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ABSTRACT

This report presents findings from a national study of the relationship between different uses of educational technology and various educational outcomes. Data were drawn from the 1996 National Assessment of Educational Progress (NAEP) in mathematics, consisting of national samples of 6,227 fourth graders and 7,146 eighth graders. Data include information on the frequency of computer use for mathematics in school, access to computers at home and in school, professional development of mathematics teachers in computer use, and the kinds of instructional uses of computers in the schools. The study finds that the greatest inequities in computer use are not in how often they are used, but in the ways in which they are used. Poor, urban, and rural students are less likely to be exposed to higher order uses of computers than nonpoor and suburban students. For both fourth and eighth grades, teachers of urban and rural students are less likely to have had professional development in technology than suburban teachers. There were few differences in the frequency of school computer use in either grade, although black fourth graders reported more frequent use than white fourth graders. Yet for both grades, black students were less likely to have a computer at school. In essence, the study found that technology could matter, but that this depended on how it was used. The size of the relationship between the various positive uses of technology and academic achievement was negligible for fourth graders, but substantial for eighth graders. Taken together, findings indicate that computers are neither a cure-all for problems facing the schools nor mere fads without impact on student learning. When used properly, computers may serve as important tools for improving student proficiency in mathematics and the overall learning environment of the school. An appendix discusses how the study was conducted. (Contains 2 tables, 14 figures, and 23 references.) (SLD)

Does It Compute?

The Relationship Between Educational Technology and Student Achievement in Mathematics

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This report was written by Harold Wenglinsky of the ETS Policy Information Center.

The views expressed in this report are those of the author and do not necessarily reflect the views of the officers and trustees of Educational Testing Service.

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PREFACE

In this age of technological imperative, we do it simply because it can be done. Massive efforts are underway to convert traditional teaching to something that can be delivered via computer. Measuring success has been a simple matter: count the number of computers, divide that by the number of students, and report how the ratio of computers to students has advanced—and it is always advancing. Then close the report lamenting that we don't know much about the software being used on these computers, we don't know how many are behind locked doors, we don't know how many are broken, and we don't know how many teachers really know how to use them (there are no assessments of teacher capability here).

The Policy Information Center reported in May of 1997 what we did know at that time, in *Computers and Classrooms*. We said then that the available data, and the research performed on it, did not tell us whether computer-delivered instruction actually improved performance. This report takes at least the first step in determining whether computer use is making a difference in mathematics, and what kind of computer use has what kind of effect, on which groups of students.

This study uses a national database, the 1996 National Assessment of Educational Progress, and advanced analysis techniques, to isolate the effects of the computer from the myriad other factors involved in student achievement. The study was suggested to us by *Education Week*, and its author, Harold Wenglinsky, of the ETS Policy Information Center, has collaborated with the staff of *Education Week* throughout the analysis and writing phases of the report.

In addition to telling us what he found, Harold Wenglinsky also tells us what further research must be conducted to learn more, and give the nation specific guidance in its efforts to raise educational achievement through greater use of technology.

Paul E. Barton
Director
Policy Information Center

ACKNOWLEDGMENTS

This project involved a close collaboration between myself and the many people working on *Technology Counts*, a yearbook on educational technology funded by the Milken Family Foundation and published by *Education Week*. Indeed, the study was inspired by a concern at *Technology Counts* that there was a lack of national information on the relationship between various aspects of educational technology and academic achievement. I am indebted to the *Technology Counts* staff for their ongoing and timely feedback on the project, particularly Craig Jerald, Virginia Edwards, and Jeffrey Archer. Such a collaboration between researchers and journalists, sometimes referred to as computer-assisted journalism, is a critical tool for making available to the public the fruits of statistical analyses of large-scale databases.

Many others also contributed to this project. Stephen Gorman, John Barone, John Mazzeo, and Alfred Rogers facilitated access to the data. Henry Jay Becker, Ellen Mandinach, and Paul Barton provided thorough and timely reviews of the draft report. Richard Coley assisted in producing the figures. Carla Cooper provided desktop publishing services. Kirsty Brown did the editing, Kelly Gibson was the cover designer, and Jim Chewning coordinated production. Any errors of fact or interpretation included in this report, however, are my responsibility.

SUMMARY OF FINDINGS

This report presents findings from a national study of the relationship between different uses of educational technology and various educational outcomes. Data were drawn from the 1996 National Assessment of Educational Progress (NAEP) in mathematics, consisting of national samples of 6,227 fourth-graders and 7,146 eighth-graders. NAEP includes information on educational technology, including:

- frequency of computer use for mathematics in the school;
- access to computers and frequency of computer use in the home;
- professional development of mathematics teachers in computer use;
- kinds of instructional uses of computers by mathematics teachers and their students

NAEP also includes various outcomes of education that are highly valued by policymakers and the public at large, including: academic achievement in mathematics as measured by a standardized test; and the social environment of the school, including student tardiness and absenteeism, teacher absenteeism, teacher morale, and student regard for school property.

The study first compared the information about educational technology among different groups of students to discover any possible inequities in technology use. It found that the greatest inequities did not lie in how often computers were used, but in how they were used.

- For eighth-graders only, Black students were less likely to be exposed to higher-order uses of computers and more likely to be exposed to lower-order uses than White students. Similarly, poor, urban, and rural students were less likely to be exposed to higher-order uses than non-poor and suburban students.
- For both eighth- and fourth-graders, urban and rural students were less likely to have mathematics teachers who had received professional development in technology over the last five years than suburban students. For eighth-graders, poor students were less likely to have mathematics teachers who had received such professional development than non-poor students.
- There was little difference in the frequency of school computer use in either grade, except that Black fourth-graders reported more frequent school computer use than White fourth-graders.
- For both eighth- and fourth-graders, Black students were less likely to have access to a home computer than White students. Similarly, poor, urban, and rural students were less likely to have access to a home computer than non-poor and suburban students.

The study then related these different aspects of technology to the educational outcomes, taking into account differences in student bodies and the other characteristics of the schools being analyzed. In essence, the study found that technology could matter, but that this depended upon how it was used. For eighth-graders, the study found that:

- Teacher's professional development in technology and the use of computers to teach higher-order thinking skills were both positively related to academic achievement in mathematics and the social environment of the school.
- The frequency of home computer use was positively related to academic achievement and the social environment of the school.
- The use of computers to teach lower-order thinking skills was negatively related to academic achievement and the social environment of the school.
- The frequency of school computer use was unrelated to the social environment of the school and negatively related to academic achievement.

For fourth-graders, the study found that:

- Using computers for learning games was positively related to academic achievement and the social environment of the school.

- By increasing the tendency of teachers to use computers for learning games, professional development of teachers was also positively related to academic achievement and the social environment of the school.

- The frequencies of home and school computer use were negatively related to academic achievement and the social environment of the school.

The size of the relationships between the various positive uses of technology and academic achievement was negligible for fourth-graders but substantial for eighth-graders. For fourth-graders, professional development and using computers for learning games each contributed about a tenth of a grade level of academic achievement, or the equivalent of a few weeks of instruction. For eighth-graders, however, professional development and using computers for higher-order thinking skills were each associated with more than a one-third of a grade level increase.

These findings come with certain caveats. First, the data were collected at a single point in time; the aspects of technology studied here occurred at the same time as the educational outcomes of interest. Thus, it may be that high-achieving students are more likely to use technology in certain ways rather than that these uses of technology promote high levels of academic achievement. Second, while the study takes into account some characteristics of teachers, it does not take into account their overall tendency to teach in certain ways, such as to teach higher-order thinking skills. It may be that computers are but one medium among many that teachers use to teach higher-order thinking skills, and that all of these media are conducive to high levels of academic achievement.

All of this suggests that computers are neither cure-alls for the problems facing schools, nor mere fads that have no impact on student learning. Rather, when they are properly used, computers may serve as important tools for improving student proficiency in mathematics, as well as the overall learning environment in the school.

INTRODUCTION

In recent years, educational technology has become a cornerstone for state and federal efforts to improve the performance of the nation's school children. "Educational technology" generally refers to the introduction of computers and related pieces of equipment to the classroom. Across the nation, governors have targeted a large share of their education budgets to making computers more available in schools. George Pataki, governor of New York, and Pete Wilson, governor of California, have asked their state legislatures for millions of dollars to purchase new computers for schools and train teachers to use them. Some states are taking a top-down approach, bringing the decision-making skills and computer expertise of the state government to bear to move technology to the classroom as quickly and inexpensively as possible. West Virginia, for example, purchased computers in bulk and sent them to school districts; the state is also responsible for teacher training. Other states are providing the funds but allowing school districts to make the decisions. Kentucky, for instance, required each school district to develop its own technology plan and make its own purchases of software and hardware with state funds (see White, 1997).

State efforts to increase access to technology have been complemented by federal action. In 1996, President Clinton and Vice President Gore announced the Technology Literacy Challenge. The overarching goal of the program was to ensure that all students had access to educational technology. Clinton and Gore identified four pillars of technological literacy, namely modern computer hardware, the Internet, teacher development, and high-quality software and online resources. The Technology Literacy Challenge Grants have been awarded to states to help them provide these elements. This and other funding from the Federal Government has resulted in a federal contribution of 25 percent of all dollars spent on educational technology. To further assist in meeting the goal of connecting students to the Internet, the Clinton Administration initiated the E-Rate program, which requires the telecommunications industry to contribute dollars to a fund to support school and library Internet access (U.S. Department of Education, 1996).

Yet with all of this money being spent on educational technology, many policymakers are wondering about the evidence on its effectiveness. The purpose of providing technology to schools is to improve student academic performance and other educational outcomes, not to provide state-of-the-art equipment for its own sake. What types of investment in technology most improve academic achievement? Does technology affect important educational outcomes at all? Unfortunately, for all of the investment in educational technology, there is a surprising lack of hard data on its effects. State data collection efforts are sketchy at best, and the federal government does not collect national data expressly for the purpose of evaluating educational technology. Prior research on computers in the classroom consists primarily of evaluations of exemplary programs; these studies have significant methodological problems, and it is highly questionable whether the programs can be replicated on a large scale.

Fortunately, a great deal of information can be gleaned from the most recent National Assessment of Educational Progress (NAEP) for which data are now available. NAEP consists of tests in various subject areas administered to national samples of students. It is generally given every two years, and is used to measure trends in student performance over time, as well as between subgroups of students such as males and females. NAEP also includes questionnaires given to students, their teachers, and their principals, to put the NAEP test scores in their educational context. The 1996 NAEP, for the first time, included detailed questions on technology in its questionnaires. By examining these questions and relating them to students' test scores and other characteristics of students, teachers, and schools, it is possible to learn a great deal about the effectiveness of technology across the nation.

This report presents the results of a national study of technological effectiveness using the NAEP in mathematics. It finds that technology can indeed be effective in increasing mathematics achievement and other educational outcomes, but that this effectiveness depends upon how technology is used. The report is organized as follows:

- Chapter One presents the debate on technology's effectiveness. It then discusses what the prior research says on this issue, and finds it to suffer from methodological problems that limit its usefulness to the debate.

- Chapter Two presents descriptive information about access to and use of educational technology by our nation's schoolchildren, particularly for mathematical tasks. It finds that large government investments in technology have eliminated gaps in access to and frequency of use of computers, but that large gaps in teacher preparation and the ways in which technology is used in the classroom remain.

- Chapter Three presents the results of a statistical analysis of the relationship between technology, academic achievement in mathematics, and other educational outcomes. It finds that the usefulness of technology depends upon how the technology is used; some uses are positively related to academic achievement and other educational outcomes, while others are not.

- Chapter Four discusses the methodological shortcomings of this study and suggests some implications of the study's findings for policymakers and practitioners.

Chapter One: The Debate on Technology's Effectiveness

The penetration of computers into the life of schools is a fact few could deny. The availability of computers nationally has increased dramatically in recent years, from a computer for every 125 students in 1983 to a computer for every 9 students in 1995 (Glennan & Melmed, 1996). Many schools now have one computer for every two students. Yet the response of educators and practitioners has been mixed. Some have been quite enthusiastic about technology, seeing it as the tool most needed to facilitate more comprehensive educational reform. Others see it as a passing fad, more a distraction from school reform than anything else. Not all advocates and critics subscribe to the views paraphrased below; these are simply illustrations of a few of the prevailing views regarding technology.

The Case for Technology

Advocates of technology argue for using technology for the wholesale transformation of the classroom.[1] They note that computers and supporting technologies have any number of uses. These are generally of five types: support for individual learning, group learning, and instructional management; communication; and administration. Applications to individual learning include drilling students on particular skills, using CD-ROMs or the Internet to find resources not available in the school, communicating with experts, word-processing, providing assistance in computations, and demonstrating simulations of mathematical or scientific concepts. Group learning applications include using e-mail to support group communication, using presentation software to allow group presentations on a project, and providing collaboration in collecting and analyzing data. Applications to instructional management include integrating standards and assessments, managing student portfolios, and developing individual student learning plans. Communications applications include communicating to remote locations such as rural schools and improving communication among students, teachers, and parents. Finally, applications to administrative functions include supporting attendance and accountability functions.[2] Clearly, using technology in all of these ways would result in the penetration of technology into every aspect of the school day, theoretically making conventional teaching techniques obsolete.

This vision has been applied, to some degree, in various innovative schools. Blackstock Junior High School in California, for instance, developed "smart" classrooms, in which each student has a computer, and these are on a network. The teacher can thus allow students to work either independently or in groups over the network. The school also developed the Tech Lab 2000 to provide even more sophisticated facilities, such as Computer Assisted Design software, a Computer Numerically Controlled flexible manufacturing system, and even a satellite dish. Even

[1] The case of technology presented here draws heavily on Glennan & Melmed (1996). Also, see page 9 for examples of studies supporting technology.

[2] An alternate schema for categorizing uses of technology can be found in Becker (1994a).

non-smart classrooms are technology-rich, with 10 computers and two printers per room. Other innovative schools have similarly technology-rich layouts. Northbrook Middle School in Texas has one computer for every two students; each classroom has five to six computers, complete with CD-ROM capabilities, a school-wide network, and Internet access.

The primary indicator used by technology advocates to assess whether a school is using technology well is how much hardware and software has actually reached the classroom. Innovative schools are identified based upon their student-to-computer ratios, the sophistication of their networks and peripherals, as well as the amount of money spent per-pupil on technology. In this view, transformation of educational practice requires a high level of access to technology; without such access, technology is educationally marginalized, rather than being an essential feature of instruction. Thus a given school is not likely to be effective in its uses of technology unless there is a substantial technological infrastructure.

In terms of the actual effects of technology on academic achievement and other educational outcomes, advocates assert that most uses of technology are beneficial, and that they can lead to improvements in most or all educational outcomes. They cite three pieces of evidence. First, they note that computers have been used to provide students with opportunities for drill and practice since the 1960s. This use, known as Computer Assisted Instruction (CAI) has been evaluated repeatedly, and the evaluations suggest that CAI students demonstrate higher levels of academic achievement than their counterparts who do not have CAI. Second, advocates note that more recent uses of technology, such as those that support higher-order thinking skills, have not been as widely evaluated, but the few evaluations done, such as that of Apple Computers of Tomorrow, show promising results. Finally, they note that technology-rich schools seem to evince gains in achievement and other educational outcomes such as student motivation and teacher morale.

The Case against Technology

Others have been quite critical of technology. They agree with the advocates that the goal of spreading educational technology is to use it to transform instruction; the critics, however, view this effort as being doomed to failure.[3] Their indicator for the success of technology programs is not the amount of technology available, but whether teachers are willing to use it. No matter how many computers are available in the classroom, if teachers are unwilling to use them for instruction, they are unlikely to have much impact on students. And, in the view of the critics, teachers are by-and-large not making use of computers. Schools tend to have a few teachers and administrators who are advocates of technology and use it widely. The majority of teachers, however, use technology as little as possible; they only do as much with computers as administrators require of them.

The critics do not claim that teacher obstruction of technology is detrimental to schooling, but quite the opposite. They regard technology as unlikely to improve academic achievement or indeed any other educational outcome of students. In support of this view they present three pieces of evidence: the history of technological innovation, research on the cost-effectiveness of CAI, and evidence on theories of learning. First, they note that teachers have historically been resistant to technological innovations when those innovations have made it more difficult for them to get through the typical school day. Early technologies, such as blackboards and desks, were supported by teachers because they made it easier for them to manage the

[3] The case against technology presented here draws heavily on Cuban (1986) and Cuban (1993). See pages 9 and 10 of this report for examples of studies criticizing technology.

classroom and convey information. Later innovations, such as films and educational television were resisted because they would undermine the teacher-student relationship; to the extent that these technologies would substitute for teachers, teachers would have less time to interact with students. Indeed, the only situations in which teachers embraced this technology were those in which teachers wanted to reduce interaction with students; for instance, when teachers wanted to waste time during low-energy periods of the day (e.g. after lunch) they might show a film. Computers, the critics claim, pose these same issues and therefore will be marginalized or not used at all by teachers.

Second, research on the cost-effectiveness of CAI shows that while there may be some gains to academic achievement, these are not proportionate to the costs of buying and maintaining computers; tutoring, for instance, was found to produce greater gains for less money.

Finally, cognitive theories of education suggest that learning may include a social, noncognitive element. Students learn not only because they process information, but also because of the complex reinforcements they receive from teachers and the socialization process in which learning is embedded. As computers move from being mere supplements to being the core of the learning environment, they limit opportunities for social interaction, thus interfering with the learning process. Hence computers should not be expected to increase student learning and, in fact, may decrease it.

The Evidence on Technology's Effectiveness

There are some problems with the assertions made by both advocates and critics regarding the relationship between technology and educational outcomes. With regard to the advocates, the CAI evaluations of drill and practice computer applications, the evaluation of higher-order applications and the data from the exemplary programs suffer from certain methodological problems that raise questions about their findings.[4] First, they treat technology as an undifferentiated characteristic of schools and classrooms. No distinction is made between different types of technology program, such as programs that involve intensive professional development or those that focus on higher-order thinking skills. Without differentiating between program components, it is not clear which are responsible for overall program effectiveness; it may be that some uses of technology are more productive than others. Second, these evaluations focus on a school or school district, but never on statewide or nationwide uses of technology. It may be that what works well in Chicago will not work well in New York City. Third, evaluations often use a poor measure of academic achievement; many use tests that have been developed for that particular study and have not been validated. Fourth, the students in technology-rich environments may be very different from those in more conventional settings. Many of these studies do not randomly assign students to different environments, and some do not even have a group of students in a conventional environment to whom to compare the students using technology. Apparent gains in achievement may therefore be attributable to the student rather than the school. These problems make the conclusion from these studies, that technology is positively associated with academic achievement, questionable.[5]

The evidence of the critics also raises difficulties. The historical argument that teachers obstruct technology because it is not useful

[4] For reviews of CAI, see Kulik & Kulik (1991), Niemiec et al. (1987), Liao (1992), and Christmann, Badgett & Lucking (1997). The reviews generally find significant differences in academic achievement and other outcomes between students exposed to CAI and those exposed to conventional teaching techniques, but find that these differences vary dramatically depending upon study methodology, with some studies finding no difference or even a negative relationship.

[5] For an example of a critique of CAI research, see Colorado (1988).

assumes that computers have as little use for education as film strips or educational television. To the extent that computers differ from these technologies, they should be embraced by teachers. Indeed, research on teacher obstruction indicates that the inability of many teachers to use computers is based upon a lack of resources supporting teacher use of technology, not a Luddite feeling among teachers that technology is useless. Henry J. Becker (1994b) analyzed data from one of the most comprehensive surveys of teacher technology use, the International Association for the Evaluation of Educational Achievement survey of 1989. Among the more than 1,000 teachers surveyed, Becker did find both low levels of computer use and low levels of effective use; only one of six teachers used computers regularly in the classroom, and of these, a majority used them mostly for drill and practice, avoiding more complicated applications. (Just 16 percent of mathematics teachers used computers for conveying "understanding of numerical relationships" as opposed to 58 percent using them for "student mastery of computation.") Yet when he tried to account for different types and levels of computer use by teachers, Becker found that teachers using computers more effectively were more likely to work in schools offering high levels of teacher development on computers and having technology coordinators available to assist teachers with ongoing problems. A more recent study found that the primary reason teachers were afraid of technology was a lack of experience using computers (Rosen & Weil, 1995). Thus teacher obstruction is not an insurmountable barrier to computer use; teachers simply need to be trained and supported before they will feel ready to use them.

The critics also argue that the CAI studies show computers to be less cost-effective than tutoring, and that technology-based education undermines the social, noncognitive components of learning.[6] The problems with CAI studies have already been discussed; regarding the social aspects of learning, it can only be said that the impact of computers on learning depends upon how they are used. If they substitute entirely for human interaction, then they may indeed undermine social components of instruction. On the other hand, if they are one important tool among many, they will still permit a great deal of face-to-face contact between students and teachers.

At this point, then, the debate on technology's effectiveness seems unresolved, leaving policymakers wondering about how to use technology or, indeed, whether to invest in it at all. Research in support of technology seems to consist of small-scale studies with serious methodological problems; research against technology is based upon unproved assertions that computers are no different from film strips.

To some degree, the paucity of clear evidence on technology's effectiveness stems from difficulties inherent in its study. As Mandinach and Cline (in press) have noted, the lack of controlled experiments in this area reflects the fact that technology is not introduced over a well-defined period of time. Most experiments involve a specific intervention with a clear beginning and end. The introduction of technology, however, involves obtaining hardware and software, training teachers, modifying curricula, and maintaining the technology, among other things. This process is therefore an ongoing one, without a clear starting or stopping point. Mandinach and Cline suggest that evidence on technology's effectiveness will have to be drawn from various nonexperimental approaches, using multiple methods at various levels (e.g. the classroom, the school, the district).

[6] The study showing the differential cost-effectiveness of various interventions is reported in Levin, Desther & Meister (1986).

This report represents one method of studying technology that can, perhaps, help break the statemate between technology's advocates and critics. It presumes that the reality of technology's effectiveness lies somewhere between the optimism of advocates and the pessimism of critics. Some uses of technology are probably conducive to academic achievement and other positive educational outcomes, while other uses of technology are not. The report analyzes national data on technology that can distinguish between practices that are effective and those that are not, while also addressing some of the shortcomings of prior research. Before relating patterns of technology use to academic achievement, however, it will be useful to examine those patterns.

Chapter Two: Patterns of Educational Technology Use

The purpose of this chapter is to describe how computers are used by students and to compare usage between different types of students. Four key indicators of computer use are discussed here:

- student access to computers in school for mathematical tasks;
- student access to computers and frequency of computer use at home;
- preparedness of mathematics teachers in computer use;
- the ways in which the mathematics teachers and their students use computers.

In addition to knowing the state of the nation in regard to these four indicators, it is important to know how they are distributed among different types of students. There may be large differences in computer access among students, and these differences may have important policy implications; if minority students, for instance, have less access to teachers who have received training on computers, it might be important to increase teacher training in schools with high proportions of minority students. Six types of subgroups of students are particularly worth examining, as they appear frequently in policy discussions:

- Ethnicity
- Gender
- Region of the country
- Governance of school (public *vs.* private)
- Economic status (poor *vs.* non-poor)
- Community status (urban, suburban, rural)

Data and Measures

The state of technology use can be measured from data from the National Assessment of Educational Progress of 1996 (NAEP). NAEP has been administered regularly since 1969 to nationally representative samples of students of various ages and grade levels. The core of NAEP is an assessment that has been given in various subject areas including mathematics, science, reading, geography, and writing. NAEP also includes background questionnaires completed by students, the principals in their schools, and the teachers in the relevant subject area. Students and teachers are asked about their social background, their experiences in school generally, and their experiences in the particular subject area; principals are asked primarily about school policies and practices. While earlier administrations of NAEP did include a few questions about technology, only the 1996 administrations included sufficient information to measure the four indicators listed above. In 1996 NAEP was administered to fourth-, eighth- and twelfth-graders in mathematics and science. This report describes technology uses among the 6,627 fourth-graders and 7,146 eighth-graders who took the core NAEP assessment in mathematics.

Student access to computers in school is measured by frequency of computer use. Often researchers use the ratio of computers to students or the level of spending as an indicator of access. Yet computers may be sitting in closets, or in classrooms unused. Thus, to avoid questions of whether school ownership of computers is the same as student access, frequency of use by students is measured instead; use weekly or more often is deemed to be true access because less frequent use suggests that computers act more as filler than as part of the curriculum. For this study, student reports of computer use rather than teacher reports are used, because of how the relevant questions are asked in NAEP. Students are asked: "When you do mathematics at school how often do you...use a computer?" Teachers are asked "How often do students in this class...use a computer?" Students are thus responding with the frequency with which they use computers specifically for mathematics. Teachers are responding with the frequency with which students in their class are using computers. For eighth-graders, the teacher most likely teaches mathematics only, and so the responses would reflect student computer use in mathematics only, but for fourth-graders the teacher probably teaches the same students in a variety of subjects, and so the responses would reflect computer use more generally, thus overstating mathematically oriented use. Student responses are measured to avoid this difficulty. Student access to a computer at home is also measured by frequency of use. Whether students' families own computers is also included, because the NAEP question on frequency of home use includes the family not owning a computer as a choice. This information comes from the student questionnaire.[7]

Teacher preparedness is measured by whether teachers have received professional development in computer use. Presumably, teachers who receive training on computers are better prepared than those who do not; the Becker study reinforces this notion, finding that teachers who receive training that is subject-specific or tool-oriented are indeed exemplary users of educational technology. The alternative is to use teachers' perceptions of their preparedness, which is asked in NAEP. Yet these perceptions of preparedness might not reflect reality; teachers could think they are prepared but may not be. Also, changing such perceptions is not as easy as funding teacher training; the perception measure thus has less policy relevance. The teacher development information comes from teacher reports.

Finally, the ways in which computers are used is measured from a NAEP question that suggests four possible uses. These are: "drill and practice," "demonstration of new topics in mathematics," "playing mathematical/learning games," and "simulations and applications." To compare subgroups, the responses that indicate a higher-order thinking activity are placed in one category and those that indicate a lower-order thinking activity are placed in another. For fourth-graders, drill and practice is deemed the lower-order activity and learning games the higher-order activity. While many learning games may simply be a form of drill and practice and therefore lower-order, other learning games may be higher-order. It is unlikely that there will be much opportunity for the demonstration of new topics or simulations and applications because so much of fourth-grade mathematics is computational. Thus, only the learning games category is likely to include substantial application of higher-order skills.

For eighth-graders, drill and practice are again deemed lower-order, but simulations and applications are deemed higher-order. Because eighth-grade mathematics does introduce algebraic and geometric concepts (among others), there is likely to be ample opportunity to apply these concepts. Learning games probably function as busywork in the eighth-grade context, and so are neither higher-order nor lower-order; new topics are probably higher-order or lower-order depending upon the topic, and

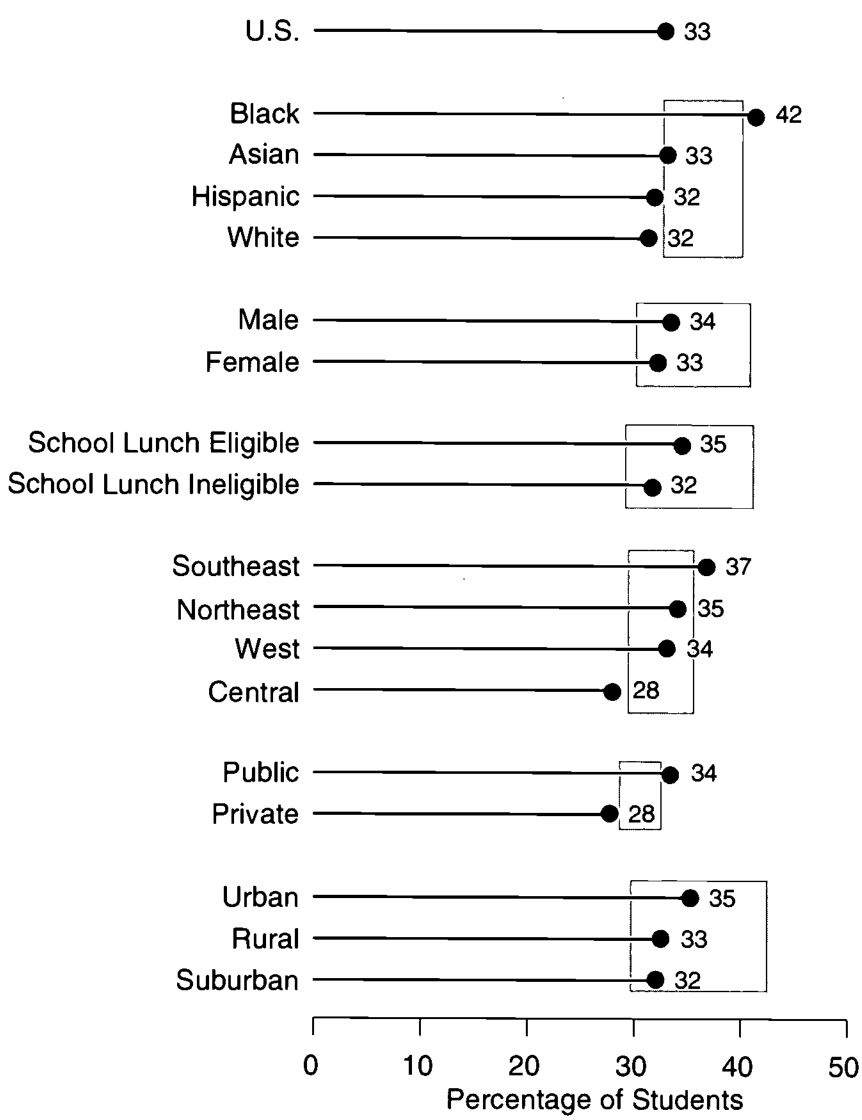
[7] Some research raises questions about the validity of even student reports (Becker, 1994c).

so are also not classified either way (See Appendix for additional information on how this part of the study was conducted.)[8]

Access to School Computers

Frequency of computer use in school among fourth-graders is presented in Figure 1. Overall, 33.2 percent of students reported using computers in school for mathematics work once a week or more often. Access was somewhat greater for Black students than for other ethnic groups; fully 41.9 percent of Black students reported frequent use (as opposed to 32.3 percent of Hispanic students and 31.7 percent of White students). There was also some regional differentiation; students in the Southeast used computers in schools more frequently than students in the Midwest. The other regions were somewhere in the middle. Finally, public school students used computers more frequently than students

Figure 1: Percentage of Fourth-Graders Who Report Using Computers at School at Least Once a Week

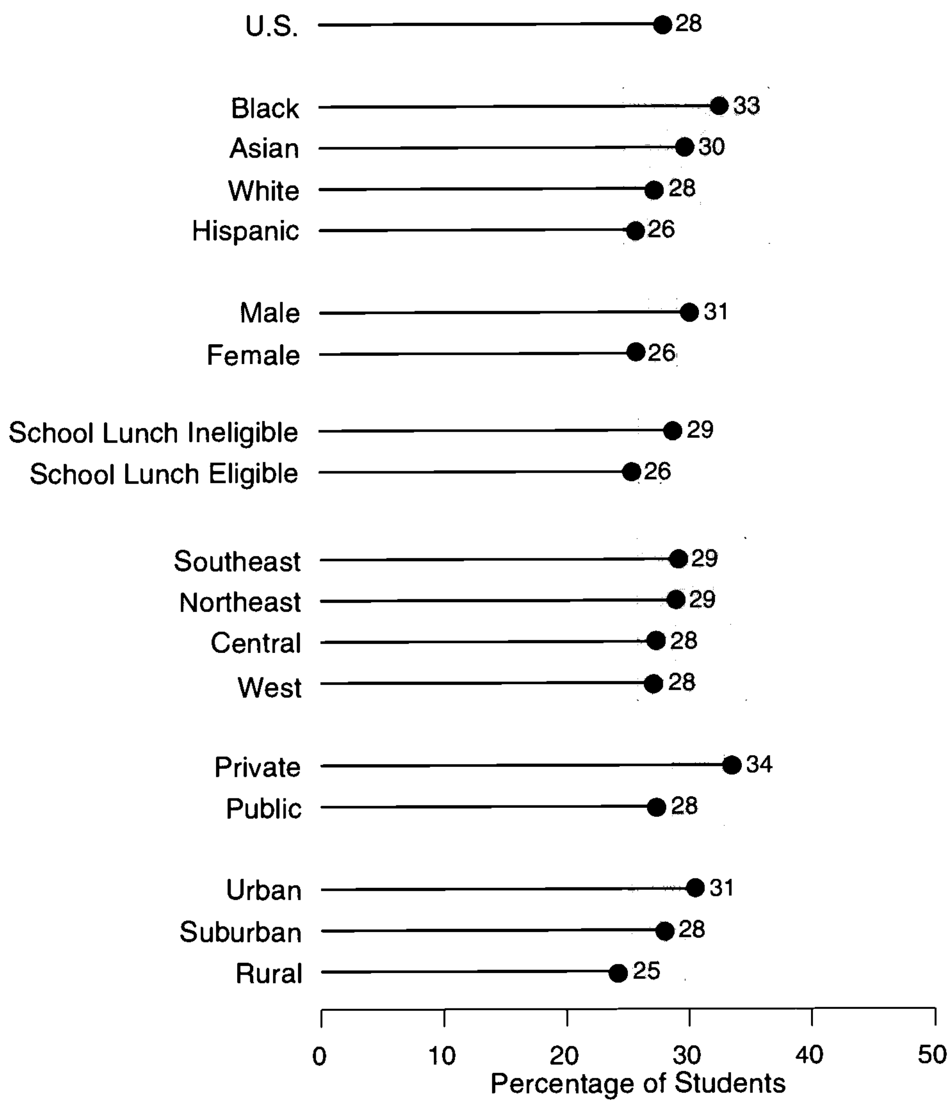


Note: Only values on opposite sides of the shaded area are statistically significantly different from one another.

Source: *1996 NAEP Mathematics Assessment*

[8] The distinction between higher-order and lower-order thinking is of long standing. For the case that technology's virtues are revealed primarily in higher-order thinking tasks, see Means (1994).

Figure 2: Percentage of Eighth-Graders Who Report Using Computers at School at Least Once a Week



Note: Only values on opposite sides of the shaded area are statistically significantly different from one another.

Source: *1996 NAEP Mathematics Assessment*

attending private school. There were no differences based upon gender, economic status, or community status.

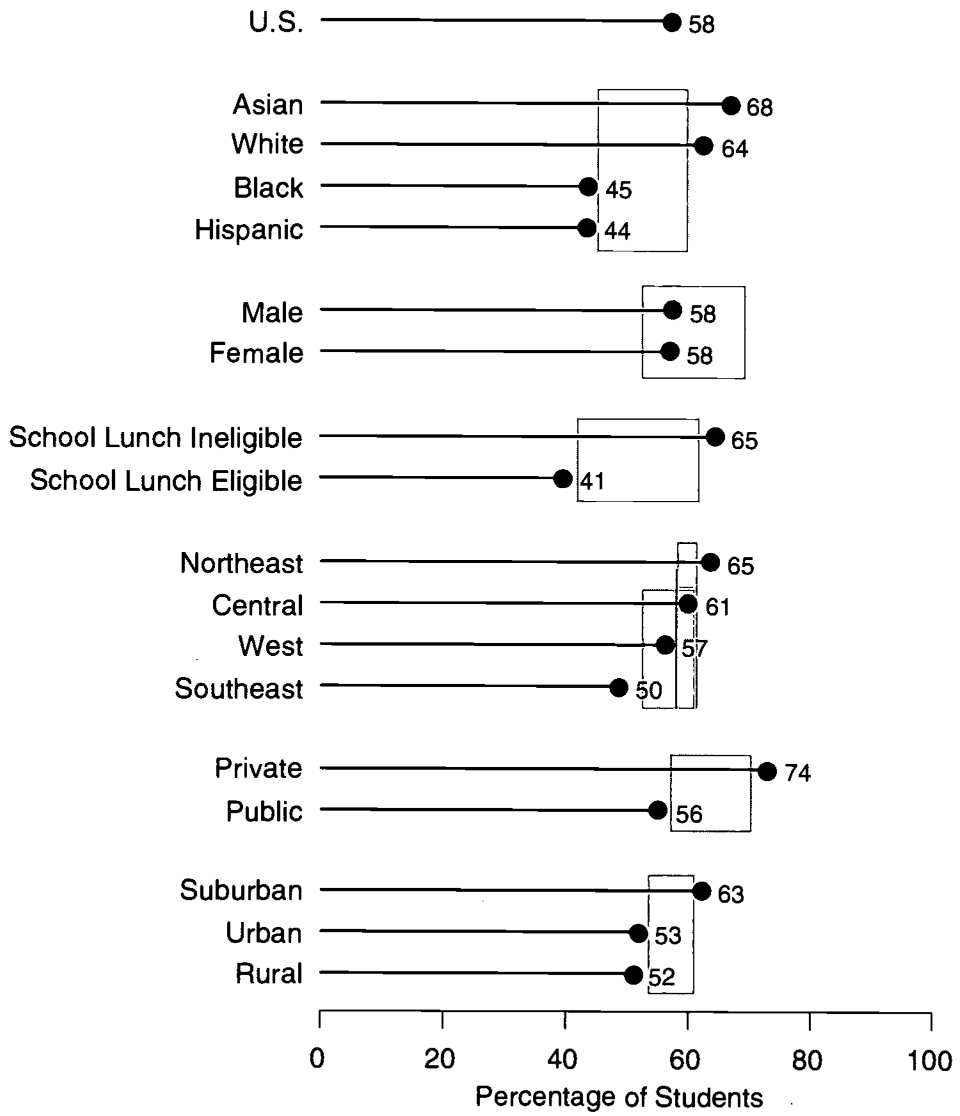
Eighth-graders appear to use computers about as frequently as fourth graders; 28.3 percent reported using computers once a week or more often (Figure 2). Unlike fourth-graders, however, there were no regional differences. Males had higher levels of computer use than females. Poor students had higher levels of computer use than non-poor students. And students attending urban schools had higher levels of computer use than students attending rural schools. Also, among eighth-graders, private school students had higher levels of computer use than public school students.

These differences suggest that traditionally disadvantaged groups do not lag in access to school computers. Compared to White, non-poor, and suburban students, those who are minority, poor, and urban find at least as much opportunity to use computers in school.

Access to Home Computers

Overall, a majority of fourth-graders have access to a computer at home (58 percent, see Figure 3). This access varies greatly between groups. Ethnic differences were quite large. Among White and Asian students, two-thirds had access to computers in the home as opposed to less than half of Black and Hispanic students. There were substantial regional differences. Less than half of the students attending schools in the Southeast had access to a home computer, as opposed to two-thirds of students in the Northeast; the other regions were in the middle. There were also differences based upon school governance, economic status, and community status; private school students were more likely to have home computer access (74 percent as opposed to 56 percent for public school students); non-poor students were more likely to have access (65.3 percent as opposed to 40.6 percent for poor students); and students attending suburban

Figure 3: Percentage of Fourth-Graders with Access to Home Computers



Note: Only values on opposite sides of the shaded area are statistically significantly different from one another.

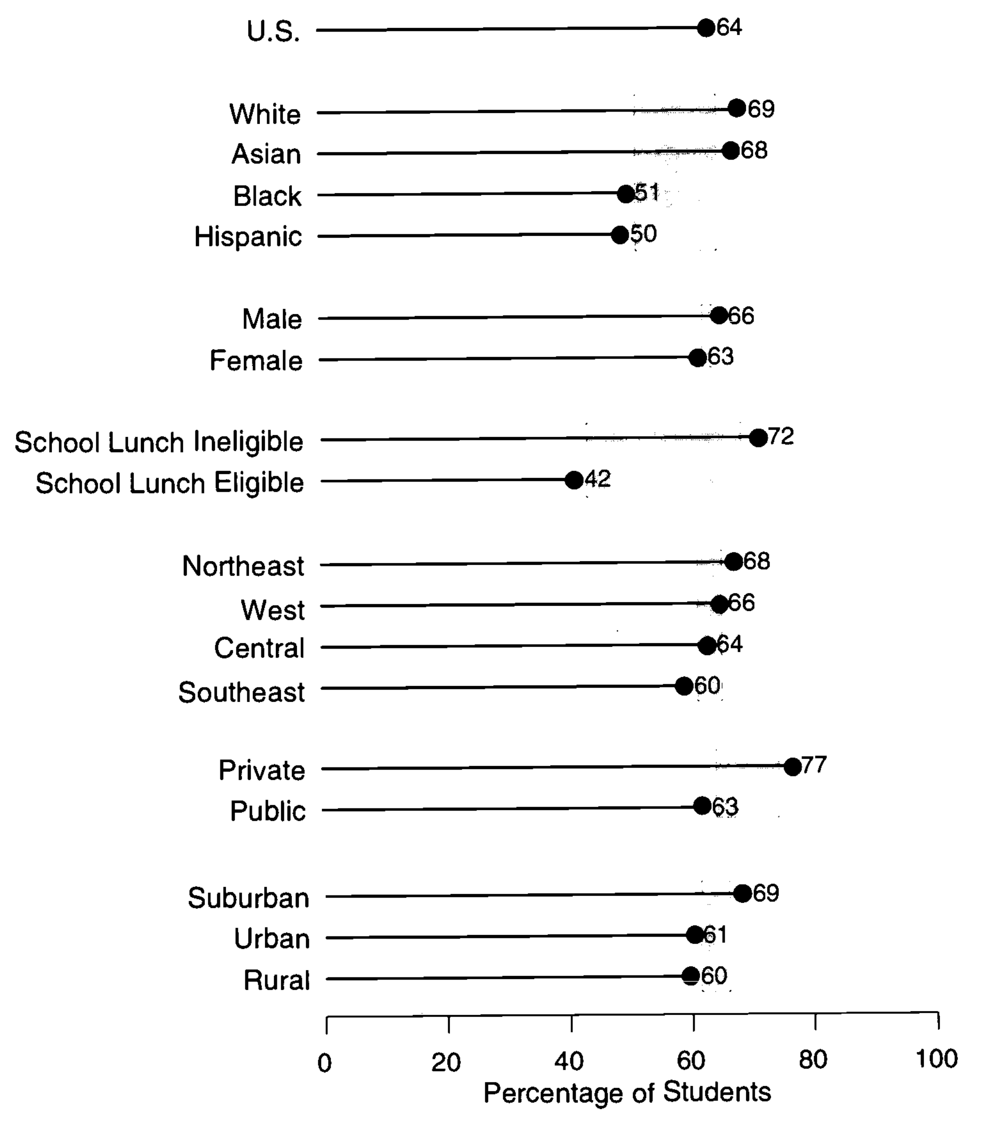
Source: *1996 NAEP Mathematics Assessment*

schools were more likely to have access (63 percent as opposed to 52.7 percent and 51.7 percent for urban and rural schools respectively). There were no gender differences.

Eighth-graders showed essentially the same pattern (Figure 4). Overall, 64.3 percent reported a computer in the home. Black and Hispanic students were much less likely to have access than White and Asian students. Students from the Northeast had higher levels of access than students from the Southeast. Private school students had higher levels of access than public school students. Non-poor students had higher levels of access than poor students. And suburban students had higher levels of access than urban or rural students. In the eighth-grade case, however, males had higher levels of access than females.

A separate question from how many students are in families that own computers is how many students use home computers regularly if they have them. For fourth-graders, among those students who have access to a

Figure 4: Percentage of Eighth-Graders with Access to Home Computers



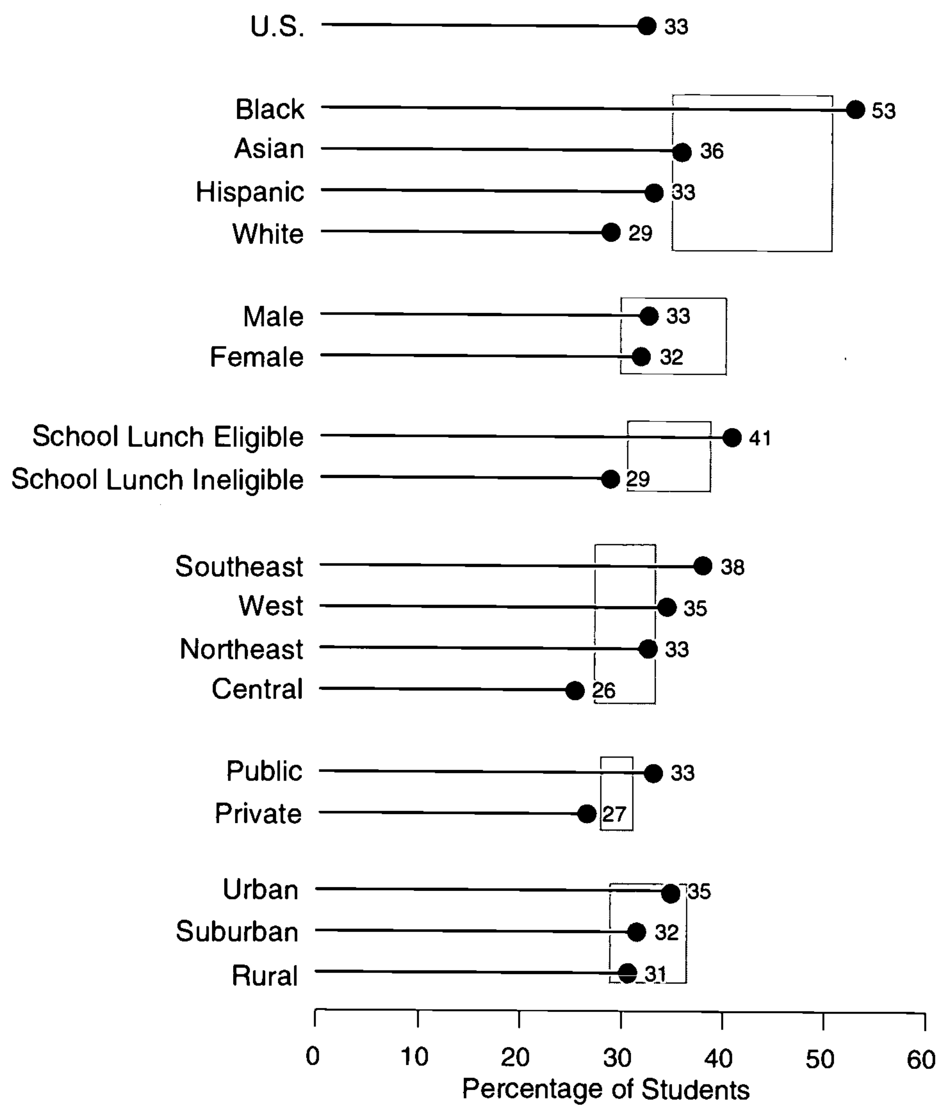
Note: Only values on opposite sides of the shaded area are statistically significantly different from one another.

Source: *1996 NAEP Mathematics Assessment*

home computer, 32.5 percent used them weekly or more often, about the same as the level of school use (Figure 5). Differences in frequency of use at home also mirrored those of frequency of use at school. Blacks showed higher levels of use than Whites and Hispanics; 53 percent of Blacks reported using computers once a week or more. There was some regional differentiation, with Southeastern and Western students using computers at home more than Midwestern students. Among students having computers in the home, public school students and poor students also used them more frequently than private school or non-poor students. There were no significant differences based upon gender or community status.

Among eighth-graders with computers at home, the patterns were less interesting (Figure 6). In all, 46.6 percent of eighth-graders reported using computers at home weekly or more often; this is a higher level than for fourth-grade home use or eighth-grade school use. There were, however, no significant differences between subgroups.

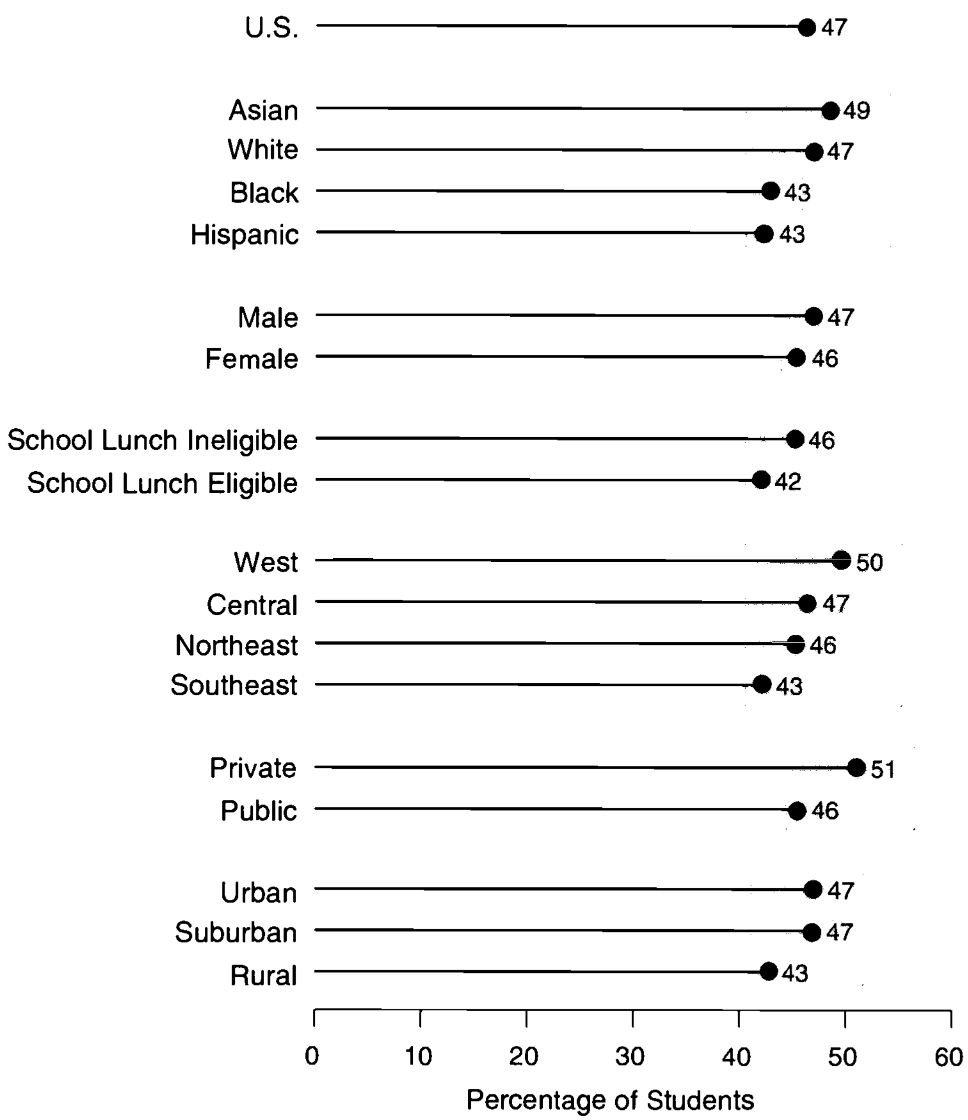
Figure 5: Percentage of Fourth-Graders Using the Computer at Home Once a Week or More



Note: Only values on opposite sides of the shaded area are statistically significantly different from one another.

Source: *1996 NAEP Mathematics Assessment*

Figure 6: Percentage of Eighth-Graders Using the Computer at Home Once a Week or More



Note: Only values on opposite sides of the shaded area are statistically significantly different from one another.

Source: *1996 NAEP Mathematics Assessment*

These patterns of home use suggest that inequities exist in the availability of computers at home, but not in their use. Poor, minority, and urban students are less likely to live in homes that possess computers in both fourth and eighth grade. However, for those families that own computers, student use tends to be as high or higher among disadvantaged groups.

Teacher Preparation

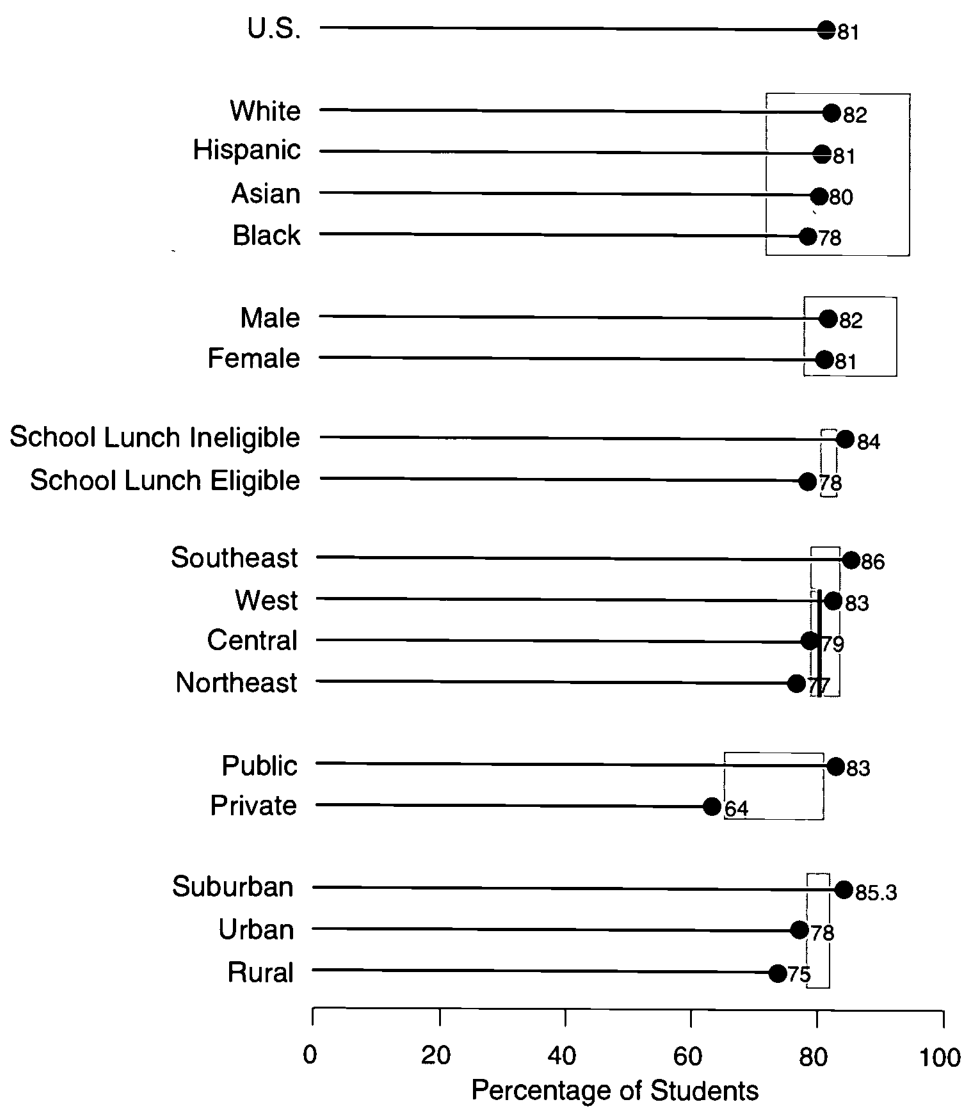
Among fourth-graders, four out of five had teachers who reported receiving professional development in the use of computers in the previous five years (Figure 7). These percentages varied by region of the country, school governance, student economic status and community status. More public school teachers than private school teachers reported professional development, as did more teachers of non-poor students than teachers of poor students, and more suburban teachers than urban or rural teachers.

Of the regions of the country, the Southeast had the most professional development (85.6 percent of students' teachers) followed by the West and the Midwest, with the Northeast trailing behind (with 77.0 percent). There were no ethnic or gender differences.

For eighth grade (Figure 8), the percentage of students with teachers reporting professional development was somewhat lower, but still quite high, at 76 percent. Again the Northeast lagged behind the other regions of the country, and suburban schools outstripped urban schools on this characteristic. In this case however, male students were more likely to have teachers who had received professional development than were female students. There were no significant differences based upon ethnicity, school governance, or economic status.

These results suggest that disadvantaged groups, to some extent, receive less exposure to teachers well prepared in technology use than do other groups of

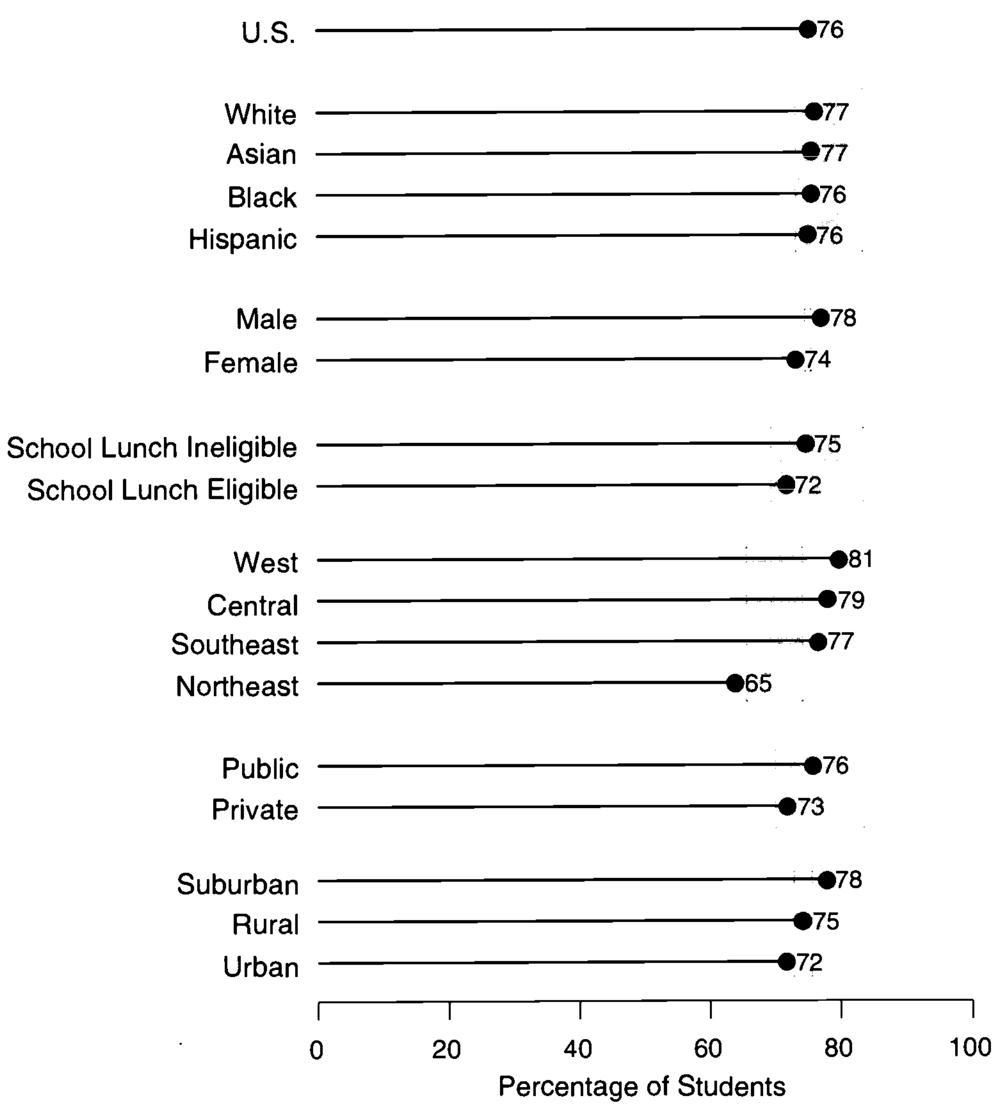
Figure 7: Percentage of Fourth-Graders Whose Teachers Report Any Professional Development in Technology Use in the Previous Five Years



Note: Only values on opposite sides of the shaded area are statistically significantly different from one another.

Source: *1996 NAEP Mathematics Assessment*

Figure 8: Percentage of Eighth-Graders Whose Teachers Report Any Professional Development in Technology Use in the Previous Five Years



Note: Only values on opposite sides of the shaded area are statistically significantly different from one another.

Source: *1996 NAEP Mathematics Assessment*

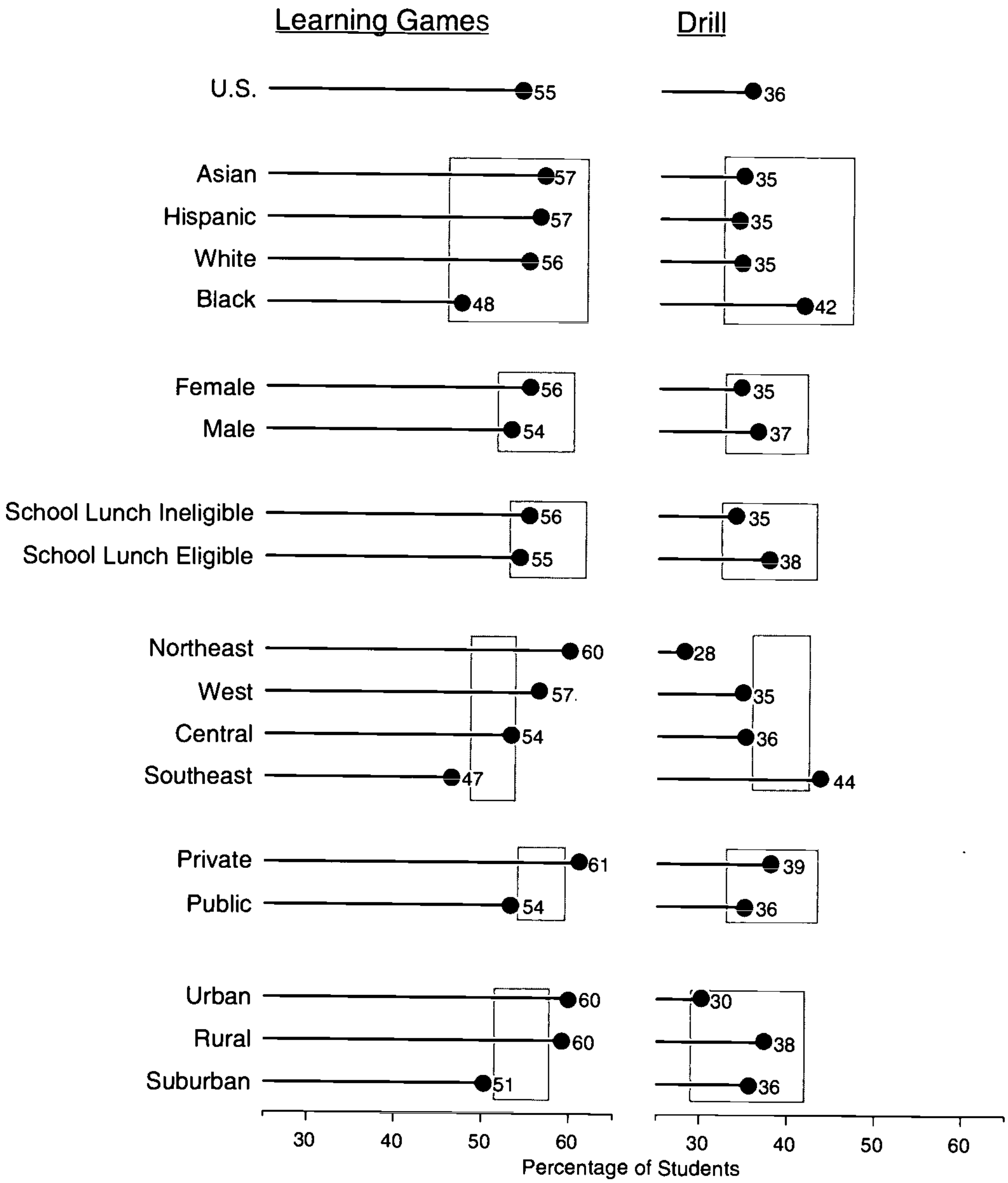
students. Suburban and affluent fourth-graders are more likely to have technologically prepared teachers than urban and poor fourth-graders; suburban eighth-graders are more likely to have technologically prepared teachers than urban eighth-graders, although there are no differences based on economic status for this grade.

Types of Computer Use

The types of use to which computers are put varies greatly between fourth and eighth grade. Among fourth-graders, 54.5 percent have teachers reporting learning games as the primary use; 35.9 percent report drill and practice; 7.5 percent report simulations and applications; and 2.1 percent report introducing new topics. Thus the activity traditionally thought of as teaching higher-order skills—applying concepts or developing simulations to illustrate them—is rarely used. Given the computational nature of fourth-grade mathematics, however, it may be that whatever higher-order thinking is occurring is being conveyed in learning games. Among eighth-graders, drill and practice is the most common activity, with teachers for 34.3 percent of students reporting it as the primary use. Playing learning games is the second most common use, followed closely by applications (29.2 percent and 27.2 percent of students respectively). Teachers report introducing new topics as the primary use just 9.2 percent of the time. Thus it seems that for fourth and eighth grades, computers are often used for lower-order activities (i.e. drill and practice), but they are also frequently used for higher-order activities (learning games for fourth-graders and applications/simulations for eighth-graders).

There are, however, substantial variations in patterns of computer use between subgroups. Among fourth-graders (Figure 9), there are differences based upon region, school governance, and community status. Southeastern students are less likely to play learning games and more likely to use computers for drill and practice. And students in public and suburban schools are less likely to use computers for such games, although there

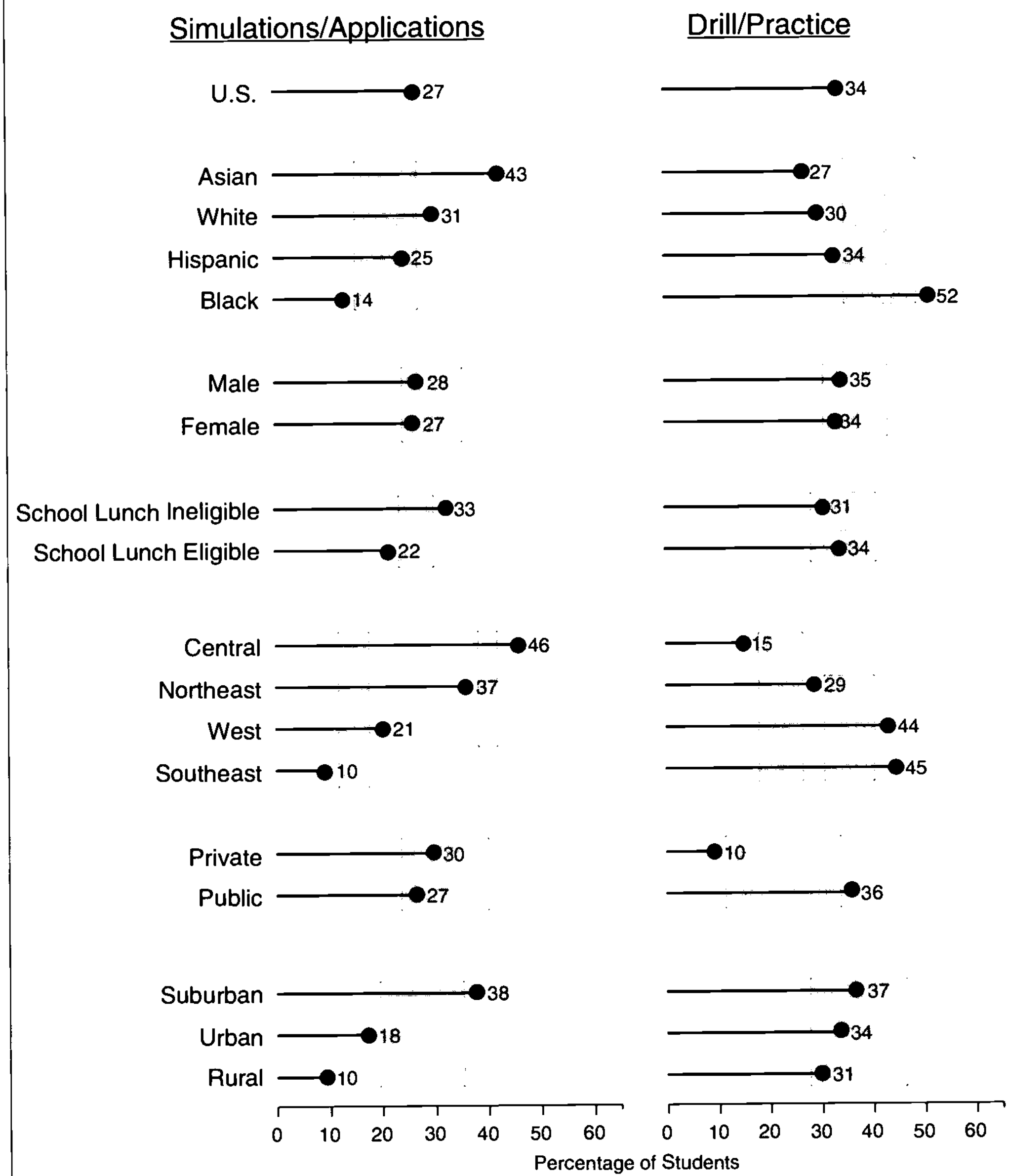
Figure 9: Percentage of Fourth-Graders Whose Teachers Report Learning Games and Drill as Primary Computer Uses



Note: Only values on opposite sides of the shaded area are statistically significantly different from one another.

Source: *1996 NAEP Mathematics Assessment*

Figure 10: Percentage of Eighth-Graders Whose Teachers Report Simulations/Applications and Drill/Practices as Primary Computer Uses



Note: Only values on opposite sides of the shaded area are statistically significantly different from one another.

Source: *1996 NAEP Mathematics Assessment*

are no differences for drill and practice. There are no significant differences based upon ethnicity, gender, or economic status.

Among eighth-graders, there are differences in use for all categories except gender (Figure 10). Blacks are less likely to use computers for applications and more likely to use them for drill and practice. Use varies with region as well. The Southeast is the most likely to drill and the least likely to do applications; the Midwest is the most likely to do applications and the least likely to drill. Also, suburban and non-poor students are more likely to use computers for applications; public school students are more likely to use computers for drill and practice.

It appears, then, that there is little difference in computer use between advantaged and disadvantaged groups in fourth grade, but great differences in eighth grade. In eighth grade, minority, poor, and urban students are more likely to find themselves learning lower-order skills than their White, non-poor, and suburban counterparts; disadvantaged students are also less likely to find themselves learning higher-order skills.

In summary, some indicators of the organization of computer use in schools raised equity issues while others did not. Disadvantaged groups do seem to be less likely to have teachers well-prepared to use computers, and disadvantaged eighth-graders seem to be less likely to be exposed to higher order learning through computers. Disadvantaged students are also less likely to come from families that own computers. However, there seems to be no disparity in access to computers at school, or in their frequency of use at home for those families that own one. It seems that policies to promote computer access in school have succeeded in eliminating inequities of this sort; yet inequities in teacher preparedness and what is taught using computers remain.

Identifying some disparities does not suggest whether these disparities matter. The importance of the disparity for a given indicator depends upon the overall significance of that indicator to academic achievement and other educational outcomes. To determine this, it is necessary to measure the relationships between each indicator and these outcomes.

Chapter Three: Modeling Technology's Effectiveness

As discussed in Chapter One, the effectiveness of educational technology has traditionally been measured through tabulating the results of evaluations of exemplary technology programs. While such evaluations may be useful in providing examples of how technology can be successfully implemented, they suffer from certain shortcomings that make it difficult to conclude that educational technology is (or is not) related to various educational outcomes: The studies do not distinguish between types of technology use or program components; they present a picture of a particular classroom, school, or school district rather than a nationwide or even statewide picture; they often use poor measures of educational outcomes, particularly of academic achievement; and they often disregard differences in the student bodies between technology-rich and technology-poor environments.

How the Study Was Conducted

The current study took a different approach to the measurement of technology's effectiveness. It conducted statistical analyses of the 1996 National Assessment of Educational Progress (NAEP) in mathematics for the two samples of students presented in Chapter Two: 6,227 fourth-graders and 7,146 eighth-graders. Using the technique of structural equation modeling, the study tested a model of how various technology characteristics might be related to various educational outcomes. For instance, the model might expect that professional development on technology leads teachers to use computers to teach higher-order thinking skills, which, in turn, improves test scores. In addition to such a flow chart, the model takes into account how other nontechnological characteristics of schools and students might affect the educational outcomes: The appearance of higher test scores in students who use technology more frequently may be due to the technology, or it may be due to the fact that such students come from more affluent families, and so are better academically prepared in the first place. Apparent higher achievement levels of students with teachers who are computer-proficient may be due to this proficiency, or it may be due to these same teachers having more teaching experience and knowledge of their subject matter. The model is then tested against the data, in this case from NAEP, to discover which relationships are significant, which relationships are not, and how strong the significant relationships are.

For this study, four indicators of the organization of technology use are related to two educational outcomes and to one another. The four aspects of technology are:

- frequency of school computer use for mathematical tasks;
- access to home computers/frequency of home computer use;
- professional development of mathematics teachers in technology use;
- higher-order and lower-order uses of computers by mathematics teachers and their students

Frequency of school computer use is based on student reports and ranges from "never or hardly ever" to "almost every day." Frequency of home computer use is the same as school computer use, except that students have the option of reporting "there is no computer at home," which is considered here the lowest possible level of use. Professional development is based upon asking teachers whether they have received such development in technology, particularly computers, in the previous five years. And higher-order and lower-order uses are measured for eighth-graders as "simulations and applications" for higher-order skills and "drill and practice" for lower-order skills; for fourth-graders, higher-order thinking is measured from "playing mathematical/ learning games."

Two outcomes are considered: academic achievement in mathematics and the social environment of the school. Academic achievement is measured by scores on the core mathematics assessment. The social environment is measured by bringing together various indicators of how teachers and students feel about going to school. These are:

- student tardiness;
- student absenteeism;
- teacher absenteeism;
- teacher morale;
- student regard for school property

All of these indicators come from reports by principals.

In addition, three characteristics of students and schools are taken into account in the model. These are:

- student socioeconomic status (SES);
- class size;
- teacher characteristics

This means that all relationships between technology and educational outcomes reported here represent the value added by technology for comparable groups of students with comparable teachers in comparably sized classes.

For both fourth- and eighth-graders, the relative affluence of a student and the student's family is measured from a series of indicators, including parent education levels and possessions in the home.[9] Also for both fourth- and eighth-graders, class size is measured from a teacher report of how many students are in their class. For fourth-graders, the teacher characteristic measured is teacher education level (less than B.A., a B.A., an M.A., a Ph.D.). For eighth-graders, teacher education levels are combined with years of experience and whether or not the teacher had majored or minored in mathematics or mathematics education.

This approach should address the shortcomings of earlier research mentioned above. It distinguishes between different aspects of the organization of technology use; it is national in scope, analyzing national samples of students; it uses robust and well-validated measures of academic achievement, as well as presenting some noncognitive outcomes; and it takes into account differences in student bodies, as well as school characteristics. (For more information on how the study was conducted, see Appendix.)

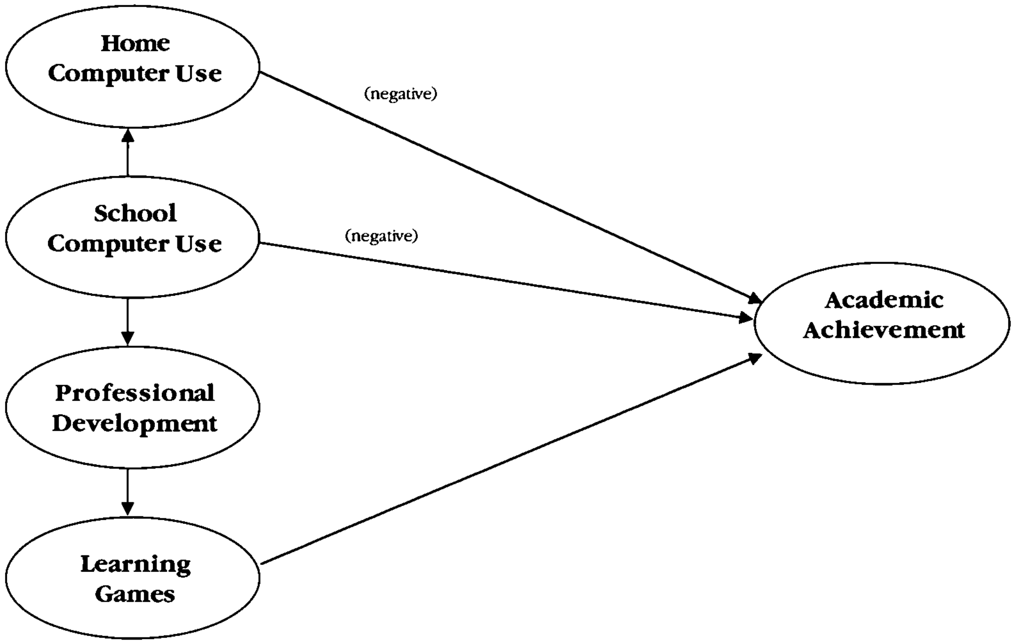
Model Results: Fourth Grade

As seen in Figures 11 and 12, many of the technology characteristics are related to one another. School computer use is positively related both to home computer use and teacher professional development. This means that students who use computers in school with great frequency are more likely to use them at home and more likely to have teachers who have received professional development in technology. Professional development in technology appears to be related to students' playing learning games; this means that teachers who have had professional development on computers are more likely to use them in that way.

These technology characteristics appear to have different relationships to the two outcomes. In both cases, the relationship to learning games seems positive, while the relationships to frequency of school and home computer use are negative. Professional development is also

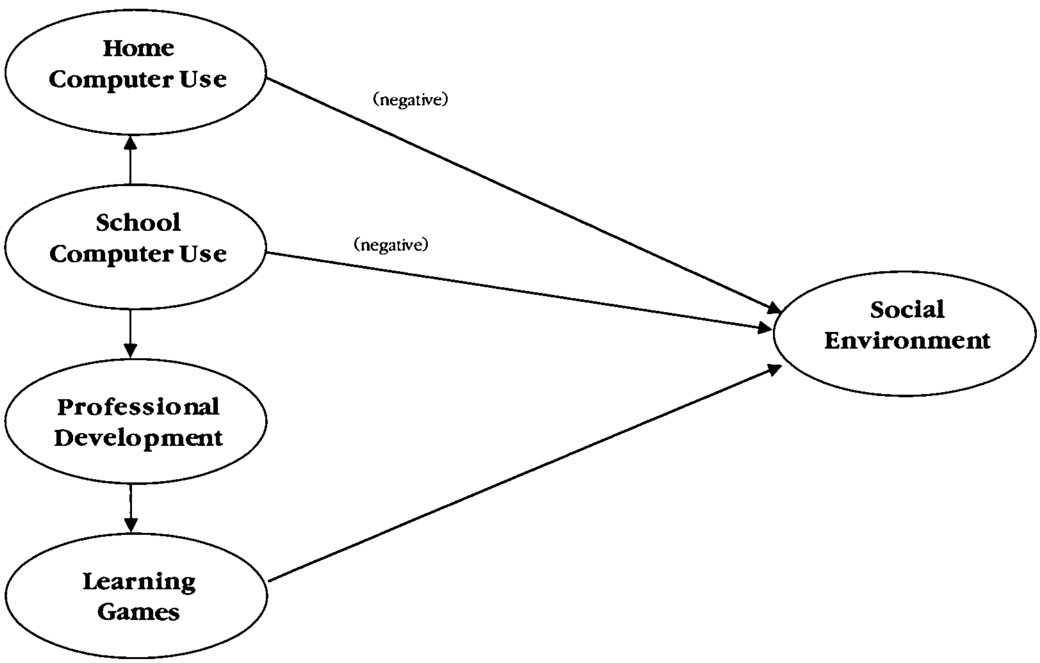
[9] Some questions have been raised regarding the validity of student reports of these measures (Berends & Koretz, 1995).

Figure 11: Influences on Academic Achievement — Fourth-Graders



Relationships take into account student socioeconomic status, teacher characteristics, and average class size.

Figure 12: Influences on Social Environment — Fourth-Graders



Relationships take into account student socioeconomic status, teacher characteristics, and average class size.

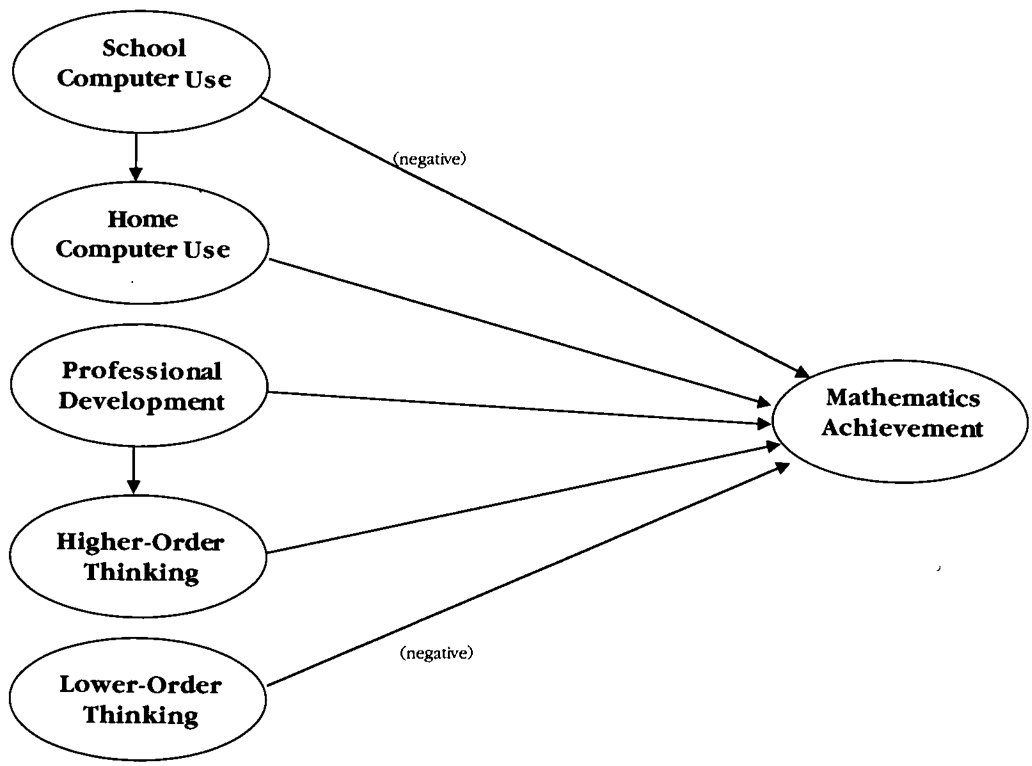
related to both outcomes, but indirectly; by virtue of increasing the use of learning games, it increases academic achievement and improves the social environment.

Model Results: Eighth Grade

For eighth-graders, the types of technology are again related to one another. School use is positively related to home use, indicating that students who use computers frequently in school are also more likely to use them frequently at home. Professional development is positively related to higher-order thinking, suggesting that teachers who are knowledgeable in the use of computers are more likely to use them for higher-order purposes.

Again, these technology characteristics appear to have different relationships to academic achievement and social environment (Figures 13 and 14). School computer use is negatively related to mathematics achievement although, in this case, home computer use is positively related to mathematics achievement. Thus, students who use computers frequently at home demonstrate higher levels of academic achievement, whereas those who use computers frequently at school evince lower levels. Yet since school computer use is associated with home computer use, school computer use does not have wholly negative consequences for academic achievement; students who use computers at school frequently are also more likely to use them at home frequently, and the latter use is positively related to academic achievement. The net effect of school computer use is negative, but it is mitigated by this indirect relationship. Professional development and higher-order thinking are both positively related to academic achievement: Students with teachers who have had such professional development show higher levels of

Figure 13: Influences on Academic Achievement — Eighth-Graders



Relationships take into account student socioeconomic status, teacher characteristics, and average class size.

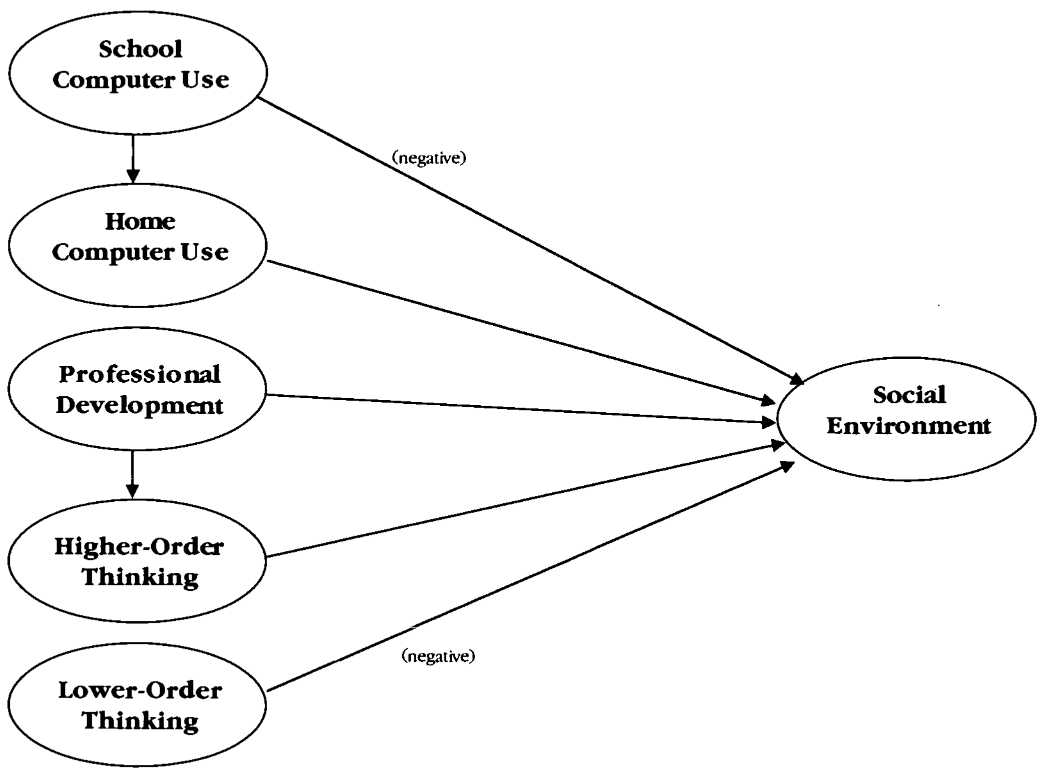
achievement, as do those who are taught higher-order skills with computers. Professional development is also associated with academic achievement indirectly; it increases the likelihood of teachers using computers to convey higher-order skills, thereby increasing academic achievement in that way. Finally, using computers for drill and practice, the lower-order skills, is negatively related to academic achievement. For social environment, the pattern is the same, except that school computer use is not directly related to it; it only has the indirect benefit of increasing home use, which is conducive to the social environment in school.

The Size of the Relationships

While the flow charts say a great deal about the differential effectiveness of the technology indicators, they do not quantify that effectiveness. Such quantification can be accomplished in two ways. First, the size of the relationships can be measured in terms of estimated grade levels. This is accomplished by taking the differences in NAEP scores between the characteristics and dividing by 12.25, the typical difference in mathematics achievement between grade levels. Yet this says little about the size of the relationships relative to other characteristics of schools and students, such as variations in class size. Fortunately, the technology characteristics can be compared to other characteristics in the model by standardizing them, meaning that they are all placed on the same scale; the numbers that result are meaningless in absolute terms, but do show the strength of each relationship relative to the others. In both cases, it should be emphasized, these numbers represent the value added by technology above and beyond student, teacher, and classroom characteristics.

The grade-level estimates suggest substantial positive benefits of technology for

Figure 14: Influences on Social Environment— Eighth-Graders



Relationships take into account student socioeconomic status, teacher characteristics, and average class size.

eighth-graders, but mixed results for fourth-graders (Table 1). In fourth grade, students using computers to play learning games are .15 of a grade level ahead of their counterparts; students with teachers who have had professional development on computers are .09 of a grade level ahead. Assuming a 36-week school year, these gains amount to three and five weeks respectively. In eighth grade, students using computers for higher-order thinking skills show gains of .42 of a grade level, and those with a teacher who has received professional development on computers show gains of .35 of a grade level. These would amount to much more substantial gains of 15 and 13 weeks respectively.

The size of the technology relationship relative to other characteristics also emphasizes differences between fourth- and eighth-graders (Table 2).[10] SES has the largest relationship to achievement, at .58 for fourth grade and .40 for eighth grade. The sums of the class size and teacher characteristic relationships are much smaller, totaling .08 and .13 for fourth- and eighth-graders respectively.

Table 1- Size of Relationships: Grade Levels

Variable	Fourth Grade	Eighth Grade
Professional Development	.09	.35
Primary Use — Applications	n/a	.42
Primary Use — Games	.15	n/a
Primary Use — Drill	n/a	-.59
School Computer Use	-.20	-.11
Home Computer Use	-.26	.14

Table 2- Size of Relationships: Relative Sizes

Variable	Fourth Grade	Eighth Grade
Socioeconomic Status	.58	.40
Class Size	.07	.06
Teacher Characteristics	.01	.07
Professional Develoment	.01	.04
Primary Use — Applications	n/a	.04
Primary Use — Games	.03	n/a
Primary Use — Drill	n/a	-.06
School Computer Use	-.09	-.05
Home Computer Use	-.14	.07

[10] The positive relationship between class size and mathematics achievement indicates that smaller classes are associated with higher levels of achievement.

The benefits of technology are smaller still, at .04 for professional development and learning games in fourth grade, and .08 for professional development and higher-order thinking in eighth grade. Yet while the impact of technology is smaller in both cases, it plays a larger role in eighth grade than in fourth grade; in eighth grade it is more than half as great as class size and teacher characteristics and a fifth as large as SES; for fourth grade it is one-half the size of class size and teacher characteristics, but one-fourteenth as large as SES.

There were also differences in relationship sizes for those types of technology that are negatively associated with academic achievement. For fourth-graders, these negative relationships are larger than the positive; while the positive total .04, the negative total .23. On the other hand, for the eighth-graders the positive relationships outweigh the negative; if using home computers is included, the positive relationships total .15 while the negative relationships total .11.

These results, then, paint a more complete picture of technology's effectiveness. In general, the indicators of professional development and higher-order uses of computers seem positively related to academic achievement in mathematics and other outcomes, while frequency of use is unrelated or even negatively related to them. Further, while the size of the positive relationships are substantial for eighth-graders, they are small for fourth-graders, so small that they are overshadowed by various negative technology relationships. The following chapter suggests what can be made of these findings from a policy perspective.

Chapter Four: Conclusion

Interpreting the Results

The results from this study suggest that, as technology advocates have asserted, technology does matter to academic achievement, with the important caveat that whether it matters depends upon how it is used. The levels of use of computers seems not to matter, and extremely high levels of use may even be counterproductive. Possibly at such high levels students are using computers in unproductive ways, such as playing non-educational games. But when computers are used to perform certain tasks, namely applying higher order concepts, and when teachers are proficient enough in computer use to direct students toward productive uses more generally, computers do seem to be associated with significant gains in mathematics achievement, as well as an improved social environment in the school.

The findings regarding home computers reinforce this point. Students using home computers frequently had higher levels of achievement in eighth grade, but lower levels of achievement in fourth grade. Presumably this was so because the computer was put to different uses in the two grades. Perhaps eighth-graders have more understanding of how to use the Internet than fourth-graders, and so can use it to provide supplementary information on academic subjects; perhaps eighth-graders are more likely to use computers as tools for doing homework, including using word processors for writing papers and spreadsheets for doing calculations and tabulating data. Without having actual data on how home computers are used by students, it is only possible to speculate, but perhaps if home computers are academically productive for eighth-graders and not for fourth-graders they are being used in substantially different ways.

The descriptive information in Chapter Two, when combined with the results of the analyses in Chapter Three, suggests the importance of various inequities in technology between groups of students. Disadvantaged groups seem to lag behind in access to those aspects of technology that do affect educational outcomes, but not in access to those aspects of technology that do not affect educational outcomes. While minority, poor, and urban students are no less likely to use computers at school frequently, frequency of use is not associated with gains in achievement or social environment. Yet minority, poor, and urban students are less likely to receive exposure to computers for higher-order learning, and poor and urban students are less likely to have teachers who have received professional development on technology use. Thus, where technology matters, there are significant inequities; only where technology does not matter have these inequities been successfully erased.

Knowing More

While this study does address problems in the prior literature, it has its own methodological limitations. First, the data used were collected at a single point in time; technology characteristics occur at the same time as the educational outcomes. There are no prior measures of mathematics achievement, making it difficult to rule out the possibility that positive educational outcomes are conducive to certain aspects of technology use rather than the other way around. The study did address this problem in part by taking into account student background, a proxy for prior achievement.

Also, an alternate model for eighth-graders was developed that took into account the level of difficulty of the eighth-grade mathematics class (algebra, pre-algebra, or regular eighth-grade mathematics). Since the class that students take depends to some degree on prior achievement, this measure may also serve as a proxy for it. The results from the alternate model, however, did not differ much from those of the original model. All technology measures remained significantly related to academic achievement and the social environment of the school, and the sizes and directions of the relationships also remained the same. The one exception was professional development, which, while still significantly and positively associated with the educational outcomes, was associated with them to a somewhat lesser extent, with a relationship size of .21 grade levels (as opposed to .35 grade levels). The relative lack of change between the two models suggests that a study that took prior achievement into account would be unlikely to produce very different results. Nonetheless, a study that follows students over time, measuring their academic achievement both before and after their exposure to various uses of technology would provide a stronger test of the findings from this study.

Second, while the study does take into account teacher characteristics, such as education levels, it does not take into account more detailed measures of teacher practices. The study found that when computers were used for higher-order thinking skills, students performed better; yet this does not exclude the possibility that students do better when teachers tend to teach higher-order thinking skills, regardless of the medium. Fortunately, this invitation does not undermine the findings of this study. Regardless of whether other media may also be successful at conveying higher-order thinking, this study does demonstrate that computers can do so; they are, at a minimum, one of a limited number of tools that can contribute to this goal.

A few other caveats are worth noting. The study only analyzes technology's effectiveness in one subject area, mathematics. Most measures of the uses of technology as well as the measure of academic achievement are specific to that subject. Computers may be less effective in other subject areas, such as history and English. Also, the study is limited to only a few indicators of the organization of technology use; other aspects of technology may be more or less effective. For instance, the study does not distinguish between the effectiveness of different types of software.

Finally, the study does not incorporate information about state technology policies, which may have a bearing on technology's effectiveness. These three caveats all suggest that it is important for states to collect more data to evaluate their technology investments; they need to know which policies and types of software are effective, and for which subject areas computers should be used.

Implications of Findings

These methodological limitations aside, the findings have significant implications for technology policy and practice.

First, the study suggests that federal and state policymakers should redouble their efforts to ensure that teachers are properly trained to use computers. The descriptive information supplied in Chapter Two shows that the vast majority of teachers already receive some professional development in technology, suggesting that there is little room for policymakers to further increase such professional development. Yet there are large disparities in the amount of professional development teachers receive. Federal and state policymakers should target teacher training efforts at high-poverty urban and rural schools, which have much lower percentages of teachers receiving such training. Also, professional development in technology, as reported in NAEP, could refer to anything from a weekend seminar to a semester-long course. Many of the teachers who do receive professional development in technology may benefit from more intensive instruction. Federal and state policymakers should make sure that the quality of the teacher training offered is high and intensive, since this training is such an important component of making technology use successful.

Second, the study suggests that teachers should focus on using computers to apply higher-order skills learned elsewhere in class. Computers should be a component of a seamless web of instruction that includes nontechnological components. For example, teachers might introduce new topics and convey basic information to their students through general class discussion and lecture, then assign projects and problems that computers as well as other media (books, field trips, etc.) can be used to address. While implementing this vision depends primarily upon the individual preferences and capabilities of teachers, federal and state policymakers can encourage it to some degree through supporting professional development of teachers that emphasizes this teaching method. Further, federal and state policymakers can encourage school districts to order software that draws on these skills, and assist school districts in connecting to the Internet, which can be used to obtain outside information for projects and problem solving. As with teacher development, extra efforts should be made to support these changes in high-poverty urban and rural school districts, which are at present most likely to be using computers for drill and practice rather than applications and simulations. This is not to say that the basics should not be taught where appropriate; the findings merely suggest that computers are not well-adapted to teaching them.

Third, the primary focus of all technology initiatives should be on middle schools rather than elementary schools. The effects of technology appear to be much smaller in the fourth than the eighth grade, and so may not be cost-effective. Further, the sequence of the typical mathematics curriculum suggests that computers are more crucial for middle school students than elementary school students. Most higher-order concepts are not introduced before middle school, with elementary school students focusing on computational skills. To the extent that the primary benefit of computers lies in applying higher order skills, there may not be much opportunity to benefit from using computers before middle school.

In conclusion, technology advocates were correct in asserting that technology can be beneficial to student learning. Used properly, technology can lead to gains in academic achievement and positively influence the social environment of the school, reducing teacher and student absenteeism and increasing morale. Yet it is important that the scope of technology in schools be limited to those areas where it provides benefits, and reduced in areas where it does not. Thus the notion of technology as a substitute for conventional forms of instruction, often hoped for by technology advocates and dreaded by technology critics, may overstate the case for technology use. It may also be counterproductive, not only introducing computers into areas where other teaching techniques are more conducive to positive educational outcomes, but also raising worries among teachers that they are being replaced by machines. By clearly delineating areas in which computers can be helpful to teachers and areas in which they cannot, it will be possible to increase the acceptance of computers. Alongside chalk and blackboards, computers will be tools teachers feel they cannot live without.

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Appendix: How The Study Was Conducted

Case and Variable Selection

Data were drawn from the 1996 National Assessment of Educational Progress in mathematics for fourth- and eighth-graders. For each grade, student and teacher data were linked to school data using the school identifier, SCRPSU. Only those cases which had plausible values for the core assessments, MRPCM1, MRPCM2, MRPCM3, MRPCM4, and MRPCM5, were used, resulting in 6,227 fourth-graders and 7,146 eighth-graders.

To measure socio-economic status the following six variables were selected: B003501M (mother's education), B003601M (father's education), B000901M (newspapers), B000903M (encyclopedias), B000904M (books), and B000905M (magazines).

To measure teacher characteristics, the following six variables were selected: T040301 (years taught), T056301 (highest degree), T040703 (mathematics major), T040704 (mathematics education major), T040803 (mathematics minor), and T040804 (mathematics education minor). Class size was measured from T044000. Academic achievement was measured from the five plausible value variables used for case selection.

To measure social environment, the following five variables were selected: C032402 (student absenteeism), C032401 (student tardiness), C032406 (teacher absenteeism), C032502 (teacher morale), and C032506 (regard for school property).

With regard to the technology variables, frequency of school computer use was taken from M812710B; frequency of home computer use was taken from B009301M; teacher development was taken from T056702; and primary use was taken from T057601. All variables were recoded to eliminate missing values.

Whether teachers had received education in mathematics, one of the teacher characteristics, was calculated by treating a "yes" response to any of T040703, T040704, T040803, or T040804 as having received such education.

The two frequency-of-computer-use variables were recoded so that a high value denoted high frequency. The class-size variable was recoded so that a small class had a high value, and the social environment measures were recoded so that a high value indicated a positive social environment.

Descriptive Analyses

All cases were weighted by the variable ORIGWT divided by the mean weight for each sample. The overall number of cases was also divided by a design effect of 1.75. Comparisons of means were then conducted using the Scheffe test.

Multivariate Analyses

Models of the relationship between technology characteristics and educational outcomes were developed based upon the literature. The models were tested for fourth- and eighth-graders separately using the technique of Structural Equation Modeling as implemented by two software packages: STREAMS 2.0 and AMOS 3.6; STREAMS is a pre- and postprocessor for AMOS. Unidimensional measurement models were developed for academic achievement, social environment, SES, and teacher characteristics based upon their corresponding variables in the database. For the remaining variables, the constructs were defined as the database variables with a factor loading of 1 and no measurement error.

The constructs were related to one another as follows: for fourth-graders, the technology indicators, class size, teacher characteristics, and SES were all related to academic achievement and school social environment. Professional development was related to use of learning games. Social environment was related to academic achievement. SES was related to frequency of school computer use and both of those were related to home computer use. Frequency of school computer use was related to professional development. For eighth-graders the model was the same, except that frequency of school computer use was not related to professional development and professional development was related to simulation/applications and drill and practice rather than learning games. Models were deemed acceptable with goodness of fit indices better than .9 and a root mean squared error of approximation better than .05. Coefficients were deemed significant with standard errors inflated by the square root of the design effect (1.75) at the .05 level. Sensitivity analyses were conducted in which standard errors were further inflated by the measurement variability of the plausible values, and the measurement error in the measurement model was correspondingly eliminated; this procedure produced similar results. For STREAMS 2.0, see Gustafsson and Stahl (1997). For AMOS 3.6 see Arbuckle (1997). For discussions of weighting, design effects, and measurement variability using NAEP, see Johnson (1989), and Johnson, Mislevy, & Thomas (1994).

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