing insights into the workplace of the future.

This report examines workers, workplaces, and challenges for the future. At the center of *Futurework* are the constants in workers' lives and how they intersect with the expected changes in the twenty-first century workforce and workplace.

It explains that American workers need to have economic security over their lifetimes, be able to balance work and family, and have safe and fair workplaces. The ability to meet these needs will, in large part, be shaped by the changes in the workforce and workplaces of today and tomorrow. In the new economy, workers are concerned about being skilled and not stuck. Work arrangements, be they traditional or nontraditional, need to meet the demands of home as well as work. And to be competitive, employers will need to embrace all American workers, those of different races and origins, as well as workers with disabilities. The new millennium promises opportunities but also creates risk.

The first few chapters discuss the future of the workforce, examining: demographic trends; changes in wages and benefits; the relationship between higher wages and higher skills; the pay gaps between women and men, among African Americans, Hispanics and whites, and between people with disabilities and those without; the effect of unions on wages, benefits, and working conditions; and the evolving work and family balance issues.

Later chapters focus on the future of the workplace, covering: changes in the relative importance of different sectors of the economy; changes in workplace conditions, including safety, health, and discrimination; and the effect of technology and globalization on the ways people work as well as the impact these changes have had on the skill requirements of the workforce.

The final chapters examine the cross cutting themes of the workforce and workplace, looking at rising skill requirements, flexibility in the workplace, and job security. The report concludes with questions and observations.

8.2 Recommendations for Future Studies

Given the highly dynamic rate of change in technology development, ownership, and adoption by most sectors of our society, and particularly in education, it is recommended that the issues and trends that have been discussed in this white paper be revisited in five years. Impact of the Information Age culture, only now starting to be appreciated, will be fully apparent. Similarly, the effects of the federal E-rate program and programs to bolster meaningful and widespread use of technology by K-12 teachers will be more easily measured.

[1] President's Committee of Advisors on Science and Technology, Panel on Educational Technology (1997). "Report to the President on the Use of Technology to Strengthen K-12 Education in the United States." Retrieved from the World Wide Web: http://www.whitehouse.gov/WH/EOP/OSTP/NSTC/PCAST/k-12ed.html
[2] Symonds, W.C., "Wired Schools," 25 September 2000, *Business Week*, p. 117-118
[3] Software & Information Industry Association, "Education Market Report 2000: K -12," Washington, D.C., 2000 p. 15
[4] Green, J., "No Lectures or Teachers, Just Software," 10 August 2000, *New York Times,* p. G6
[5] A discussion of the "Digital Divide" appears on pp. 36-37of this report.
[6] Based on NIMA Project Director's descriptions of current employees holding these positions, our studies focused on students from upper middle class, suburban areas with household income of more than $75,000/year, and who finished in the top 20% of class rankings. We also looked at high-end technology users (determined by frequency of use, variety of applications, and depth of engagement) as predictors of future behavior of a more general population.
[7] A discussion of the E-rate program, which provides discounts on telecommunications services for schools and libraries serving low-income populations, appears on pp. 36-37 of this report.
[8] For the purposes of this report, we have defined the target group as students attending middle and high schools in which 11% or fewer of the population were eligible for a free or reduced lunch. This free- and reduced-lunch program is a common measure of socioeconomic status in U.S. public education.
[9] Anderson, R.A. & Ronnkvist, A. (1999). "The Presence of Computers in American Schools." Teaching, Learning and Computing: A research project of the Center for Research and Information Technology and Organizations. Retrieved on the World Wide Web: http://www.crito.uci.edu/tlc/findings/computers_in_american_schools/ p. 3
[10] Smerdon B. & Cronen, S. (2000). "Teachers' Tools for the 21st Century: A Report on Teachers' Use of Technology," National Center for Education Statistics. Retrieved from the World Wide Web: http://nces.ed.gov/spider/Webspider/2000102.shtml p. 35
[11] University of Minnesota (1992). "Computers in American Schools, 1992." A Report of the IEA Computers in Education Study. Retrieved from World Wide Web: http://hera.soc.umn.edu/research/synopsis.htm
[12] University of Minnesota (1992)
[13] Smerdon B. & Cronen, S., p 5.
[14] Williams, C. "Internet Access in U.S. Public Schools and Classrooms: 1994-1999," National Center for Education Statistics. Retrieved from World Wide Web: http://nces.ed.gov/pubsearch/pubsinfo.asp?pubid=2000086
[15] Smerdon B. & Cronen, S, p. 5.
[16] Williams, C.
[17] Anderson, R.A. & Ronnkvist, A., p. 7
[18] Anderson, R.A. & Ronnkvist, A., p. 8
[19] President's Committee of Advisors on Science and Technology, Panel on Educational Technology (1997).
[20] Anderson, R.A. & Ronnkvist, A.,p. 8
[21] Anderson, R.A. & Ronnkvist, A., p. 8
[22] Anderson, R.A. & Ronnkvist, A., p. 9
[23] Anderson, R.E. & Ronnkvist, A., p. 10
[24] Williams, C.
[25] Becker, H.J. (1999). "Internet Use by Teachers, Teaching, Learning and Computing," A research project of the Center for Research on Information Technology and Organizations. Retrieved from World Wide Web: http://www.crito.uci.edu/TLC/FINDINGS/internet-use/
[26] Rowand, C., (1999). "Internet Access in Public Schools and Classrooms: 1994-98," National Center for Education Statistics. Retrieved from World Wide Web: http://nces.ed.gov/pubsearch/pubsinfo.asp?pubid=1999017
[27] Williams, C.
[28] Anderson, R.A. & Ronnkvist, A.
[29] Smerdon B. & Cronen, S., p. 57.
[30] Smerdon B. & Cronen, S., p. 44.
[31] Smerdon B. & Cronen, S., p. 42.
[32] Smerdon B. & Cronen, S., p. 65.
[33] Smerdon B. & Cronen, S., p. 43.
[34] Smerdon B. & Cronen, S., p. 13.
[35] Smerdon B. & Cronen, S., p. 22.
[36] Smerdon B. & Cronen, S., p. 26-27.

[37] Smerdon B. & Cronen, S., p. 26-27.
[38] Smerdon B. & Cronen, S., p. 25.
[39] Becker, H.J., Ravitz, J. & Wong, YT (1999). "Teacher and Teacher-Directed Student Use of Computers and Software, Teaching, Learning and Computing," A research project of the Center for Research on Information Technology and Organizations. Retrieved from the World Wide Web: http://www.crito.uci.edu/tlc/findings/computeruse
[40] Becker, H.J., Ravitz, J. & Wong, YT
[41] Becker, H.J., Ravitz, J. & Wong, YT
[42] Education Week on the Web. "Technology Counts '98: Putting School Technology to the Test," October 1, 1998. Retrieved from World Wide Web: http://www.edweek.com/sreports/tc98/
[43] Valdez, G., McNabb, M., Foertsch, M., Anderson, M., Hawkes, M. & Raack, L. "Computer-Based Technology and Learning: Evolving Uses and Expectations," North Central Regional Educational Laboratory. Retrieved from World Wide Web: http://www.ncrel.org/tplan/cbtl/toc.htm
[44] Jonassen, D. H., & Reeves,T. C. (1996). Leaning with technology: Using computers as cognitive tools. In D. H. Jonassen (Ed.), *Handbook of research for educational communications and technology* (pp. 693-719). New York: Simon & Schuster Macmillan.
[45] Statham, D. S., & Torell, C. R. (1996). *Computers in the classroom: The impact of technology on student learning.* Boise, ID: U.S. Army Research Institute and Boise State University.
[46] Becker, H.J., Ravitz, J. & Wong, YT
[47] North Central Regional Educational Laboratory, "Phase III: Data-Driven Virtual Learning." Retrieved from World Wide Web: http://www.ncrel.org/tplan/cbtl/phase3.htm
[48] International Society for Technology in Education. "National Technology Standards (NETS) for Teachers Project." Retrieved from World Wide Web: http://cnets.iste.org/index3.html
[49] Smerdon B. & Cronen, S., p. 65.
[50] Smerdon B. & Cronen, S., p. 58.
[51] Becker, H.J.
[52] Rowand, C. (2000). "Teacher Use of Computers and the Internet in Public Schools." Retrieved from World Wide Web: http://nces.ed.gov/pubsearch/pubsinfo.asp?pubid=2000090
[53] Becker, H.J.
[54] Becker, H.J.
[55] Becker, H.J.
[56] Northwestern University (1998). "Learning Through Collaborative Visualization." Retrieved from World Wide Web: http://www.covis.nwu.edu
[57] North Western University (1996). "Learning Through Collaborative Visualization, A National Science Education Collaboratory: Overview of the CoVis Project." Retrieved from World Wide Web: http://www.covis.nwu.edu/info/papers/pdf/covis-2page-overview.pdf
[58] Edelson, D., Gomez, L., Polman, J., Gordin, D., & Fishman, B. (1994). "Scaffolding Student Inqujiry with Collaborative Visualization Tools. School of Education and Social Policy, Northwestern University. Retrieved from World Wide Web: http://www.covis.nwu.edu/info/papers/pdf/edelson-gomez-aera-94.pdf, p. 2
[59] Edelson, D., Gomez, L., Polman, J., Gordin, D., & Fishman, B., p. 16-17.
[60] EdGrid, "Moving K-12 Teachers into 21st Century Science with 21st Century Technology: Building the Educational Grid for Pre-Service Training. Retrieved from World Wide Web: http://www.eot.org/edgrid/
[61] Friedman, E.A., McGrath, & Baron J. (1997). "Web Adventures in K-12 Science." Technos, Vol. 6, No. 4, Winter 1997.
[62] Education Market Research, Rockaway Park, N.Y. "Education Week's 1999 National Survey of Teachers' Use of Digital Content." Technology Counts '99. Retrieved from World Wide Web: http://www.edweek.org/sreports/tc99/articles/survey.htm
[63] Anderson, R.A. & Ronnkvist, A., p. 8
[64] Smerdon B. & Cronen, S., p. 98
[65] Ronnkvist, A.M., Dexter, S.L. & Anderson, Ronald E. (2000). "Technology Support: Its Depth, Breadth and Impact in America's Schools, Teaching, Learning and Computing," a research project of the Center for Research on Information Technology and Organizations. Retrieved from World Wide Web: http://www.crito.uci.edu/tlc/findings/technology-support/ America's schools.
[66] Smerdon B. & Cronen, S., p. 98
[67] Smerdon B. & Cronen, S., p. 75

[68] Smerdon B. & Cronen, S., p. 78
[69] Education Market Research
[70] Office of Technology Assessment, 1995, p. 2
[71] CEO Forum "Teacher Preparation StaR Chart (2000) p. 1
[72] Education Week on the Web. "Technology Counts '98: Building the Digital Curriculum," October 1, 1998. Retrieved from World Wide Web: http://www.edweek.com/sreports/tc90/
[73]U.S. Department of Commerce, Bureau of the Census, Current Population Survey, October 1997. "Access to home computers, by selected characteristics of students and other users." Retrieved from World Wide Web: http://nces.ed.gov/pubs2000/digest99/d99t431.html
[74] U.S. Department of Commerce, Bureau of the Census, "Current Population Survey," October 1997.
[75] U.S. Department of Commerce, Bureau of the Census, "Current Population Survey," October 1997.
[76]U.S. Census Bureau. "Households with Computers and Year of Purchase by Presence of Children, Family Income, and Age of Householder: October 1997". Retrieved from U.S. Census Bureau, October 14, 1999 release on World Wide Web: http://www.census.gov/population/socdemo/computer/report97/tab01.pdf
[77]Kominski, R. & Newburger, E., U.S. Census Bureau, Population Division (1999). "Access Denied: Changes in Computer Ownership and Use: 1994-1997". Retrieved from World Wide Web: http://www.census.gov/population/socdemo/computer/confpap99.pdf
[78] U.S. Census Bureau. "Households with Computers and Year of Purchase by Presence of Children, Family Income, and Age of Householder: October 1997".
[79] U.S. Department of Commerce, National Telecommunications and Information Administration (1998). "Percent of U.S. Households with a Computer By Income By Rural, Urban, and Central City Areas." Retrieved from World Wide Web: http://www.ntia.doc.gov/ntiahome/fttn99/FTTN_I/Chart-I-12.html
[80] U.S. Census Bureau. "Households with Computers and Year of Purchase by Presence of Children, Family Income, and Age of Householder: October 1997".
[81] U.S. Department of Commerce, Bureau of the Census, "Current Population Survey," October 1997.
[82] U.S. Department of Education, The Condition of Education 1998, Supplemental Table 37-2, "Percentage of students who reported watching television, by grade, hours per day, and selected characteristics: 1996." Retrieved from National Center for Education Statistics, National Assessment of Educational Progress, Summary Data Tables: Math 1996 release on World Wide Web: http://nces.ed.gov/pubs98/condition98/c9837d02.html
[83] U.S. Census Bureau. "Purposes and Frequency of Computer Use at Home by Persons 3 to 17 Years Old: October 1989." Retrieved from U.S. Census Bureau release on World Wide Web: http://www.census.gov/population/socdemo/computer/p23-171/tab03.pdf
[84] U.S. Census Bureau. "Households with Computers and Year of Purchase by Presence of Children, Family Income, and Age of Householder: October 1997".
[85]U.S. Census Bureau. "Computer Use in the United States: October 1993." Retrieved from World Wide Web: http://www.census.gov/population/socdemo/computer/report93/comp1.txt
[86] U.S. Census Bureau. Computer Use in the United States: October 1993.
[87] U.S. Census Bureau. "Purpose of Computer Use at Home by People 3 to 17 Years: October 1997." Retrieved from World Wide Web: http://www.census.gov/population/socdemo/computer/report97/tab05.txt
[88] Kominski, R. & Newburger, E.
[89] U.S. Department of Commerce, National Telecommunications and Information Administration. "Percent of U.S. Households with a Modem By Income 1989-1997 (Selected Years)." Retrieved from World Wide Web: http://www.ntia.doc.gov/ntiahome/fttn99/App_III/Chart-A-f.html
[90] U.S. Department of Commerce, National Telecommunications and Information Administration. "Percent of U.S. Households Using the Internet By Income By U.S., Rural, Urban and Central City Areas, 1998." Retrieved from World Wide Web: http://www.ntia.doc.gov/ntiahome/fttn99/FTTN_I/Chart-I-21.html
[91]U.S. Department of Commerce, National Telecommunications and Information Administration. "Percent of U.S. Persons Using the Internet at Home By Income By Type of Use." 1998. Retrieved from World Wide Web: http://www.ntia.doc.gov/ntiahome/fttn99/InternetUse_II/Chart-II-33.html
[92] U.S. Department of Commerce, National Telecommunications and Information Administration. "Percent of U.S. Persons Using E-Mail at Home by Subject Matter By Age." 1998. Retrieved from World Wide Web: http://www.ntia.doc.gov/ntiahome/fttn99/InternetUse_II/Chart-II-48.html
[93] Reeves, T.C., (1998). "The Impact of Media and Technology in Schools," A Research Report prepared for The Bertelsmann Foundation. Retrieved from World Wide Web: http://www.athensacademy.org/instruct/media_tech/reeves0.html

[94] North Central Regional Educational Laboratory (NCREL). "Critical Issue: Using Technology to Improve Student Achievement." Retrieved from World Wide Web: http://www.ncrel.org/sdrs/areas/issues/methods/technlgy/te800.htm
[95] North Central Regional Educational Laboratory (NCREL)
[96] Market Data Retrieval. "Successful school marketing starts here." Retrieved from World Wide Web: www.schooldata.com
[97] TIMSS, Boston College (1998). "Mathematics and Achievement in the Final Year of Secondary School: IEA's Third International Mathematics and Science Report." Retrieved from World Wide Web: http://timss.bc.edu/TIMSS1/MathScienceC.html
[98] This concept is discussed on p. 38 under "Information Age Culture"
[99]American Association for the Advancement of Science. "Project 2061 Science Literacy for a Changing Future." Retrieved from World Wide Web: http://www.project2061.org
[100] American Association for the Advancement of Science. Benchmarks On-Line. Retrieved from World Wide Web: http://www.project2061.org/tools/benchol/bolframe.html
[101] Ravitz, J.L., Becker, H.J. & Wong, Y. (2000). "Constructivist-Compatible Beliefs and Practices among U.S. Teachers." Retrieved from World Wide Web: http://www.crito.uci.edu/TLC/FINDINGS/REPORT4/body_startpage.html
[102]National Commission on Excellence in Education (1983). "A Nation at Risk: The Imperative for Educational Reform." A Report to the Nation and the Secretary of Education, U.S. Department of Education. Retrieved from World Wide Web: http://www.ed.gov/pubs/NatAtRisk/
[103] U.S. Department of Labor, Secretary's Commission on Achieving Necessary Skills (1991). Retrieved from World Wide Web: http://wdr.doleta.gov/SCANS/
[104] Ravitz, J.L., Becker, H.J. & Wong, Y.
[105] Sivin-Kachala, J. & Bialo, E.R. (2000). "2000 Research Report on the Effectiveness of Technology in Schools," Software & Information Industry Association, p. 10.
Symonds, W.C., p. 128
[106] Heinecke, W.F., Blasi, L., Milman, N. & Washington, L., (1999). "New Directions in the Evaluation of the Effectiveness of Educational Technology," University of Virginia Curry School of Education, The Secretary's Conference on Educational Technology-1999
[107] Ravitz, J.L. & Becker, H. (1998). "When Does Project-Based Teaching Lead to Cognitive Challenge?" Data from the TLC 1998 National Survey
Reeves, T.C.
North Central Regional Educational Laboratory (NCREL).
[108] Sivin-Kachala, J. & Bialo, E.R. p. 106
[109] Schacter, J., "The Impact of Education Technology on Student Achievement, What the Most Current Research Has to Say." Retrieved from World Wide Web: http://www.mff.org/pubs/ME161.pdf
[110] Schacter, J., p. 5-6.
[111] Schacter, J., p. 8
[112] Center for Research on Information Technology and Organizations (1999). Teaching, Learning and Computing: 1998, A National Survey of Schools and Teachers. Retrieved from World Wide Web: http://www.crito.uci.edu/tlc/html/tlc_home.html
[113] Ravitz, J.L. & Becker, H.
[114] Ravitz, J.L. & Becker, H.
[115] Ravitz, J.L., Becker, H.J. & Wong, Y.
[116] Telephone interview, D. Gerber, Oct. 9, 2000.
[117] Telephone interview, E. O'Rourke, Oct. 9, 2000.
[118] McGrath, B. (April 1998). "Partners in Learning: Twelve Ways Technology Changes the Teacher-Student Relationship," *T.H.E. Journal*, p. 60
[119] McGrath, B., p. 58, E. O'Rourke, Oct. 9, 2000 interview
[120] Focus group, Sept. 13, 2000; telephone interviews Oct. 1, 7, 8, 2000.
[121] President's Committee of Advisors on Science and Technology, Panel on Educational Technology (1997).
[122] CEO Forum, "Teacher Preparation StaR Chart (2000). A Self-Assessment Tool for Colleges of Education. " Retrieved from World Wide Web: http://www.ceoforum.org/reports.cfm?RID=3
http://www.ceoforum.org/downloads/97report.pdf p. 5

[123] National Science Foundation, Interagency Educational Research Initiative: Retrieved from World Wide Web: http://www.ed.gov/offices/OERI/ieri.html
[124] National Science Foundation, Interagency Educational Research Initiative Award #REC-0089134
[125] Darling-Hammond, L. (1996). "What Matters Most: Teaching for America's Future," New York: National Commission on Teaching and America's Future
[126] "Workforce Economics," National Alliance of Business Occasional Report, Vol. 6, No. 1 Spring 2000, p. 10
[127] Miller, M., "Short Fall," 28 February 2000, *The New Republic*, February 28, 2000.
[128] Puma, M.J., Chaplin, D.D. & Pape, A.D. (2000). "E-Rate and the Digital Divide: A Preliminary Analysis From the Integrated Studies of Educational Technology (2000)." Retrieved from World Wide Web: http://www.ed.gov/offices/OUS/eval/elem.html#technology
[129] U.S. Department of Commerce, National Telecommunications and Information Administration (1998). "Falling Through the Net: Defining the Digital Divide. Retrieved from World Wide Web: http://www.ntia.doc.gov/ntiahome/fttn99/contents.html
[130] Miller, M.
[131] Becker, H.J., p. 11
[132] CEO Forum
U.S. Department of Education, OPE, "Preparing Tomorrow's Teachers to Use Technology (2000)." Retrieved from World Wide Web: http://www.ed.gov/teachtech/
National Council for Accreditation of Teacher Education (2000). "NCATE 2000 Unit Standards." Retrieved from World Wide Web: http://www.ncate.org/2000/2000stds.pdf
International Society for Technology in Education. "National Technology Standards (NETS) for Teachers Project." Retrieved from World Wide Web: http://cnets.iste.org/intro_side3.htm
[133]Becker, H.J. (1999). "Internet Use by Teachers: Conditions of Professional Use and Teacher-Directed Student Use." Retrieved from World Wide Web: http://www.crito.uci.edu/TLC/findings/Internet-Use/startpage.htm
[134] Symonds, W.C.
[135135] U.S. Department of Labor (1999). "Futurework: Trends and Challenges for Work in the 21st Century." Retrieved from World Wide Web: http://www.dol.gov/dol/asp/public/futurework/report/intro.htm

REFERENCES

American Association for the Advancement of Science. Benchmarks On-Line. Retrieved from World Wide Web: http://www.project2061.org/tools/benchol/bolframe.html

American Association for the Advancement of Science. "Project 2061 Science Literacy for a Changing Future." Retrieved from World Wide Web: http://www.project2061.org

Anderson, R.A. & Ronnkvist, A. (1999). "The Presence of Computers in American Schools." Teaching, Learning and Computing: A research project of the Center for Research and Information Technology and Organizations. Retrieved on the World Wide Web: http://www.crito.uci.edu/tlc/findings/computers_in_american_schools/

Baker, E. (1999). "Technology: How Do We Know It Works?" National Center for Research on Evaluation, Standards and Student Testing, UCLA. Retrieved from World Wide Web: http://www.ed.gov/Technology/TechConf/1999/whitepapers/paper5.html

Becker, H.J. (1999). "Internet Use by Teachers, Teaching, Learning and Computing," A research project of the Center for Research on Information Technology and Organizations. Retrieved from World Wide Web: http://www.crito.uci.edu/TLC/FINDINGS/internet-use/

Becker, H.J. (1999). "Internet Use by Teachers: Conditions of Professional Use and Teacher-Directed Student Use." Retrieved from World Wide Web: http://www.crito.uci.edu/TLC/findings/Internet-Use/startpage.htm

Becker, H.J., Ravitz, J. & Wong, YT (1999), "Teacher and Teacher-Directed Student Use of Computers and Software, Teaching, Learning and Computing," A research project of the Center for Research on Information Technology and Organizations. Retrieved from the World Wide Web: http://www.crito.uci.edu/tlc/findings/computeruse/

Becker, H.J., Wong, YT, & Ravitz (1999). "Computer Use and Pedagogy in Co-NECT Schools, A Comparative Study," University of California, Irvine.

Center for Research on Information Technology and Organizations (1999). Teaching, Learning and Computing: 1998, A National Survey of Schools and Teachers. Retrieved from World Wide Web: http://www.crito.uci.edu/tlc/html/tlc_home.html

CEO Forum, "Teacher Preparation StaR Chart (2000). A Self-Assessment Tool for Colleges of Education. " Retrieved from World Wide Web: http://www.ceoforum.org/reports.cfm?RID=3 http://www.ceoforum.org/downloads/97report.pdf

Darling-Hammond, L. (1996). "What Matters Most: Teaching for America's Future," New York: National Commission on Teaching and America's Future

Edelson, D., Gomez, L., Polman, J., Gordin, D., & Fishman, B. (1994). "Scaffolding Student Inqujiry with Collaborative Visualization Tools. School of Education and Social Policy, Northwestern University. Retrieved from World Wide Web: http://www.covis.nwu.edu/info/papers/pdf/edelson-gomez-aera-94.pdf

Education Market Research, Rockaway Park, N.Y. "Education Week's 1999 National Survey of Teachers' Use of Digital Content." Technology Counts '99. Retrieved from World Wide Web: http://www.edweek.org/sreports/tc99/articles/survey.htm

Education Week on the Web. "Technology Counts '98," October 1, 1998. Retrieved from World Wide Web: http://www.edweek.com/sreports/tc98/

Education Week on the Web. "Technology Counts '98: Building the Digital Curriculum," October 1, 1998. Retrieved from World Wide Web: http://www.edweek.com/sreports/tc90/

Friedman, E.A., McGrath, & Baron J. (1997). "Web Adventures in K-12 Science." Winter 1997. Technos, Vol. 6, No. 4.

Green, J., "No Lectures or Teachers, Just Software," 10 August 2000, *New York Times*

Guernsey, L., "For the New College B.M.O., 'M' Is for 'Machine,'" 10 August 2000, The New York Times

Hafner, K., The Modern Student: Batteries Not Included," 10 August 2000, The New York Times

Heinecke, W.F., Blasi, L., Milman, N. & Washington, L., (1999). "New Directions in the Evaluation of the Effectiveness of Educational Technology," University of Virginia Curry School of Education, The Secretary's Conference on Educational Technology-1999

Honey, M., McMillan Culp, K., & Carrigg, F. (1999). "Perspectives on Technology and Education Research: Lessons from the Past and Present." Retrieved from World Wide Web: http://www.ed.gov/Technology/TechConf/1999/whitepapers/paper1.html

International Society for Technology in Education. "National Technology Standards (NETS) for Teachers Project." Retrieved from World Wide Web: http://cnets.iste.org/intro_side3.htm

Kominski, R. & Newburger, E., U.S. Census Bureau, Population Division (1999). "Access Denied: Changes in Computer Ownership and Use: 1994-1997". Retrieved from World Wide Web: http://www.census.gov/population/socdemo/computer/confpap99.pdf

Leibovich, L., "Choosing Quick Hits Over the Card Catalog," 10 August 2000, The New York Times

Lewis, P.H., "PC 101: Pitfalls to Avoid," 10 August 2000, The New York Times

Market Data Retrieval. "Successful school marketing starts here." Retrieved from World Wide Web: www.schooldata.com

McGrath, B. (April 1998). "Partners in Learning: Twelve Ways Technology Changes the Teacher-Student Relationship," *T.H.E. Journal*

Miller, M., "Short Fall," 28 February 2000, *The New Republic*, February 28, 2000.

National Commission on Excellence in Education (1983). "A Nation at Risk: The Imperative for Educational Reform." A Report to the Nation and the Secretary of Education, U.S. Department of Education. Retrieved from World Wide Web: http://www.ed.gov/pubs/NatAtRisk/

National Council for Accreditation of Teacher Education (2000). "NCATE 2000 Unit Standards." Retrieved from World Wide Web: http://www.ncate.org/2000/2000stds.pdf

North Central Regional Educational Laboratory (NCREL). "Critical Issue: Using Technology to Improve Student Achievement." Retrieved from World Wide Web: http://www.ncrel.org/sdrs/areas/issues/methods/technlgy/te800.htm

North Central Regional Educational Laboratory, "Phase III: Data-Driven Virtual Learning." Retrieved from World Wide Web: http://www.ncrel.org/tplan/cbtl/phase3.htm

Northwestern University (1998). "Learning Through Collaborative Visualization." Retrieved from World Wide Web: http://www.covis.nwu.edu

North Western University (1996). “Learning Through Collaborative Visualization, A National Science Education Collaboratory: Overview of the CoVis Project.” Retrieved from World Wide Web: http://www.covis.nwu.edu/info/papers/pdf/covis-2page-overview.pdf

President’s Committee of Advisors on Science and Technology, Panel on Educational Technology (1997). “Report to the President on the Use of Technology to Strengthen K-12 Education in the United States.” Retrieved from the World Wide Web: http://www.whitehouse.gov/WH/EOP/OSTP/NSTC/PCAST/k-12ed.html

Puma, M.J., Chaplin, D.D. & Pape, A.D. (2000). “E-Rate and the Digital Divide: A Preliminary Analysis From the Integrated Studies of Educational Technology (2000).” Retrieved from World Wide Web: http://www.ed.gov/offices/OUS/eval/elem.html#technology

Ravitz, J.L. & Becker, H. (1998). “When Does Project-Based Teaching Lead to Cognitive Challenge?” Data from the TLC 1998 National Survey

Ravitz, J.L., Becker, H.J. & Wong, Y. (2000). “Constructivist-Compatible Beliefs and Practices among U.S. Teachers.” Retrieved from World Wide Web: http://www.crito.uci.edu/TLC/FINDINGS/REPORT4/body_startpage.html

Reeves, T.C., (1998). “The Impact of Media and Technology in Schools,” A Research Report prepared for The Bertelsmann Foundation. Retrieved from World Wide Web: http://www.athensacademy.org/instruct/media_tech/reeves0.html

Ronnkvist, A.M., Dexter, S.L. & Anderson, Ronald E. (2000). “Technology Support: Its Depth, Breadth and Impact in America’s Schools, Teaching, Learning and Computing,” a research project of the Center for Research on Information Technology and Organizations. Retrieved from World Wide Web: http://www.crito.uci.edu/tlc/findings/technology-support/ America's schools.

Rowand, C. (2000). “Teacher Use of Computers and the Internet in Public Schools.” Retrieved from World Wide Web: http://nces.ed.gov/pubsearch/pubsinfo.asp?pubid=2000090

Rowand, C., (1999). “Internet Access in Public Schools and Classrooms: 1994-98,” National Center for Education Statistics. Retrieved from World Wide Web: http://nces.ed.gov/pubsearch/pubsinfo.asp?pubid=1999017

Schacter, J., “The Impact of Education Technology on Student Achievement, What the Most Current Research Has to Say.” Retrieved from World Wide Web: http://www.mff.org/pubs/ME161.pdf

Sivin-Kachala, J. & Bialo, E.R. (2000). “2000 Research Report on the Effectiveness of Technology in Schools,” Software & Information Industry Association

Smerdon B. & Cronen, S. (2000). “Teachers’ Tools for the 21st Century: A Report on Teachers’ Use of Technology,” National Center for Education Statistics. Retrieved from the World Wide Web: http://nces.ed.gov/spider/Webspider/2000102.shtml

Software & Information Industry Association, “Education Market Report 2000: K-12,” Washington, D.C., 2000

Symonds, W.C., “Wired Schools,” 25 September 2000, *Business Week*

TIMSS, Boston College (1998). “Mathematics and Achievement in the Final Year of Secondary School: IEA’s Third International Mathematics and Science Report.” Retrieved from World Wide Web: http://timss.bc.edu/TIMSS1/MathScienceC.html

U.S. Census Bureau. “Computer Use in the United States: October 1993.” Retrieved from World Wide Web: http://www.census.gov/population/socdemo/computer/report93/comp1.txt

U.S. Census Bureau. "Households with Computers and Year of Purchase by Presence of Children, Family Income, and Age of Householder: October 1997". Retrieved from U.S. Census Bureau, October 14, 1999 release on World Wide Web: http://www.census.gov/population/socdemo/computer/report97/tab01.pdf

U.S. Census Bureau. "Purpose of Computer Use at Home by People 3 to 17 Years: October 1997." Retrieved from World Wide Web: http://www.census.gov/population/socdemo/computer/report97/tab05.txt

U.S. Census Bureau. "Purposes and Frequency of Computer Use at Home by Persons 3 to 17 Years Old: October 1989." Retrieved from U.S. Census Bureau release on World Wide Web: http://www.census.gov/population/socdemo/computer/p23-171/tab03.pdf

U.S. Department of Commerce, Bureau of the Census, Current Population Survey, October 1997. "Access to home computers, by selected characteristics of students and other users." Retreived from World Wide Web: http://nces.ed.gov/pubs2000/digest99/d99t431.html

U.S. Department of Commerce, National Telecommunications and Information Administration (1998). "Falling Through the Net: Defining the Digital Divide. Retrieved from World Wide Web: http://www.ntia.doc.gov/ntiahome/fttn99/contents.html

U.S. Department of Commerce, National Telecommunications and Information Administration (1998). "Percent of U.S. Households with a Computer By Income By Rural, Urban, and Central City Areas." Retrieved from World Wide Web: http://www.ntia.doc.gov/ntiahome/fttn99/FTTN_I/Chart-I-12.html

U.S. Department of Commerce, National Telecommunications and Information Administration. "Percent of U.S. Households with a Modem By Income 1989-1997 (Selected Years)." Retrieved from World Wide Web: http://www.ntia.doc.gov/ntiahome/fttn99/App_III/Chart-A-f.html

U.S. Department of Commerce, National Telecommunications and Information Administration. "Percent of U.S. Households Using the Internet By Income By U.S., Rural, Urban and Central City Areas, 1998." Retrieved from World Wide Web: http://www.ntia.doc.gov/ntiahome/fttn99/FTTN_I/Chart-I-21.html

U.S. Department of Commerce, National Telecommunications and Information Administration. "Percent of U.S. Households with a Computer/Web TV® Accessing the Internet At Home." 1998. Retrieved from World Wide Web: http://www.ntia.doc.gov/ntiahome/fttn99/InternetUse_II/Chart-II-24ab.html

U.S. Department of Commerce, National Telecommunications and Information Administration. "Percent of U.S. Persons Using the Internet at Home By Income By Type of Use." 1998. Retrieved from World Wide Web: http://www.ntia.doc.gov/ntiahome/fttn99/InternetUse_II/Chart-II-33.html

U.S. Department of Commerce, National Telecommunications and Information Administration. "Percent of U.S. Persons Using E-Mail at Home by Subject Matter By Age." 1998. Retrieved from World Wide Web: http://www.ntia.doc.gov/ntiahome/fttn99/InternetUse_II/Chart-II-48.html

U.S. Department of Education, OPE, "Preparing Tomorrow's Teachers to Use Technology (2000)." Retrieved from World Wide Web: http://www.ed.gov/teachtech/

U.S. Department of Education, The Condition of Education 1998, Supplemental Table 37-2, "Percentage of students who reported watching television, by grade, hours per day, and selected characteristics: 1996." Retrieved from National Center for Education Statistics, National Assessment of Educational Progress, Summar6y Data Tables: Math 1996 release on World Wide Web: http://nces.ed.gov/pubs98/condition98/c9837d02.html

U.S. Department of Labor (1999). "Futurework: Trends and Challenges for Work in the 21st Century." Retrieved from World Wide Web: http://www.dol.gov/dol/asp/public/futurework/report/intro.htm

U.S. Department of Labor, Secretary's Commission on Achieving Necessary Skills (1991). Retrieved from World Wide Web: http://wdr.doleta.gov/SCANS/

University of Minnesota (1992). "Computers in American Schools, 1992." A Report of the IEA Computers in Education Study. Retrieved from World Wide Web: http://hera.soc.umn.edu/research/synopsis.htm

Valdez, G., McNabb, M., Foertsch, M., Anderson, M., Hawkes, M. & Raack, L. "Computer-Based Technology and Learning: Evolving Uses and Expectations," North Central Regional Educational Laboratory. Retrieved from World Wide Web: http://www.ncrel.org/tplan/cbtl/toc.htm

Williams, C. "Internet Access in U.S. Public Schools and Classrooms: 1994-1999," National Center for Education Statistics. Retrieved from World Wide Web: http://nces.ed.gov/pubsearch/pubsinfo.asp?pubid=2000086

"Workforce Economics," National Alliance of Business Occasional Report, Vol. 6, No. 1 Spring 2000