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Effects of Using Instructional Technology in Colleges and Universities: What Controlled Evaluation Studies Say

Final Report

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Executive Summary

Use of computers by college students has grown rapidly during the last decade. Today nearly two-thirds of all college students use computers at school, and nearly half use computers at home for schoolwork. The students log on to computers in libraries, computer laboratories, classrooms, and residence halls. They use computers for word processing, graphics preparation, and spreadsheet calculations, and they rely on the Internet for sending and receiving electronic mail, downloading course material, and retrieving information for research and reports.

No one questions the value to students of computerized word processing, scientific calculation, information retrieval, and report preparation. Nor does anyone doubt the value to colleges of computerized record keeping, communication, and information storage. But opinions begin to diverge when the topic of instructional technology comes up. Can computers also be effective teaching devices? Can colleges teach better by handing off some teaching tasks to computers? Would students learn more or better as a result? Questions spring up on all sides.

To answer such questions, this report reviews the literature on effectiveness of instructional technology in colleges and universities. The main focus of the report is on controlled evaluation studies carried out during the last decade. Researchers have already written comprehensive reviews of earlier evaluation studies of technology effects in college teaching. While it is important to know about the findings of these earlier reviews, it is not critical to reexamine each of the studies that were reviewed. The literature of the past decade, however, requires careful scrutiny. It is still unexplored territory, extensive, unmarked, and inviting.

Findings in earlier reviews on technology in college teaching

During the 1980s, reviewers of research on instructional technology began using effect size measures to summarize their findings. Effect sizes express results from different studies on a single uniform scale of effectiveness. They specify the number of standard deviation units that separate outcome scores of experimental and control groups. A study's effect size is positive when the experimental group outperforms the control group, and it is negative when the control group comes out on top. Experts in social science research classify effect sizes of around 0.2 as small, 0.5 as moderate in size, and 0.8 as large (e.g., J. Cohen, 1977). Experts in educational evaluation usually consider effect sizes above 0.25 as large enough to be educationally meaningful (e.g., Slavin, 1990).

Three reviews on technology in college teaching published during the 1980s and early 1990s covered more than 100 controlled studies of use of instructional technology in college courses. The average effect of computer-based teaching in these studies was to increase student test performance by between 0.25 and 0.30 standard deviations. That means that the average student working with computer help scored around the 60th percentile on course examinations, whereas the typical student working without such help in a conventional course scored at the 50th percentile.

The reviews examined findings from several different types of computer use, including computer-assisted instruction, computer-managed instruction, and computer-enriched instruction. In computer-assisted instruction, the computer provided drill-and-practice or tutorial instruction; in computer-managed instruction, the computer evaluated student test performance and guided students to appropriate instructional resources; in computer-enriched instruction, the computer served as a tool, simulation device, or programming device. Each type of computer use made small, positive contributions to student learning. There was no significant difference in findings for the three types of computer use.

Methodology for this review

A computerized search of three library databases yielded 46 studies from the past decade on effects of instructional technology in college courses. The studies fell into five areas: (a) computer and calculator tools in mathematics; (b) computer tutoring in science; (c) computer simulations in science; (d) computer animations in science; and (e) computer-assisted language learning. In each of the studies, instructional outcomes for students taught with computer help were compared to outcomes for students taught without computer help. The instructional outcome measured most often in the studies was student learning. Very few studies carried out controlled comparisons of other instructional outcomes, such as performance on follow-up or retention examinations, time needed for instruction, or attitudes toward instruction, computing, or subject matter.

Computer and calculator tools in mathematics

Twelve studies examined effects of computer and calculator tools in mathematics. These studies can be viewed as one important byproduct of the movement to reform algebra and calculus teaching during the late 1980s and 1990s. The reformers believed that computer and calculator use could reduce computational drudgery in algebra and calculus classes and free students to focus their attention on the underlying mathematical concepts.

Early studies of digital calculators. Before reformers rallied around computers and graphing calculators during the 1990s, they argued for more extensive use of digital calculators in math instruction. Evaluations of this innovation during the 1980s set the pattern for evaluations of later technological innovations in mathematics education. The studies of digital calculators showed that at least three factors influenced evaluation results: (a) whether students were taught with or without calculators; (b) whether students used calculators or paper and pencil when taking the final tests; and (c) whether student achievement was measured on conceptual or computational tests.

When experimental group students were allowed to use digital calculators on final examinations and control group students used only paper and pencil, the experimental group outperformed the control group by a great deal on computational problems and by a modest amount on problem-solving items. Findings were different, however, when the experimental and control groups took outcome tests under common conditions. When students in the experimental group were not allowed to use calculators on final examinations, performance of the experimental and control groups was similar. Using calculators during instruction did not negatively affect development of computational skill, but it also did not have a positive effect. Using calculators during instruction had at best a small positive effect on development of conceptual understanding.

Evaluators of mathematics reforms learned two important lessons from these research studies. First, they learned that technology could have different effects on conceptual and computational performance. Second, evaluators learned that it was important to pay attention to conditions under which criterion examinations were taken. Specifically, it was important to note whether students in the experimental and control groups took tests under conditions that were similar to their instructional conditions (i.e., calculators for the experimental group and paper and pencil only for the control group) or under common conditions (i.e., paper and pencil only for both groups).

Recent studies of computers and graphing calculators. Each of the 12 recent studies of computers and graphing calculators examined effects on conceptual understanding. Six of the studies took place in algebra courses. Three of these six studies examined effects of computer algebra systems, and three examined effects of graphing calculators. The remaining six studies took place in calculus courses. In each of the studies, the experimental group used a commercially produced computer algebra system while the control group received traditional instruction without having access to computer algebra tools.

Effects on conceptual tests in the 12 studies were surprisingly homogeneous. In 11 of the studies, computer and calculator effects were positive and statistically significant. In nine of the cases, the effects were large in size, and in two cases, they were moderate in size. In only one case was a computer or calculator effect negative, and in this special case, the computer tools were used in a very restricted way. The experimental group used a computer algebra system for homework only; the system was not integrated into regular instruction. When used in this fashion, a computer algebra system might do more harm than good. It seems safe to say that computer and calculator tools have proven their value in mathematics education, but to get the most out of such tools, teachers must integrate their use into instruction.

The overall picture that emerges from these studies is therefore very positive. In the typical study, computer and calculator tools raised students' scores on tests of mathematical understanding by a large amount. In the median case, the effect size was 0.88 on conceptual tests. This means that students who were allowed to use computer or calculator tools during the instructional period scored 0.88 standard deviation units higher on conceptual tests than did students in the control group. If control group students scored at the 50^{th} percentile on these tests, scores of experimental group students would be at the 81^{st} percentile. An effect of this size is unusually large and very significant educationally.

The 12 studies provided additional evidence showing that results on computational exams are strongly influenced by the conditions under which the tests are taken. In two studies, experimental group students were permitted to use computers or calculators on computational items on final exams. In both studies, the experimental group students outscored the control group students on these items. In other studies, neither the experimental groups nor the control groups were allowed to use computers and calculators for computational items on final exams. In these studies, experimental group students performed computations about as well as students who learned in more traditional classes. The studies provide no evidence that using computer and calculator tools have a deleterious effect on college students' computational skills. The studies suggest instead that experimental group students have learned to use tools that can help them significantly to perform computations in algebra and calculus.

Finally, the studies did not suggest any definite conclusion about the effects of computer and calculator tools on student attitudes toward mathematics. In two studies, mathematics attitudes were clearly more positive in the experimental groups, but in three other studies, math attitudes were not significantly different in experimental and control groups.

Computers in science teaching

Among the methods that have been developed to improve science teaching are three that involve computer technology:

- Computer tutoring. These programs present instructional material to learners in small manageable amounts, require learners to respond to questions frequently, evaluate learner responses immediately, and on the basis of the evaluations decide what to present next.
- Computer simulations. Computer simulations provide science students with theoretical or simplified models of real-world phenomena and give students the opportunity to change features of the models so that they can observe the results. For example, a simulation program might give students a chance to make changes in a frictionless world where the laws of Newtonian physics would be more apparent.
- Computer animations. These programs usually link observable phenomena with scientific representations of these phenomena. In chemistry, for example, a computer animation might provide simultaneous views of an observable chemical reaction, the same reaction viewed schematically at the molecular level, and a third view of the reaction at the symbolic level of graphs and equations.

Evaluators have been examining the effects of the first two approaches for more than three decades. Computer animations are a more recent innovation. Evaluations of the effects of animations on science learning first started appearing in the literature during the 1990s.

Earlier review results. A review of technology in college teaching published in 1991 examined effect sizes in 37 studies of computer tutoring in college courses (C. Kulik & Kulik, 1991). Results of these studies favored the computer-tutored students by only a small amount. The median effect size in the 27 studies was 0.15. This effect is not large enough to be considered educationally meaningful. The review also contained findings from 13 studies of computer simulations in science. Results of these studies were favorable to the groups that viewed the computer simulations. In 11 of the 13 studies, for example, the group viewing the simulations outperformed the control group, but in the remaining studies, the control group outscored the simulation group. The median effect size in the 13 studies was 0.25. Effect sizes of 0.25 and over are usually considered to be educationally meaningful. By this standard, therefore, the effects of computer simulations were large enough to be judged as educationally meaningful.

More recent results. Seven studies published during the 1990s examined the effects of tutorial instruction in college science courses. The seven studies examined two kinds of instructional outcomes: student achievement and student attitudes. Effects of computer tutorials on both outcomes were mixed. Four of the six studies of student learning reported significant positive effects of tutoring, for example, and two studies reported trivial effects. The median effect size in the studies was 0.33. Tutorial effects on attitudes were likewise mixed. One study reported strong positive effects of computer tutoring on student attitudes; one study reported a strong negative effect; and one study reported a nonsignificant positive effect.

Eleven studies of computer simulations in science also presented a somewhat mixed picture of effectiveness. In 7 of the 11 studies, effects were positive and large enough to be considered statistically and educationally meaningful; in 2 other studies computer results were nonsignificant; and in the remaining 2 studies results were significant and negative. Median effect size in the 11 studies from the past decade was 0.39. While the most likely outcome of using simulations in teaching was an increase in student test performance, using simulations could also have a negative effect or no effect at all on student test scores. The studies suggest that computer simulations can be valuable tools for teachers, but teachers must use some care in deciding on how to use simulations and which simulations to use.

As mixed as these findings on tutoring and simulations are, they are stronger than results from tutoring and simulation programs in earlier decades. Studies from the 1970s and 1980s showed that computer-tutored students outscored students in conventional classes by only a small amount. The median effect size for computer tutoring was 0.15 during the 1970s and 1980s—smaller than the median tutoring effect size of 0.33 in studies from the past decade. The median effect size in simulation studies was 0.25 in studies published between 1970 and 1982. Again, this value is smaller than the median effect size of 0.39 in studies from the last decade.

Computer animation is the most recent addition to the science teacher's toolkit, but this instructional innovation has already compiled a record of strong contributions to science instruction. In each of nine studies of computer animations, the group that viewed the animations outscored the control group but the effects differed in size from small to large. In seven of the nine studies, the improvement was large enough to be considered educationally meaningful. The remaining two studies reported positive effects of animations, but the effects were not large enough to be practically important. The median effect of computer animations in the nine studies was to increase student scores on science tests by 0.48 standard deviations. As a group, therefore, these studies suggest that animations can help students substantially in their attempts to understand scientific phenomena.

Computer-assisted language learning

Developers began evaluating programs of computer-assisted language learning (CALL) during the early years of the computer revolution, but they soon lost interest in the area. Today it is no longer possible to ignore computer-assisted language learning. The field has its own organizations, print journals, and refereed on-line journals; and new books on the field come out every year. A comprehensive review published in 1996, however, deplored the lack of an agreed-upon research agenda in the area. In 1996 CALL research seemed to be a series of one-shot studies on different topics, and it was impossible for reviewers to draw firm conclusions on CALL effectiveness from the scattered studies. The lack of a clear evaluation agenda is still a problem for the field today.

Computer searches yielded a total of only seven controlled quantitative evaluations of CALL programs carried out during the past decade, and these studies were extremely varied in focus. Each of the studies examined its own approach to improving language instruction with technology, and so the studies do not provide a sound basis for conclusions about CALL effects. The point that earlier reviewers made about the area of CALL—it lacks an agreed-upon research agenda—seems to be as valid today as it was when it was first made.

Diverse though evaluations of CALL may be, they have yielded enough strong positive results to encourage CALL enthusiasts. In each of seven evaluations, CALL had at least a small positive effect on instructional outcomes, and in five of the seven studies, CALL effects were large enough to be considered educationally meaningful. The median effect of a CALL program in the seven studies was an increase in language test scores of 0.60 standard deviations. This is a moderate to large improvement in student performance, equivalent to a jump in scores from the 50^{th} to the 73^{rd} percentile. These results suggest that a number of approaches to CALL may have positive effects on student learning. Although the various approaches still need in-depth examination, the future of CALL appears to be promising.

Conclusion

The use of instructional technology in colleges has come a long way during the last four decades. Over the years instructional technology has proven to be increasingly helpful for improving learning in college courses. The median effect size in studies of computer-based college teaching was –0.13 in 5 evaluation studies published during the 1960s, 0.22 in 85 studies published during the 1970s, 0.35 in 35 studies published during the 1980s, and 0.46 in 44 studies published during the 1990s. Originally almost a hindrance to learning, computer-based instruction is now an important ingredient in many successful college courses. The growing effectiveness of instructional technology in college programs should not come as a great surprise. Computers have improved dramatically during the last three decades. They are faster, friendlier, and vastly more sophisticated than they were 35 years ago. In addition, many educators have become sophisticated designers of instructional software, and many college students are now proficient users of technology. The evaluation studies suggest that instructional technology may be especially helpful in these circumstances. Computers—which have transformed society in so many ways—are now making college teaching more effective.

Introduction

Computers are now an accepted part of college life. At the beginning of a semester, college students use them to register for courses and to download their course outlines and assignments. During the term, students use computers for writing reports, performing calculations, preparing presentations, and communicating with teachers, teaching assistants, and classmates. At the end of a term, students may take computer-graded examinations and fill out machine-readable course evaluation forms. Even after graduation, students continue to use their computers to keep in touch with classmates via e-mail.

Colleges without computers seem almost inconceivable, and no one would seriously suggest a return to presilicon days. No one doubts the value for colleges of computerized record keeping, communication, and information storage. Nor does anyone question the importance for students of computerized word processing, scientific calculation, and report presentation. But opinions begin to diverge when it comes to instructional technology. Not everyone agrees that computers can be effective teaching devices. Do colleges teach better when they hand off some teaching tasks to computers? Do students learn more or better as a result? Should colleges invest more heavily in instructional technology? Are colleges making the best use of existing instructional technologies? Questions spring up on all sides.

This report reviews controlled studies of the effects of instructional technology on college students. It focuses especially on the literature of the last decade. The earlier literature on technology in college teaching has been examined in major reviews (J. Kulik, Kulik, & Cohen, 1980; C. Kulik & Kulik, 1986; C. Kulik & Kulik, 1991), and there is not much need to revisit the literature of the 1960s, 1970s, and 1980s once again. The literature of the last decade, however, is still largely unmapped territory. The purpose of this review is to put this literature into perspective.

The author of this review used a methodology that is similar to the meta-analytic approach developed by Glass (Glass, McGaw, & Smith, 1981). Meta-analytic reviewers use objective procedures to locate as many studies of an issue as possible. They describe features and outcomes of the studies using objective and quantitative methods. Finally, meta-analysts use sophisticated statistical methods to describe overall findings and to chart the relationships between study features and outcomes. Like meta-analytic reviewers, this author used objective procedures to locate and describe studies for this report, but unlike meta-analytic reviewers, he used only simple descriptive statistics to report the results of the data collection. For the most part, he let the studies speak for themselves.

Computers in colleges

The effectiveness studies that are reviewed in this report were carried out during a decade of rapid change and growth in school computing. The United States Census Bureau documented this change in surveys of national samples of American households in 1985, 1989, 1993, and 1997. The National Center for Education Statistics provides a useful tabulation of the Census data on college students from the 1993 and 1997 surveys in its *Digest of Education Statistics, 2000* (National Center for Education Statistics, 2000).

According to the *Digest*, about 65% of college students used computers at school in 1997, up from 55% in 1993. Interestingly, the percentage of students using computers in colleges (65%) is lower than the percentage using computers in elementary schools (80%) and high schools (70%). However, college students are more likely than other students to use computers at home for schoolwork. According to the *Digest*, 41% of college students used computers for schoolwork at home, whereas only 24% of elementary school students and 39% of high school students used computers at home for schoolwork. College students used their home computers for word processing (80%), Internet connectivity (58%), graphics (25%), spreadsheets (25%), desktop publishing (14%), and databases (less than 1%).

Recent reports suggest that students from different socioeconomic strata and different racial and ethnic groups have different access to computers. The U.S. Department of Commerce's National Telecommunications and Information Administration, for example, has issued several reports recently on a digital divide that separates the information-rich and the information-poor segments of American society (e.g., National Telecommunications and Information Administration, 1995, 1998, 1999, 2000). Information-rich groups include Whites, Asians/Pacific Islanders, the more affluent, the more highly educated, and those in dual-parent households. The information-poor include Blacks and Hispanics, those with lower incomes and education levels, and those in rural areas or central cities. Data suggest that the digital divide is uneven at the college level.

The *Digest of Education Statistics* reports, for example, that White college students are no more likely than minority students to use computers at school. The percentage of Whites using computers in colleges in 1997 was 64%; Blacks, 69%; Hispanics, 63%; and other minorities, 63%. However, White college students were far more likely than nonminorities to use computers at home for schoolwork. The percentage of Whites using computers at home for college work was 46%; Blacks, 19%; Hispanics, 16%; and other minorities, 45%. Overall, it seems that a digital divide exists for home computer use, with Blacks and Hispanics on one side and Whites and other minorities on the other side. A similar divide does not appear on college and university campuses, however. In 1997, Blacks were somewhat more likely than others to be users of campus computers, and there were only slight differences in campus computer use among other racial and ethnic groups.

College students from affluent homes are somewhat more likely than students from low-income homes to use computers at school. In 1997, 68% of college students from households with incomes greater than $75,000 used computers at school, compared to 61% of students from households with incomes of less than $5,000. However, college students from affluent homes are clearly more likely than students from low-income homes to use computers at home for schoolwork. In 1997, 52% of college students from high-income households ($75,000 per year or more) used computers at home for schoolwork, compared to only 32% of students from families with the lowest incomes (less than $5,000 per year).

College males are more likely than college females to use computers at school. In 1997, 68% of males and 62% of females used computers at school. College males are also somewhat more likely to use computers at home for schoolwork. Differences in home use, however, are smaller than differences in school use. In 1997, 42% of males and 40% of females used computers at home for schoolwork. Gender inequity in the use of computers at school has increased slightly since 1993. In 1993, 58% of males and 53% of females used computers at school, compared to 68% of males and 62% of females in 1997. Inequity in use of computers at home, however, has decreased in the past four years. In 1993, 26% of males and 20% of females used computers at home for schoolwork, compared to 42% of males and 40% of females in 1997. Overall, a digital divide appears to separate college men and women, but the gender divide in computer use in colleges is not so dramatic as the gender split in other areas: the percentage of men and women majoring in computer science, the percentage of male and female doctorates in computer science, and the percentage of computer science faculty who are men and women.

Internet use in colleges

Virtually all colleges provide Internet access for their students. This is the conclusion in two authoritative surveys on computer use in colleges: Green's *Campus Computing* (Green, 1999) and the Market Data Retrieval (MDR) report on computers in colleges (Market Data Retrieval, 2000). The latest *Campus Computing* report tabulates data from 1999, and the latest issue of the MDR survey contains data on Internet use in colleges in 1999. According to the MDR survey, college students could access the Internet from the library in 93% of all colleges in 1999, up from 86% in 1998. They could access the Internet from computer labs in 92% of all colleges, up from 85% in 1998. The increases in Internet access from classrooms and residence halls were even more striking. In 1999, nearly half (49% of all colleges) had computers with Internet access in classrooms, up from 42% in 1998; and 38% provided access in residence halls, up from 25% in 1998.

More college courses are using Internet resources each year (Green, 1999). Over half (54%) of all college courses in 1999 made use of electronic mail, up from 44% in 1998 and just 20% in 1995. Similarly, the percentage of college courses using Web resources in the syllabus rose from 11% in 1995 to 33% in 1998 to 39% in 1999. More than one-fourth of all college courses (28%) had a Web page in 1999, compared to 22% in 1998 and 6% in 1995. In addition, more institutions are providing more services via the World Wide Web: more than two thirds (70%) of the institutions surveyed in 1999 provided on-line undergraduate applications on their Web sites, up from 55% in 1998. Three-fourths (77%) made their course catalogs available on-line, and one quarter made library-based course reserve readings available on-line (Green, 1999).

Purpose

The purpose of this report is to describe current knowledge of the effectiveness of instructional technology in colleges and universities based on findings in controlled studies. The studies cited in the report were found in systematic computer searches of library databases of educational literature. The searches focused on individual studies of instructional technology published during the 1990s and on reviews of studies published before 1990. The next section of this report gives an overview of findings from studies carried out before 1990. The three sections that follow look in greater depth at specific technological applications evaluated during the 1990s. Finally, a concluding section summarizes the review results.

Background & Methods

During the 1980s meta-analysis became the methodology of choice for reviews on instructional technology. Gene V Glass, the developer of this review methodology, first described this methodology in his 1976 presidential address to the American Educational Research Association. He defined meta-analysis formally as the statistical analysis of a collection of results from individual studies for the purpose of integrating the findings. More simply, it is the statistical analysis of analyses. Reviewers who carry out meta-analyses first locate studies of an issue by clearly specified procedures. They then characterize the outcomes and features of the studies in quantitative or quasi-quantitative terms. Finally, meta-analysts use multivariate techniques to relate characteristics of the studies to outcomes.

One of the most important innovations in meta-analysis was the use of *effect sizes* to summarize study results. Researchers had used effect sizes in designing studies long before meta-analysis was developed, but they failed to see the contribution that effect sizes could make to research reviews. Glass saw that results from a variety of different studies could be expressed on a common scale of effect size. After making such transformations, reviewers could carry out statistical analyses that were as sophisticated as those carried out by experimenters.

Size of effect can be measured in several ways, but the measure most often used is the standardized mean difference. This index gives the number of standard deviation units separating the outcome scores of experimental and control groups. Reviewers calculate effect sizes by subtracting the average outcome score for a control group from the average outcome score for an experimental group, and then dividing the remainder by the standard deviation of the outcome measure. For example, if a group that receives computer-based coaching on the SAT obtains an average score of 550 on the test, whereas a group that receives conventional teaching averages 500, the effect size for the coaching treatment is 0.5 since the difference between experimental and control means is 50 and the standard deviation on the SAT is 100.

Effect sizes can be negative or positive. They are positive when the experimental group outperforms the control group. They are negative when the control group comes out on top. Effect sizes can be large or small. J. Cohen (1977) suggested rough guidelines for classifying effect sizes. Effects are small, he said, when effect sizes are around 0.2; medium when they are around 0.5; and large when they are around 0.8. Looking specifically at educational effects, Slavin (1990) suggested that effect sizes of +0.25 or more are large enough to be considered educationally meaningful.

In this section, the author describes some meta-analytic findings on instructional technology from a decade ago. He first looks at findings on instructional technology in general and then focuses specifically on instructional technology in college settings. The purpose is to provide a background for the detailed examination of recent studies in the remaining sections of this report. After providing this background, the author describes the methods used in the detailed examination of recent studies.

Meta-analytic findings on instructional technology

Twelve meta-analyses of evaluation studies carried out before 1990 yielded the conclusion that programs of computer-based instruction have a positive record in the evaluation literature (J. Kulik, 1994). The meta-analyses and their main findings are listed in Table 1. The following are the major points emerging from these meta-analyses:

1. Students usually learn more in classes in which they receive computer-based instruction. This is the finding in 12 meta-analyses of studies in which students in computer-based and control classes took common final examinations. The 12 meta-analyses produced slightly different estimates of the magnitude of the effects, but all the estimates were positive. The median effect size in the 12 meta-analyses was 0.35. This means that the average effect of computer-based instruction was to raise examination scores by 0.35 standard deviations, or from the 50^{th} to the 64^{th} percentile.

2. Students learn their lessons in less time with computer-based instruction. This is the finding in meta-analyses of studies that examined teacher, student, and computer records of instructional time. The average reduction in instructional time was 34% in 17 studies of college instruction, 24% in 15 studies in adult education.

3. Students also like their classes more when they receive computer help in them. The average effect of computer-based instruction in 22 studies was to raise attitude-toward-instruction scores by 0.28 standard deviations.

4. Students develop more positive attitudes toward computers when they receive help from them at school. The average effect size in 19 studies on attitude toward computers was 0.34.

5. Computers do not, however, have positive effects in every area in which they were studied. The average effect of computer-based instruction in 34 studies of attitude toward subject matter was near zero.

During the 1980s, therefore, meta-analytic reviewers agreed that computer-based instruction has positive effects on students. The reviewers reported that adding computer-based instruction to an instructional program, on the average, improves the results of the program.

It may be useful to view these findings in a broader context. In his 1994 review, the author of this report also summarized evaluation records of seven different instructional innovations in studies carried out at the K-12 level (J. Kulik, 1994). Table 2 lists the results. The average effect sizes in Table 2 come from studies that (a) were at least one month in duration; (b) used standardized rather than locally developed tests as outcome measures; and (c) were reported in journal articles or technical reports. Judging from the table, computer-based instruction is neither the most nor the least potent educational reform that evaluators have studied. Innovations that made the biggest difference for student learning were those that provided more curricular challenge for high-achieving students. The average effect size for programs of accelerated instruction for gifted and talented students, for example, was 0.93. The next most potent innovations involved individual tutoring by computers or by other students. Average effect sizes for peer tutoring, cross-age tutoring, and computer tutoring were between 0.38 and 0.48 standard deviations. At the bottom of the scale of effectiveness were innovations that relied on paper-and-pencil presentation of instructional material. Average effect sizes for programmed instruction and individual learning packages were less than 0.2 standard deviations.

Table 1. Features and results of 12 meta-analytic reviews of studies on instructional technology

Meta-analytic review	Instructional level	Type of application	Number of studies	Average effect size
Bangert-Drowns, J. Kulik, & C. Kulik, 1985	Secondary	CAI, CMI, CEI	51	0.25
Burns & Bozeman, 1981	Elementary & secondary	Drill & tutorial	44	0.36
P. Cohen & Dacanay, 1992	Health professions education	CAI, CMI, CEI	38	0.46
Fletcher, 1990	Higher & adult education	Computer-based interactive video	28	0.50
Hartley, 1977	Elementary & secondary math	Drill & tutorial	33	0.41
C. Kulik & Kulik, 1986	College	CAI, CMI, CEI	119	0.29
C. Kulik , Kulik, & Shwalb, 1986	Adult education	CAI, CMI, CEI	30	0.38
J. Kulik, Kulik, & Bangert-Drowns, 1985	Elementary	CAI, CMI, CEI	44	0.40
Niemiec & Walberg, 1987	Elementary	CAI, CMI, problem-solving	48	0.37
Roblyer, Castine, & King, 1988	Elementary to adult education	CAI, CMI, CEI	82	0.31
Schmidt, Weinstein, Niemiec, & Walberg, 1985	Special education	Drill & tutorial, CMI	18	0.57
Willett, Yamashita, & Anderson, 1983	Precollege science	CAI, CMI, CSI	11	0.22

Note: CAI = computer-assisted instruction; CMI = computer-managed instruction; CEI = computer-enriched instruction; CSI = computer-simulated instruction.

Table 2. Results of studies of innovations in K-12 education

Innovation	Number of studies	Average effect size
Accelerated classes for gifted and talented students	13	0.93
Enriched classes for gifted and talented students	29	0.50
Classes with computer tutoring programs	58	0.48
Peer and cross-age tutoring programs	52	0.38
Grouping students for instruction by achievement or aptitude	80	0.19
Learning packages or modular instruction	47	0.19
Mastery learning systems of instruction	17	0.10
Programmed instruction	47	0.07

Meta-analytic findings on technology in college teaching

This author and his colleagues carried out three major syntheses of evaluation findings on instructional technology at the college level during the 1980s (J. Kulik et al., 1980; C. Kulik & Kulik, 1986; C. Kulik & Kulik, 1991). They used meta-analytic methods in each of the three syntheses. Each of these meta-analyses showed that computer-based instruction made small but significant contributions to academic achievement and also produced positive, but again small, effects on student attitudes. In addition, the three analyses also found that computer-based instruction reduced substantially the amount of time needed for instruction.

The 1980 review examined results from 59 independent evaluations (J. Kulik et al., 1980). In the typical implementation, computer-based instruction raised examination scores by 0.25 standard deviations. Thus, the typical student in a computer-based class scored at the 60th percentile on an achievement examination on course material, whereas the typical student in a conventional class scored at the 50th percentile. Computer-based teaching also had small and positive effects on attitudes of college students. College students tended to like their courses somewhat more and became more interested in the subject of these courses when instruction was computer-based. The most dramatic finding in this meta-analysis, however, came from studies that examined teacher, student, and computer records of instructional time. The studies suggested that use of instructional technology has a dramatic effect on time required for instruction. In the average study, computer-based instruction reduced instructional time to about two-thirds of the amount of time used for instruction in conventional classes.

The 1986 review covered 101 studies (C. Kulik & Kulik, 1986). All but two of the studies compared examination results from experimental and control groups. In 77 of these 99 studies, the students in the computer-based class had the higher examination average; in 22 studies, the students in the conventionally taught class had the higher average. In the average study, computer-based instruction raised student performance by 0.26 standard deviations, or from the 50th to the 60th percentile. This figure is very close to the average effect size of 0.25 reported in the 1980 analysis of findings from 59 studies (C. Kulik & Kulik, 1986). The authors also divided computer implementations into three classes: *computer-assisted instruction*, in which the computer provided drill-and-practice or tutorial instruction; *computer-managed instruction*, in which the computer evaluated student test performance and guided students to appropriate instructional resources; and *computer-enriched instruction*, in which the computer served as a tool, simulation device, or programming device. Each type of implementation made small, positive contributions to student learning, and there was no significant difference in findings for the three types of implementations. The authors also found that effects were somewhat lower in unpublished studies than in published ones, and they were also somewhat lower in the hard sciences than in the social sciences and education.

In 1991, C. Kulik and Kulik published an updated analysis of their earlier work on computer-based instruction. This report contained results of 20 studies at the college level that had not been included in their earlier reports. The average effect size in these 20 studies was 0.49. When the results of these studies were added to the results of earlier studies, the average effect size for 119 studies of computer-based teaching at the college level was 0.30. The authors carried out a composite analysis of results from these studies along with results from an additional 29 studies of computer-based teaching in adult education settings. With this large pool of studies, they found that three study features were significantly related to effect size. These were (a) study duration, (b) control for instructor effects, and (c) publication source. Computer-based effects were especially pronounced when the duration of treatment in a study was four weeks or less. Effects were also larger when different instructors taught experimental and control classes; effects were smaller when the same instructor taught both computer-based and conventional classes. Finally, results found in journal articles were clearly more positive than were results from dissertations and technical documents.

Methodology for this review

Preliminary literature searches for evaluation studies conducted after 1990 convinced this author that vital evaluation literatures existed in five areas: (a) computer algebra systems in mathematics; (b) computer tutoring in science; (c) computer simulations in science; (d) computer animations in science; and (e) computer-assisted language learning. After defining these areas, he located relevant evaluation studies by computer searching three library databases: the Road Maps database of the National Science Foundation's Division of Science Resources Statistics; the ERIC database of the U.S. Department of Education's Office of Educational Research and Improvement; and the Dissertation Abstracts International (DAI) of Bell and Howell Information and Learning. Evaluation studies considered for inclusion in this review had to meet two basic methodological standards. First, the studies had to provide quantitative results on outcome variables measured in the same way in both experimental and comparison groups. Second, the studies had to be free from such crippling methodological flaws as substantive differences in pretests or other aptitude measures, unfair teaching of the criterion test to one of the comparison groups, and differential rates of subject attrition from the groups being compared.

A total of 46 studies in the five areas were located. Table 3 gives the number of studies in each area. The instructional outcome measured most often in the studies was student learning, as indicated on an achievement examination given at the end of the program of instruction. Very few studies carried out controlled comparisons of other instructional outcomes: performance on follow-up or retention examinations; attitudes toward instruction, computing, or subject matter; or time needed for instruction. Where controlled comparisons of these outcome measures were available, they are mentioned in this report. The author calculated effect sizes for study outcomes from the statistics included in the reports, following Glass's guidelines for calculating these statistics (Glass et al., 1981). The application of these formulas was straightforward in most cases.

Table 3. Recent studies of instructional technology, by program type

Program type	Number of studies
Computer and calculator tools in mathematics instruction	12
Computer tutoring in science	7
Computer simulations in science	11
Computer animations in science	9
Computer-assisted language learning	7

It is important to note that this review does not cover all evaluation studies of instructional technology. The focus throughout is on controlled and quantitative evaluation studies. Such studies do not address all questions relevant for an assessment of the promise of new technologies. Theoretical works, qualitative case studies, policy studies, and anecdotal reports also address relevant evaluation questions, but it is beyond the scope of this report to review or evaluate such works.

The method used in this review combines features of narrative and meta-analytic reviews. Specifically, objective methods for locating studies are used, and results from all studies are expressed in terms of effect sizes. However, the author did not carry out regression analyses between study features and outcomes as some meta-analysts have done in the past. Instead of focusing on such difficult-to-interpret analyses, the author describes the studies more fully.

The next three sections of this report review the evaluation literature in three areas: (a) computer and calculator tools in mathematics teaching; (b) computer-based science teaching; and (c) computer-assisted language learning. These are the three broad areas in which vital and active research literatures seem to exist. The final section of this report presents overall conclusions.

Computer & Calculator Tools in Math Instruction

During the late 1980s, mathematics educators launched a major effort to reform algebra and calculus teaching in this country. Expanding the use of computer and calculator tools in math teaching was a key item on the reformers' agenda. The reformers believed that students would benefit in at least two ways from use of these tools. First, computer and calculator tools would free students of computational drudgery. Students who used them could concentrate on mathematical concepts rather than tiresome computations. Second, these tools would help students represent problems graphically as well as in more conventional symbolic ways. The tools could thus contribute to broader student understanding of mathematical solutions to problems.

Writers on educational issues trace the origins of the algebra-reform movement to work carried out during the late 1980s by Chazan, Houde, and Reston (1989), Fey (1989), Heid (1988), Schwartz and Yerushalmy (1987), and others. The work of Fey and Heid is representative. Both educators emphasized the concept of function in their proposals for algebra reform, and they sought to develop teaching methods that would move students from procedural knowledge to conceptual understanding of functions. Fey and Heid presented students with question-rich situations and asked the students to analyze the situations with the help of computer tools. The students in Fey and Heid's classes also talked over possible solutions with classmates and wrote explanations of their answers in plain English.

Writers usually trace the origin of calculus reform to two events in the 1980s. The first was a conference held at Tulane University in 1986 on curriculum and teaching methods for college calculus. The conference resulted in the report *Toward a Lean and Lively Calculus* (Douglas, 1986), which is still frequently cited in the literature on calculus reform. The second important event in the calculus-reform movement was the conference *Calculus for a New Century*, held in Washington, D.C. a year later (Steen, 1987). Following the conference, the National Science Foundation launched a major initiative to support calculus reform projects in this country. Since then, colleges and universities throughout the country have developed new approaches to calculus, and many of these new calculus courses are taught with the help of computer algebra systems.

The themes emphasized by the calculus reformers were similar to the themes emphasized by the algebra reformers. Advocates of calculus reform stressed the use of computer algebra systems to reduce computational drudgery so that students could focus on calculus concepts. The calculus reformers also emphasized use of computer tools to help students visualize mathematical problems, an increase in student writing about mathematics, a constructivist rather than behavioral philosophy of pedagogy, cooperative rather than solitary learning, and resequencing topics to put additional emphasis on conceptual understanding.

During the late 1980s, mathematics educators began evaluating the effects on students of the reformed mathematics courses. A few evaluators threw up their hands at the idea of comparing reformed and traditional courses. They thought that the two types of courses could not be compared because the courses differed not only in teaching methodology but also in goals. Although this factor inhibited some, it challenged others, and evaluation studies accumulated during the 1990s. Today enough evaluation reports are available for reviewers to reach some overall conclusions.

Before the results of evaluation studies conducted during the 1990s are examined, some results from an earlier era in instructional technology are briefly reviewed. The introduction of ordinary scientific calculators in K-12 mathematics classes was an important innovation in the 1970s. The evaluation of this innovation during the 1980s set the pattern for evaluations for later technological innovations in mathematics education, and it is instructive to examine the earlier evaluation results.

Background

Before computers and graphing calculators, there were simple digital calculators, and before reformers rallied around computers and graphing calculators in the 1990s, they were arguing for more extensive use of digital calculators in math classrooms during the 1980s. The goals of reformers of the two eras were very similar. Like today's computer advocates, the reformers who advocated more extensive use of digital calculators a generation ago felt that mathematics teachers were placing too much stress on computation and not enough on problem-solving. They thought that students armed with ordinary scientific calculators would be free to concentrate on concepts rather than computations.

Hembree and Dessart's report (1986) gives a succinct account of the early story of calculator use in K-12 mathematics education. In 1974 the National Council of Teachers of Mathematics issued a call for the use of calculators in schools, and many schools accepted the challenge. Schools began introducing calculators into classrooms and encouraging students to use calculators for homework assignments and tests. From 1978 through 1982, the Calculator Information Center at Ohio State University issued reports on the adoption and use of calculators in schools, and the last of the reports contained a comprehensive review of research on the effects of calculators on student learning (Suydam, 1982). The review covered a total of 95 comparisons of achievement scores of students in calculator-using and traditional classes. The conclusion from the review was very clear: The use of calculators in instruction did not hinder students in their development of basic skills.

In 1986 Hembree and Dessart carried out a more systematic analysis of the effects of calculators in mathematics education. They identified 79 studies that compared performance of students in classes taught with and without calculators. Table 4 summarizes Hembree and Dessart's results. It shows that study results were affected by two factors: (a) whether students used calculators or paper and pencil when taking the final tests; and (b) whether student achievement was measured on a test of basic operational skills (or computations) or on a test of problem-solving (or conceptual understanding).

Consider first the results when students in experimental and control groups took the achievement tests under different conditions. When experimental group students used calculators and control group students used only paper and pencil during final examinations, the experimental group outperformed the control group on both computational and problem-solving items. Average effect size was 0.63 for computational items and 0.33 for problem-solving items. These results seem to indicate that using calculators in instruction has a positive effect on both computational and conceptual skill, but this conclusion does not hold up to scrutiny. Treatment differences are confounded with measurement differences in these studies. Does superior performance of experimental group students indicate that the experimental group learned better during the course, or does it indicate only that testing conditions favored these calculator-using students?

Table 4. Results of studies of calculator use in K-12 education

	Testing condition for calculator group			
	Calculators not allowed		*Calculators allowed*	
Type of test	Number of effect sizes	Average effect size	Number of effect sizes	Average effect size
Basic operational skills	84	0.06	15	0.63
Problem-solving skills	64	0.11	31	0.33

More interesting are the findings when experimental and control groups took outcome tests under common conditions. When both experimental and control groups took the outcome tests without calculators, the students in both groups performed at a similar level. Average effect size for computational items was 0.06; average effect size for conceptual items was 0.11. Calculator use does not negatively affect computational skill or conceptual understanding, but its effect is trivial in size.

Overall conclusions from Hembree and Dessart's review are clear. Use of calculators in mathematics classes does not hinder development of computational skill or conceptual understanding. Using calculators during tests, however, increases student test scores on both computational and problem-solving tests. The effect of calculator use during testing is especially large on items that measure computational skill.

Evaluators of mathematics reforms learned two important lessons from these research studies. First, they learned that technology could have different effects on conceptual and computational performance. Second, evaluators learned that it was important to pay attention to conditions under which criterion examinations were given. Students in experimental and control groups might take tests under common conditions (i.e., paper and pencil only for both groups) or under the conditions that prevailed during instruction (i.e., calculators for the experimental group and paper and pencil only for the control group). The two types of experimental designs could produce very different results.

Recent studies of computer and calculator tools

Twelve recent studies investigated effects of computer and calculator tools on conceptual understanding (Table 5). Of these 12 studies, 9 studies found large positive effects on conceptual understanding; 2 studies found moderate-sized positive effects; and 1 study found a small negative effect. In addition to examining conceptual effects, some of the studies looked at effects of tool use on computational skills and student attitudes (Table 6). Overall, the study results suggest that use of these tools does not hinder development of computational skills or positive attitudes toward mathematics. They suggest instead that tool use during instruction promotes development of computer and calculator skills that are beneficial in algebra and calculus computations. In this section, findings from algebra courses are described first, followed by descriptions of the effects from calculus courses.

Algebra

The six studies of algebra effects were carried out by Hollar and Norwood (1999), Mayes (1995), O'Callaghan (1998), Quesada and Maxwell (1994), Runde (1998), and Trout (1993). Three of these studies examined effects of full-fledged computer algebra systems. These were the studies by Mayes, O'Callaghan, and Trout. The remaining studies examined effects of graphing calculators, sometimes called portable computer algebra systems. These were the studies of Hollar and Norwood, Quesada and Maxell, and Runde.

Hollar and Norwood (1999) studied the effects of graphing calculators in an intermediate algebra course offered at a large state university. They assigned two classes with a total of 46 students to the experimental treatment and two classes with a total of 44 students to the control treatment. The curriculum for the experimental group emphasized use of graphing calculators, whereas the control curriculum was a traditional one taught without graphing calculators. The researchers measured effects of the graphing calculators both on a special test of understanding functions and on a final examination that emphasized traditional computational skills in algebra. They found that students in the experimental group demonstrated significantly better understanding of functions (effect size = 1.15) and scored as high as traditional students on the test of computational skills. Hollar and Norwood found no significant difference between the two groups in math attitudes, but math attitudes were slightly more favorable in the experimental group.

Mayes (1995) studied the effects of a computer algebra system on student performance in an algebra course at the University of Northern Colorado. Mayes assigned four classes with 61 students to the experimental treatment and three classes with 76 students to the control group. Students in the experimental group used the computer algebra system *Derive*. The software was used as a demonstration device in the classroom and as a hands-on tool in computer laboratories. Students in the control group learned algebra in a traditional manner. On an examination that emphasized conceptual understanding, the experimental group outperformed the control group (effect size = 0.88). The experimental group performed at approximately the same level as the control group on an examination that emphasized manipulation skills (effect size = -0.10).

O'Callaghan (1998) examined the effects of a computer-intensive curriculum on students in an algebra course at a mid-sized southern university. O'Callaghan compared performance of three groups of students: 32 students in an experimental class taught by the researcher; 45 students in a traditional class taught by the researcher; and 32 students in a traditional class taught by another teacher. The experimental group followed a computer-intensive algebra curriculum that stressed active student involvement and the use of the computer as a tool to explore mathematics; the control group followed a traditional algebra curriculum. Students took a pretest on understanding of functions at the beginning of the semester. At the end of the semester, they took a posttest on understanding of functions and a departmental final exam that emphasized solution of routine problems with algebraic formulas. Students in the experimental group achieved a better understanding of functions than did other students (effect size = 0.96), and experimental group students also outperformed control group students in computational skills (effect size = 0.77). O'Callaghan found no significant difference between the two groups in math attitudes, but math attitudes were slightly more favorable in the experimental group.

Table 5. Features and results of 12 postsecondary studies of conceptual skills in mathematics

Study	Study duration	Location	Type of system	Sample size	Effect size
Algebra & precalculus courses					
Hollar & Norwood, 1999	1 semester	Large state university	Graphing calculator	90	1.15
Mayes, 1995	1 semester	University of Northern Colorado	CAS – *Derive*	137	0.88
O'Callaghan, 1998	1 semester	Mid-sized southern university	CAS	109	0.96
Quesada & Maxwell, 1994	1 semester	Large university	Graphing calculator	534	1.06
Runde, 1998	1 week	Community college	Graphing calculator	173	0.45
Trout, 1993	1 semester	4-year private university	CAS – *Mathematics Exploration Toolkit*	128	0.78
Calculus courses					
Cooley, 1997	1 semester	New York University	CAS – *Mathematica*	160	0.41
Cunningham, 1991	1 semester	Temple University	CAS – *Calculus*	53	0.88
Melin-Conejeros, 1992	1 semester	University of Iowa	CAS – *Derive*	28	-0.38
Palmiter, 1991	10 weeks	Large university	CAS – *MACSYMA*	81	0.83
Park & Travers, 1996	1 semester	University of Illinois	CAS – *Calculus & Mathematica*	68	0.87
Tiwari, 1999	1 semester	Mississippi State University	CAS – *Mathematica*	56	1.63

Note: CAS = computer algebra system.

Table 6. Results of 10 postsecondary studies of computational skills and attitudes in mathematics

Study	Effect size: Computational skills — Posttest taken *without* computer or calculator	Effect size: Computational skills — Posttest taken *with* computer or calculator	Effect size: Mathematics attitudes
Algebra courses			
Hollar & Norwood, 1999	*nsd*	—	*nsd*
Mayes, 1995	-0.10	—	—
O'Callaghan, 1998	0.77	—	*nsd*
Trout, 1993	—	—	0.69
Calculus courses			
Cooley, 1997	0.37	—	—
Cunningham, 1991	0.10	0.94	—
Melin-Conejeros, 1992	—	—	-0.21
Palmiter, 1991	—	0.84	—
Park & Travers, 1996	-0.16	—	0.55
Tiwari, 1999	—	0.96	—

Note: nsd = not significantly different.

Quesada and Maxwell (1994) examined the effects of graphing calculators in a precalculus course offered at a large university. The experimental group in the study consisted of 199 students in five sections of the course; the control group was made up of 335 students in eight sections. During the semester-long course, the experimental group used graphing calculators and a textbook written for use with these calculators, whereas the control group used regular textbooks and scientific calculators. At the end of the term, students in the experimental group scored significantly higher on the examination (effect size = 1.06). Students in the experimental group took the final examination using graphing calculators; students in the control group took the final examination using ordinary scientific calculators. Students were given credit for solutions, however, only when the solutions included an analytic explanation in addition to a decimal solution.

Runde (1998) investigated the effectiveness in community college algebra instruction of using digital calculators along with problem-solving heuristics. Runde assigned students randomly to experimental and control groups for instruction in solving word problems. The experimental group students (N = 97) solved equations using digital calculators both in class and on homework for one week of instruction; the control group students (N = 76) did not use calculators during this time. Runde developed a 10-problem test, which he used as a pretest and posttest. He found that experimental group students outscored control group students on the posttest (effect size = 0.45). On a final examination given some weeks after the experimental treatment, however, the experimental and control groups performed at the same level.

Trout (1993) investigated the effect of the computer algebra system *Mathematics Exploration Toolkit* on student achievement and attitudes in an intermediate college algebra course at a four-year private university. The experimental group consisted of 50 students in three sections of intermediate college algebra; the control group was made up of 78 students in six sections of the course. The experimental group used the *Mathematics Exploration Toolkit* both during class to solve discussion problems and outside class to solve homework problems. The control group learned through a traditional lecture-and-discussion approach. Students took pretests and filled out surveys at the beginning of the term and then completed two researcher-designed tests and a survey at the end of the term. Trout found that the experimental group's scores were higher on both achievement and attitude measures. Effect size was 1.19 on the final examination and 0.37 on a researcher-designed test. The average effect size was 0.69 on five scales measuring mathematics attitudes.

Calculus

The six studies of calculus effects were by Cooley (1997), Cunningham (1991), Melin-Conejeros (1992), Palmiter (1991), Park and Travers (1996), and Tiwari (1999). In each of the studies, the experimental group used a commercially produced computer algebra system, whereas the control group received traditional instruction without using a computer algebra system.

Cooley's study (1997) examined effects on achievement and conceptual understanding in an introductory calculus course enhanced with a computer algebra system at New York University. Cooley compared student performance in two sections of calculus that were taught using the same materials. Students registered for the two sections without knowing that different teaching methods would be used in the sections. Students in the experimental section (N = 85) used the computer algebra system *Mathematica* during a recitation section and during laboratory hours, whereas students in the control section (N = 75) used paper and pencil when working on assigned problems. Cooley measured the effects of the computer algebra system by comparing performance of the two groups on both a test of conceptual understanding and a final examination that emphasized computations. Students in the experimental group earned significantly higher scores on both the test of conceptual understanding (effect size = 0.41) and the test of computational skill (effect size = 0.37).

Cunningham (1991) investigated the effects on students of using a computer algebra system in a semester-long calculus course at Temple University. A calculus class with 26 students served as the experimental group; another class with 27 students served as the control group. The researcher used the computer algebra system *Calculus* for classroom demonstrations for both groups. The experimental group relied extensively on the software for homework assignments, whereas the control group relied on traditional methods to perform manipulations. Students in both groups completed pretests at the beginning of the semester and both conceptual and computational posttests at the end of the semester. The students took the posttests both with and without computer access during testing. Cunningham found that results on the conceptual portion of the test did not depend on testing conditions. Conceptual effect size was 0.71 with computer access and 0.88 without computer access. Results on the computational portion of the test, however, depended on whether or not students had computer access during testing. Computational effect size was 0.94 with access to a computer and 0.10 without access to a computer.

Melin-Conejeros (1992) examined effects of the computer algebra system *Derive* on the achievement and attitudes of first-semester calculus students at the University of Iowa. Twelve students in the experimental class completed their homework in a computer laboratory with *Derive*; the 16 control group students completed essentially the same type of homework using paper and pencil. At the end of the semester, students took a final examination and also filled out a mathematics survey attitude. Melin-Conejeros used ACT mathematics scores and presurvey scores as covariates in his data analysis. He found that students in the experimental group performed at a lower level on the overall final examination (effect size = -0.38) as well as on the conceptual items of the final exam (effect size = -0.38). The treatment also seemed to have a negative effect on the attitudes of students in the experimental group (effect size = -0.21).

Palmiter (1991) examined the effects of a computer algebra system on concept and skill acquisition in a calculus course for engineers at a large university. Palmiter randomly assigned students to experimental and control conditions at the beginning of the semester. The experimental group of 40 students used a computer algebra system, *MACSYMA*, for 5 weeks of calculus instruction; the control group of 41 students covered the material in a 10-week period. The experimental group scored significantly higher than the control group on both a conceptual knowledge test (effect size = 0.83) and a calculus computational exam (effect size = 0.84). Students in the experimental group were allotted one hour for the computational exam, and they were allowed to use the computer algebra system while working on solutions. Control students were allotted two hours for the computational exam, but they were allowed to use only paper and pencil on this part of the examination.

Park and Travers (1996) studied cognitive and affective outcomes in a computer laboratory calculus course, *Calculus and Mathematica*, at the University of Illinois at Urbana-Champaign. The researchers compared performance of students in this experimental course with performance of students in a standard first-year calculus course. The experimental group consisted of two sections of the course with a total enrollment of 26 students; the control group was made up of 42 students in a standard course. The researchers administered pretests and attitude scales at the beginning of the semester, and administered posttests at the end of the term. The students in the experimental class obtained a higher level of conceptual understanding (effect size = 0.87) without a significant loss in computational proficiency (effect size = -0.16). In addition, attitudes toward mathematics were more positive in the computer group than in the control group (effect size = 0.55).

Tiwari (1999) examined the effect of a computer algebra system, *Mathematica*, on the conceptual knowledge and problem-solving abilities of students in a differential calculus course at Mississippi State University. The experimental group consisted of a class of 29 students who used *Mathematica* to reinforce concepts explained in the lecture section of the course. The control group consisted of 27 students who solved problems without using *Mathematica*. To measure experimental effects, Tiwari examined student performance on tests of conceptual understanding and computational ability. He used pretest scores on a standardized mathematics placement test as a covariate in his analyses. He found that the experimental group scored significantly higher than the control group did on both a test of conceptual knowledge (effect size = 1.63) and a test of calculus computation (effect size = 0.96). Experimental group students were allowed to use the computer algebra system for the take-home final computational examination. Method differences and measurement differences were therefore confounded in these analyses.

Summary

The overall picture that emerges from these studies is very positive. In the typical study, use of computer and calculator tools raised student scores on tests of mathematical understanding by a large amount. In the median case, the effect size was 0.88. This means that students who used computers and graphing calculators while learning algebra and calculus scored 0.88 standard deviation units higher on conceptual tests than did students in the control group. If control group students scored at the 50th percentile on these tests, scores of computer- and calculator-using students would be at the 81st percentile. By most standards, an effect of this size is considered large and educationally meaningful. J. Cohen (1977), a pioneer in the use of effect sizes in the social sciences, classified effect sizes of around 0.2 as small, 0.5 as moderate in size, and 0.8 as large. Slavin (1990), an expert in educational evaluation, judged effect sizes above 0.25 to be large enough to be considered educationally meaningful. Median effect sizes for educational innovations are very rarely as high as 0.8.

Effects of computer- and calculator-use on conceptual learning did not vary greatly from study to study. In 11 of the studies, effects were statistically significant and positive. In nine of these cases, the effects were large, and in two cases, they were moderate in size. In only one case was a computer effect negative, and this negative effect was small in size. Melin-Conejeros (1992), who carried out the study that found the negative effect, wrote that his anomalous result could probably be attributed to the way in which a computer algebra system was used in his study. The experimental group used the system for homework only; it was not used in regular instruction. Melin-Conejeros warned that when used in this fashion, a computer algebra system might do more harm than good. It seems safe to say that computer algebra systems have proven their value in mathematics education, but to get the most out of these systems, teachers should demonstrate use of these systems during regular classroom instruction.

From the evidence now available, computer and calculator tools seem to be helpful in algebra instruction as they are in calculus instruction. The median effect for computer and calculator use in algebra courses was 0.92; the median effect in calculus courses was 0.85. In both cases, the median effect sizes are large and statistically significant. There is no reason to believe that computer and calculator tools help more at one level of beginning college math instruction than at another.

The studies also provided evidence showing that results on computational exams are strongly influenced by the conditions under which the tests are taken. In two studies, experimental group students were permitted to use computers or calculators on computational items on final exams. In both studies, experimental group students outscored control group students by a large amount on computational items. In other studies, neither experimental nor control group students were allowed to use computers and calculators for doing computations on final exams. In these studies, experimental group students performed computations about as well as students who learned in more traditional classes. Overall, the studies provided no evidence that using computer and calculator tools have a deleterious effect on college students' computational skills. The studies suggested instead that experimental group students had learned to use tools that were useful for performing algebra and calculus computations quickly and well.

Finally, a review of study results did not yield any definite conclusions about the effects of computer and calculator use on student attitudes toward mathematics. In two studies, mathematics attitudes were clearly higher in the experimental groups, but in three other studies, attitudes toward mathematics were not significantly different in experimental and control groups.

Computers in Science Teaching

Science educators have different ways of describing naive scientific thinking. They may call it Aristotelian, concrete, preformal, or just plain wrong. But whatever terms they use, science educators agree that many students have naïve concepts of scientific phenomena and that college courses often fail to clear up their misconceptions. Some science educators have concluded that we therefore need new teaching approaches in science. Among the methods that have been proposed for improving science understanding are three that involve technology: computer tutoring, computer simulations, and computer animations.

Computer tutoring programs use a familiar educational format. The computer presents material; the learner responds; the computer provides feedback. B. F. Skinner used the same stimulus-response-reinforcement cycle in his programmed teaching machines during the 1950s. But computers can do much more than Skinner's mechanical teaching machines did. Computers can store vast amounts of instructional material, and they can present it with sophisticated graphics, animations, and audio help. The programs can collect information on student responses and then use this information to guide students through the material on individualized paths.

Science educators who advocate the use of tutorial programs feel that they are aptly named because the programs seem to do the things that individual tutors do. People sometimes refer to computer tutorials as computer-assisted instruction. Again, many advocates consider the name to be apt because the programs also seem to do things that good teaching assistants do. Critics of computer tutoring are less generous in their nomenclature, and they sometimes refer to tutorial programs as "drill and kill" instruction. They think that tutorial programs too often emphasize rote learning and destroy student motivation. The critics also think that tutorial programs are sadly out-of-step with modern constructivist ideas of pedagogy.

Computer simulations provide science students with theoretical or simplified models of real-world phenomena—for example, a frictionless world where the laws of Newtonian physics are more apparent—and give students the opportunity to change features of the models and observe the results. Science teachers use computer simulations in a variety of instructional ways. A teacher might use a simulated frog dissection, for example, as preparation for an actual dissection. A teacher might also use a simulation to replace regular instruction. The simulated frog dissection, for example, might substitute for a real dissection. Most important, however, science teachers can use simulations to help students integrate facts, concepts, and principles that they learned separately. For example, students might play the role of world leaders or citizens in other countries in a simulation designed to help them apply their learning to realistic problems. Many science educators therefore consider simulation programs to be an advance over tutorial programs. This is because simulation programs are designed to help students achieve higher order instructional objectives, whereas tutorial programs seem to focus on more mundane objectives.

Computer animations usually link observable phenomena with scientific representations of the phenomena. In chemistry, for example, a computer animation might provide simultaneous views of an observable chemical reaction, the same reaction viewed schematically at the molecular level, and a third view of the reaction at the symbolic level of graphs and equations. Like simulations, computer animations seem to be an advance over computer tutoring. Advocates are especially taken with the fact that computer animations present different representations of scientific events simultaneously, giving students a chance to link the representations mentally. Scientists are usually able to move easily between different representations of phenomena, and science educators consider it vital for students to be able to achieve the same kind of facility with multiple representations.

Early studies of effectiveness

By 1991, this author's research team at Michigan had carried out meta-analyses of findings from 121 controlled studies of teaching in colleges and universities (J. Kulik et al., 1980; C. Kulik & Kulik, 1986; C. Kulik & Kulik, 1991). The studies contained results from a variety of computer applications in a number of different disciplines. Among the 121 studies were a substantial number on computer tutorials and computer simulations in science. The results from these early studies provide a good standard for gauging recent contributions of tutorials and simulations to science teaching, and are therefore reviewed here.

Listed in the 1986 and 1991 reviews were achievement effect sizes from 37 studies of computer tutoring in college courses. Results of these studies favored the computer-tutored students by a small amount. In 26 of the 37 studies, the tutorial group outperformed the control group; in the remaining 11 studies, the control group scores were higher. The effect sizes in the 37 studies were between –1.20 and 1.25. The median effect size was 0.15. This effect is not large enough to be considered educationally meaningful. It suggests that computer-tutored students would perform at the 56th percentile on relevant achievement tests, whereas conventionally taught students would perform at the 50th percentile. Results of computer tutoring in science courses were similar to results in nonscience areas.

These reviews also contained findings from 13 studies of computer simulations in science. Results of these studies were favorable to the groups that worked with the computer simulations. In 11 of the 13 studies, the simulation group outperformed the control group, but in the remaining studies, the control group outscored the simulation group. The effect sizes in the 13 studies were between –0.14 and 1.27. The median effect size was 0.25. Effect sizes of 0.25 and over are usually considered to be educationally meaningful. By this standard, the effects of computer simulations are just large enough to be judged as educationally meaningful. An effect size of 0.25 suggests that students who worked with simulations would perform at the 60th percentile on relevant achievement tests, whereas conventionally taught students would perform at the 50th percentile.

Computer tutoring

Seven studies of computer tutorials from the 1990s were identified for this literature review. The studies examined two kinds of instructional outcomes: student achievement and student attitudes (Table 7). Effects of computer tutorials on both outcomes were mixed.

Large or moderate positive effects. The effects of computer tutoring were large and positive in two studies (Kitz & Thorpe, 1995; Vitale & Romance, 1992). Both of these studies examined effectiveness of videodisc software from Systems Impact Corporation.

Table 7. Features and results of 7 postsecondary studies of computer tutoring

Study	Study duration	Subject	Location	Sample size	Effect size	
					Achievement	Attitudes
Cracolice, 1994	35 minutes	Chemistry	University of Oklahoma	446	-0.04	——
Kitz & Thorpe, 1995	8 weeks	College algebra	University of Wisconsin–Oshkosh	26	0.86	——
Leonard, 1992	3 hours	Biology	Large university in Midwest	142	0.03	——
Oxford, Proctor, & Slate, 1998	10 weeks	Algebra	Technical school in South	115	0.37	——
Vitale & Romance, 1992	1 semester	Science methods	——————	74	3.45	——
White, 1998	1 semester	Algebra	Community college in South Florida	1500	——	-0.81
Worthington, 1996	1 semester	Psychology	Virginia Commonwealth University	442	0.29	——

Kitz and Thorpe (1995) studied the effectiveness of videodisc instruction in a course in college algebra for students enrolled in Project Success, an eight-week summer transition program for students entering the University of Wisconsin–Oshkosh. Twenty-six students who were judged to have a good grasp of basic arithmetic operations but limited skill in algebraic concepts were assigned randomly to experimental and control groups. Students in the experimental group (N = 13) received instruction from a videodisc program, Systems Impact Corporation's *Mastering Equations, Roots and Exponents*. Students in the control group (N = 13) received direct instruction in class and used a standard textbook for out-of-class work. The treatment phase of the project lasted six weeks. Both the experimental and control groups received one hour of instruction daily over 28 class days. Analysis of covariance revealed that the experimental group outscored the control group on the algebra posttest (effect size = 0.86). The videodisc-instructed group also earned significantly higher grades in their first algebra class in the fall semester following the treatment phase of the study (effect size = 1.06).

Effects were especially strong in the study by Vitale and Romance (1992). However, the evidence from this study is not so compelling as it might be because the study has a methodological flaw. Vitale and Romance studied the effectiveness of video-based instruction in a one-semester science methods course for elementary education majors. The experimental subjects were 42 students enrolled in one section of the course; the control subjects were 32 students enrolled in another section. During the semester-long study, students in the experimental group used 24 commercial lessons contained on Systems Impact Corporation's videodisc *Earth Science* and participated in instructor-led discussions of paper-and-pencil workbook activities. Control group students were instructed without the videodisc material. A paper-and-pencil test developed by Systems Impact Corporation served as the learning criterion in this study. The test was keyed to the lessons taught in the computer-based section, and this may explain in part the unusually large effects of videodisc tutorials in this study. The experimental group showed a very high degree of mastery of relevant concepts, significantly more than the control group (effect size = 3.45). Students in the videodisc section also gave significantly higher ratings on scales measuring attitudes toward science teaching (effect size = 0.91), confidence in science knowledge (effect size = 0.64), confidence in teaching skills (effect size = 0.21), and importance of elementary science (effect size = 0.26).

Two studies found significant positive effects from computer tutorials (Oxford, Proctor, & Slate, 1998; Worthington, 1996). Although large enough to be considered educationally meaningful, effects in these studies were nonetheless of moderate size.

Oxford, Proctor, and Slate (1998) assessed the effects of computer-based instruction on academic achievement and attitudes of adult learners in a course on algebra concepts offered at a state-supported technical school in the South. Intact classes were assigned to experimental and control treatments. Students in both groups took the same pretest in algebra. Students in the experimental group (N = 59) received instruction on the mathematics portion of the PLATO system developed by TRO Learning. Students in the control group (N = 56) received traditional instruction. During the end of the ninth week of a 10-week quarter, students took posttests. Results showed statistically greater gains for students in the computer-based class (effect size = 0.37).

Worthington (1996) studied the effectiveness of computer-assisted instruction in an introductory psychology course at Virginia Commonwealth University. Subjects were 442 students in two sections of the course. Students in one section (N=196) spent an additional 50 minutes per week on computer-assisted instruction lessons. Students in the other section (N = 246) did not work on the computer-assisted exercises. Students self-selected into the two sections through university registration procedures using a registration booklet that explained that one section was scheduled to meet an additional 50 minutes per week for computer-assisted instruction. Students in the computer-supplemented class scored higher than did those in the lecture-only class on both the overall final examination (effect size = 0.29) and on critical questions that were covered in the computer-assisted exercises as well as in the book or lecture (effect size = 0.70). The authors concluded that computer-assisted exercises, as a supplement to traditional lecture, produced additional learning in an introductory psychology class. The study has two weaknesses, however. Self-selection may have produced the observed outcome differences and differences in time-on-task may have also affected study outcomes.

Trivial effects. The studies that found little or no effect of computer tutorials were by Cracolice (1994) and Leonard (1992).   In these studies, effects were trivial or small in size and statistically nonsignificant.

Cracolice (1994) investigated the effectiveness of computer-assisted instruction in a college general chemistry course for science and engineering majors at the University of Oklahoma. A total of 446 students were randomly assigned to three groups. One of the groups studied gas laws using a computer tutorial program; another group studied the topic from a programmed workbook; and the remaining group learned in traditional discussion sections. For each group, the time allotted for instruction on gas laws was 35 minutes. The computer-tutorial and traditional-discussion groups performed at the same level on test items that measured their content knowledge (average effect size = -0.04). Student attitudes toward instruction were also similar for the two groups (effect size = 0.20).

Leonard (1992) examined effectiveness of videodisc interactive instruction on conceptual understanding and science process skills in a biology course at a large university in the Midwest. Students were randomly assigned to experimental and control groups. Students in the experimental group (N = 70) studied respiration and biogeography from an interactive videodisc program; those in the control group (N = 72) received conventional laboratory instruction. On lab reports, students from videodisc and conventional groups performed at the same level; and on lab quizzes, they also received similar scores. The two approaches also appeared equivalent when judged by student performance on the final exam (effect size = 0.03).   However, laboratory activities on respiration and biogeography required about three hours of time for completion under standard teaching conditions, whereas the interactive videodisc group required approximately one half this amount of time for completion of these activities.

Strong negative effect. White (1998) studied effectiveness of computer tutorials used in introductory algebra courses offered at a community college in Central Florida. Subjects in her study were more than 1,500 students enrolled during two consecutive semesters in Preparatory Algebra, Introduction to College Algebra, and College Algebra. During the first and last week of each term, participants who received their primary instruction via computer (using software developed by Academic Systems) completed surveys on their attitudes toward mathematics. Control students, who received traditional algebra instruction, completed the same surveys. The tutorial instruction had a strong negative effect on student attitudes toward mathematics, with mathematics attitudes being far less favorable in the experimental group (effect size = -0.81).

Summary of results for computer tutorials. Overall, the effects of computer tutoring on science and mathematics learning were mixed. Four of the six studies of student learning reported significant positive effects of tutoring, and two studies reported trivial effects. The range of effect sizes in the six studies was –0.04 to 3.45. The median effect size in the studies was 0.33. Tutorial effects on attitudes were likewise mixed. One study reported a moderate positive effect of computer tutoring on student attitudes; one study reported a strong negative effect; and one study reported a nonsignificant positive effect. The picture emerging from studies during the 1990s is more positive than the one that came out of research from the 1970s and 1980s. In 26 of the 37 studies from the 1970s and 1980s, the tutorial group outperformed the control group; in the remaining 11 studies, the control group scores were higher. The median effect size was 0.15, or not large enough to be considered educationally meaningful.

Computer simulations

The 11 studies of computer simulations that were located differed in their results (Table 8). Seven studies presented positive results that were moderate in size; two studies presented nonsignificant results; and two studies found negative effects that were moderate in size.

Medium-sized positive effects. The seven studies with medium-sized positive effects were carried out by Brant, Hooper, and Sugrue (1991), Carlsen and Andre (1992), Chien (1997), Chou (1998), Farynaiarz and Lockwood (1992), Rueter and Perrin (1999), and Sterling and Gray (1991).

Brant, Hooper, and Sugrue's study (1991) examined effectiveness of simulations placed in different positions in an instructional sequence. Subjects were 101 students enrolled in a course in introductory animal science at a large university in the Midwest. The researchers used a stratified random sampling to form three groups: one experimental group of students (N = 34) that solved computer simulation problems before a classroom lecture on the topic; a second experimental group (N = 32) that worked on the simulation problems after a lecture; and a control group (N = 35) that received only a lecture on the topic. A 17-item posttest measured ability to apply genetics principles to practical and hypothetical breeding problems. The first group significantly outscored the control group on the genetics test (effect size = 0.91). The second group also outscored the control group (effect size = 0.36), but the difference between the two groups was not large enough to be considered statistically significant. The results support the supposition that the effectiveness of a simulation is dependent on the sequence of the presentation.

Carlsen and Andre (1992) studied the effectiveness of a computer simulation of electric circuits. Subjects were 83 students in an introductory psychology course who received extra credit for participating in the study. Students assigned to the experimental group used a computer simulation of circuits either before reading the text or while reading the text. Students assigned to the control group did not use the simulation. The experiment was conducted in three one-hour sessions on three successive days (two hours of instruction and one hour for posttesting). Order of viewing the simulation did not make a difference in test performance. Use of the simulation, however, helped students to form a developmentally advanced model of a series circuit. Students in the two experimental groups outscored the control group students on the posttest (effect size = 0.56).

Table 8. Features and results of 11 postsecondary studies of computer simulations

Study	Study duration	Subject	Location	Sample size	Effect size
Brant, Hooper, & Sugrue, 1991	———	Introductory animal science	Large university in Midwest	101	0.91
Barnet, 1999	———	Statistics	Iowa State University	127	-0.02
Carlsen & Andre, 1992	2 lessons	Electric circuits	———	83	0.56
Chien, 1997	———	Physics	Large university in Midwest	188	0.34
Chou, 1998	6 weeks	Physics	National Tsing Hua University	60	0.45
Dewhurst, Hardcastle, Hardcastle, & Stuart, 1994	35 hours	Physiology	University of Sheffield	14	0.24
Farynaiarz & Lockwood, 1992	5 weeks	Environmental science & biology	Mattatuck Community College	58	0.45
Moslehpour, 1993	1 semester	Basic electronics	Iowa State University	76	-0.52
Roulette, 1999	2 sessions	Anatomy & physiology	Mt. San Jacinto Community College	32	-0.42
Rueter & Perrin, 1999	———	Biology	Portland State University	181	0.39
Sterling & Gray, 1991	4 hours	Statistical methods	The American University	62	0.70

Chien (1997) examined the effects of interactive computer simulations on conceptual understanding and problem-solving ability of engineering students in a physics course at a large university in the Midwest. Chien selected students in one recitation section of the course to serve as the experimental group (N = 23); students in the other seven recitation groups served as the comparison group (N = 165). Students in the experimental section worked on computer simulations while students in the comparison sections worked on paper-and-pencil exercises. The investigator measured conceptual problem-solving ability on a midterm examination and conceptual understanding on the final examination. Students in the experimental section performed at a higher level on both the conceptual test (effect size = 0.29) and on the problem-solving test (effect size = 0.39). The average of the two effect sizes was 0.34.

Chou (1998) examined the effectiveness of computer simulations in teaching electricity and magnetism in an introductory physics course at National Tsing Hua University in Taiwan. Chou randomly assigned 60 students from this course to experimental and control conditions. Students in the experimental group viewed computer simulations during lectures and worked interactively with the simulations during laboratory sessions. The computer simulations were the CD-ROM programs *Open Physics* and *Physics by Pictures*, distributed by Scientific Center Physicon. Students in the control group received traditional classroom lectures and completed conventional laboratory work. After six weeks, all students took tests of physics achievement and formal operations. On both tests, students who studied with simulations performed at a higher level (average effect size = 0.45).

Farynaiarz and Lockwood (1992) studied the effect of computer simulations on students' skill in environmental problem-solving. Subjects were students (N = 58) enrolled in environmental science and general biology at Mattatuck Community College in Waterbury, Connecticut. The researchers assigned two groups of students from this course to experimental and control treatments. Students in the experimental group (N = 34) completed three self-paced simulation modules in small teams over five weeks. The modules covered relationships among variables in lake pollution analysis, waste-water quality management, and population dynamics. Students in the control group (N = 24) covered these topics in lectures and textbook assignments and did not have access to the computer simulations. The experimental group outscored the control group on a test of problem-solving skills (effect size = 0.45).

Rueter and Perrin (1999) studied the effects of a computer simulation of food-web dynamics on student understanding of ecological systems. Subjects were 181 students in two sections of introductory biology at Portland State University. All students viewed simulations of food-web dynamics during lecture sections of the course. Students in the experimental group also used the simulations in laboratory sections of the course; the control group did not use the simulations in laboratories. Students who used the simulation performed significantly better than the control group on an open-ended essay question on food-chain relationships (effect size = 0.39).

Sterling and Gray (1991) studied effects of a computer simulation on student understanding of statistical methods. Subjects were students in two sections of an introductory course in statistics at The American University. Students in one section of the course (N = 38) did homework assignments that required use of computer simulations. The average amount of time that the students spent using the simulations was four hours. Students in the control section (N = 24) did not use simulations. The students in the experimental group scored significantly higher on relevant questions in several hour-long exams (effect size = 0.70).

Small effects. Barnet's study (1999) was one of two that found small, nonsignificant learning increments from computer simulations. The study examined conceptual understanding and attitudes of 127 students in an introductory statistics course at Iowa State University. The investigator randomly assigned the students to experimental and control groups. The experimental group used Web simulations in laboratory work on sampling distributions and confidence intervals. The control group used hands-on exercises in laboratory work on the same topics. Barnet measured effects of the simulation by including questions on confidence intervals and sampling distributions on two tests: a quiz given two weeks after completion of laboratory work and on the final examination. The two groups did not differ in scores on the relevant test items (average effect size = -0.02). Nor did the groups differ in their attitudes toward statistics (effect size = 0.08).

The other study that found nonsignificant simulation effects was by Dewhurst et al. (1994). The study examined effects of simulated experiments in a module on epithelial transport in an undergraduate physiology course. The program required students to simulate the design and conduct of several experiments, including data collection, analysis, and interpretation. Subjects in the study were 14 second-year physiology students at the University of Sheffield. The students were divided into experimental and control groups. Students in the experimental group (N = 6) received an introductory lecture on the topic and then worked independently on the simulations. Students in the control group (N = 8) worked in the laboratory under close supervision using a conventional laboratory approach. Control group students spent a total of 35 hours on the activities of this instructional module. Experimental group students estimated working on the module for a shorter period of time: about 19 hours. Knowledge gains were measured on a test with a range of question types (e.g., short-answer factual, calculation, interpretation) given to students before and after the module. Scores of the experimental group were slightly but not significantly higher than the scores of the control group (effect size = 0.24).

Medium-sized negative effects. Moslehpour's study (1993) is one of two studies that found negative effects of computer simulations. The study examined conceptual learning in a basic electronics course at Iowa State University. Thirty-eight students enrolled in the course during the spring semester served as the control group, and 38 students enrolled during the fall term served as the experimental group. For each of 12 topics covered during the term, the experimental group received two hours of traditional laboratory instruction and two hours of instruction with a computer simulation, MicroSim Corporation's *The Design Center*. The control group received four hours of traditional laboratory instruction. Students took pretests during the first two weeks of the course and took a final exam after covering 12 laboratory topics during the term. Adjusted mean scores on the final examination were lower for the group that received instruction with computer simulations (effect size = -0.52).

Roulette (1999) examined the effects of a computer simulation on anatomy learning of students at Mt. San Jacinto Community College. Subjects in the study were 32 students in a course in anatomy and physiology. Students in the experimental group learned the names of human muscles on a computer simulation of the human body. The control group learned the names by studying tags on cadavers. Subjects were exposed to two study sessions of three hours each over a period of one week. Immediately following the treatment, subjects were given a posttest requiring identification of muscles. Three weeks later, subjects took a second posttest on the same material. The students who learned from computer simulations performed at a lower level on both the first posttest (effect size = -0.46) and on the second posttest (effect size = -0.37). The average of the two effect sizes was -0.42.

Summary of results for computer simulations. The effects of computer simulations varied in size. In 7 of 11 studies, effects were large enough to be considered statistically and educationally meaningful; in 2 studies computer results were nonsignificant; and in 2 studies results were significant and negative. Median effect size in the 11 studies from the past decade is 0.39. These findings suggest that computer simulations can be valuable tools for teachers, but teachers must use some care in deciding on how to use simulations and which simulations to use. It is also notable that results from evaluation studies of the past 10 years are more encouraging than earlier results. C. Kulik and Kulik (1986) reported an average effect size of 0.25 in 12 college-level simulation studies carried out between 1970 and 1982. Lee's meta-analytic review (1999) yielded an average effect size of 0.22 for 12 college-level studies of simulations published between 1982 and 1993.

Computer animations

The review of the recent literature on instructional technology located nine controlled studies of effectiveness of computer animations in science (Table 9). In each of the nine studies, the group that viewed the animations outscored the control group, but the effects differed in size from small to large. Effects in two studies are classified as large, effects in five studies as moderate in size, and effects in two studies as small.

Large positive effects. A study by Kann, Lindemann, and Heller (1997) found the greatest effect of computer animations. The study examined two methods of teaching recursion to computer science students in a course on data structures at George Washington University. Twenty-eight students were randomly assigned to experimental and control groups. Students in the experimental groups (N = 14) read a text description of a problem involving recursion, viewed a relevant algorithm animation, and worked on a problem involving recursion for two hours. Students in the control groups (N = 14) did not have access to the animated algorithm. On a test problem involving recursion, experimental group students outperformed the control group students (effect size = 1.03).

The other study in which computer animations produced large positive gains on learning measures was by Szabo and Pookhay (1996). The study examined effects of computer animation in a course on methods of teaching mathematics in elementary education. Subjects were 173 students enrolled in the course at a large university in western Canada. These students were randomly assigned to three conditions. In each of the conditions, the students studied a one-hour lesson on construction of triangles, a tenth-grade mathematics topic. The experimental group studied using text plus computer animations. One comparison group used text plus static visuals, and the other studied from text only. On a test of ability to construct triangles and knowledge of trigonometric concepts, students who viewed the computer animations outperformed the students who viewed static visuals (effect size = 0.74). The students who viewed the computer animations also outperformed the students who read text only (effect size = 1.29).

Moderate positive effects. The five studies that found medium-sized positive effects were conducted by Aldahmash (1995); Jensen, Wilcox, Hatch and Somdahl (1996); Nicholls, Merkel, and Cordts (1996); Varghese (1996); and Williamson and Abraham (1995).

Table 9. Features and results of 9 postsecondary studies of computer animations

Study	Study duration	Subject	Location	Sample size	Effect size
Aldahmash, 1995	1.5 to 3 hours	Organic chemistry	University of Oklahoma	142	0.48
Graves, 1998	10 minutes	Chemistry	Large university	190	0.21
Jensen, Wilcox, Hatch, & Somdahl, 1996	50 minutes	Biology	University of Minnesota	184	0.55
Kann, Lindeman, & Heller, 1997	2 hours	Computer science	George Washington University	28	1.03
Nicholls, Merkel, & Cordts, 1996	40 minutes	Microbiology	————	44	0.43
Spotts & Dwyer, 1996	————	Biology	————	63	0.18
Szabo & Poohkay, 1996	1 hour	Math teaching methods	Large university in Western Canada	173	0.74
Varghese, 1996	60 to 70 minutes	Chemistry	University of Oklahoma	139	0.33
Williamson & Abraham, 1995	Less than 30 minutes	Chemistry	Comprehensive university in Midwest	124	0.55

Aldahmash (1995) compared the effects of animated and static visuals on student understanding of organic reaction mechanisms in chemistry. Subjects were students enrolled in the first organic chemistry course at the University of Oklahoma. A total of 142 students were randomly assigned to two treatment groups. Students in the Kinetic group (N = 71) viewed computerized animated representations of molecules, atoms, and equations. Students in the Static group (N = 71) viewed static representations of the same material. The students took a pretest on content covered by the class prior to the experimental treatment, and then spent 1.5 to 3 hours viewing the visuals over a 6-week treatment period. On a posttest on content covered in the visualization treatment, students viewing animated visuals outperformed students viewing static visuals (effect size = 0.48).

Jensen, Wilcox, Hatch, and Somdahl (1996) evaluated the effectiveness of a computer-animated instructional unit on diffusion and osmosis. Subjects in the study were 184 students enrolled in a general biology course offered at the University of Minnesota. Students in six sections of the course (N = 121) served as the experimental group. These students viewed the computer-animated lessons in lecture sections of the course during a 50-minute period in the eighth week of the course. Students in three sections of the course (N = 63) served as the control group and did not view the computer animations. The researchers used a two-item pretest and posttest to evaluate student understanding of diffusion and osmosis. They found that the increase in test scores was significantly different for the two groups. The experimental group students outscored the control group (effect size = 0.55).

Nicholls, Merkel, and Cordts (1996) compared effects of animated and static visuals on student understanding of the nitrogen cycle in an introductory microbiology course. Forty-four subjects, who were randomly assigned to experimental and control treatments, completed a 10-minute pretest at the start of the experiment. The students in the experimental group then viewed an animated tutorial on the nitrogen cycle, whereas those in the control group studied from a comparable textual handout with static diagrams. Students were given 40 minutes to complete the lesson and answer study questions. They then completed a 20-minute posttest. Students who viewed the animated tutorial outscored the control group on the test (effect size = 0.43).

Varghese (1996) compared the effects of three kinds of molecular representations on student comprehension of chemistry concepts. Students enrolled in an organic chemistry course at the University of Oklahoma were randomly assigned to three treatment groups. Students in the experimental group (N = 49) worked on activities involving computer-animated molecular models. Students in one of the control groups (N = 45) worked on exercises using ball-and-stick models, and students in the other control group (N = 45) worked on exercises using two-dimensional representations of molecules. Students took three tests: a pretest on the unit of instruction preceding the unit covered by the experimental treatment; a researcher-constructed quiz taken immediately after completion of the lesson; and an achievement test taken two weeks after completion of the lesson. Each group of students spent 60 to 70 minutes working on the lesson. Varghese found that on several measures of conceptual understanding, students who viewed the computer animations outperformed students studying from ball-and-stick models (average effect size = 0.28) and from two-dimensional models (average effect size = 0.33).

Williamson and Abraham (1995) investigated the effects of computer animation on students' conceptual understanding in a general chemistry course offered at a Midwestern comprehensive university. Subjects in the study were 124 students enrolled in two large lecture sections of the course. Students in one of the lecture sections were assigned to two experimental groups, whereas students in the other lecture section served as a control group. Students in one experimental group (N = 48) viewed animations as a supplement in large group lectures; students in the other experimental group (N = 41) viewed the animations in lectures and also worked with the animations in a computer laboratory. Students in the control group (N = 35) received traditional instruction and did not view the computer animations. Experimental group students were exposed to the animations for only a short period of time (e.g., less than one-half hour for the lecture-only group). Computer animations had a positive effect on student learning in both lecture and laboratory situations. The group with lecture-only access to animations outperformed the control group (effect size = 0.54), as did the group with lecture and laboratory access to animations (effect size = 0.56).

Small positive effects. Graves (1998) carried out one of the two studies that found smaller and more mixed effects from computer animations. Graves carried out his study in a freshman chemistry course at a large university. Subjects in the experiment were 190 students who were randomly assigned to experimental and control groups. Students in the experimental group viewed two videos showing a physical phenomenon along with a three-dimensional molecular representation of the phenomenon. One of the experimental groups also viewed a digital video that provided a macroscopic view of the phenomenon. Students in the control group saw two-dimensional representations of the same phenomena sketched on the blackboard. Total instructional time was approximately 10 minutes. Graves found that the animations had mixed effects on students' conceptual understanding and knowledge of particles. Average effect size in four comparisons was 0.21.

Spotts and Dwyer (1996) examined effects of computer animation on student achievement in college biology. Subjects were 63 college students who were randomly assigned to instructional treatments. Students in two experimental groups (N = 43) studied from a programmed text presented with computer-animated visual material. Students in the control condition (N=20) studied from textbook-like materials that presented verbal information and static visuals. Students then took four criterion tests that measured their knowledge and understanding of the heart, its parts, and functioning. The experimental groups outscored the control group in one comparison, but the control group outscored the experimental groups in another. Average effect size was a modest 0.18.

Summary of results on computer animation. Each of the nine animation studies reported positive effects of animations, and in most cases (seven out of the nine studies) the effects of computer animation were large enough to be considered educationally meaningful. The remaining two studies reported positive effects of animation, but the effects were not large enough to be considered practically significant. As a group, therefore, these studies suggest that animations can help students substantially in their attempts to visualize and understand scientific phenomena. The range of learning effects in these studies was 0.18 to 1.03. The median effect size in the nine studies was 0.48; the average effect size was 0.50.

Summary

Reviewing instructional technology studies in science can be complicated because the studies are so varied. Simulation programs obviously differ from tutorial and animation programs, but even programs of the same type can be implemented in a variety of ways. Simulations, for example, can be used to teach procedural knowledge or concepts. They can be used at the beginning of a lesson to motivate students or at the end of a lesson to draw together ideas that were originally presented separately. A simulation may be used for only a few minutes in one course but for most of the semester in another.

Given the diversity of technology applications in science education, it is not surprising that study results are somewhat varied. In most studies, technology effects were positive, but in some, effects were negative. It is possible to speculate about factors that produced this variation in study results, but decisive evidence is hard to find. No individual study investigated all of the factors that may affect a study's results, and the accumulated set of studies is too small to allow for systematic analysis of relations between study features and study results. Under these circumstances, attempts to account for variation in study findings are an exercise in empty speculation.

It may be more useful to focus on the main thrust of the study results. As a group, the studies suggest that instructional technology is making significant positive contributions to college science courses. In addition, instructional technology is apparently being used more effectively in science courses today than it was in earlier years of the computer revolution. Finally, the applications that are making the most difference—simulations and animations—are the ones that are used most often to achieve higher level educational goals. Although many details remain to be filled in, evaluation studies have already given us the broad outlines of a picture of technological contributions to science education today.

Computer-Assisted Language Learning

Developers began evaluating programs of computer-assisted language learning (CALL) during the early years of the computer revolution, but they soon lost interest in the area. Of the 121 controlled evaluations of computer applications to college teaching reviewed by C. Kulik and Kulik (1986, 1991), only 3 examined effects on language learning. Two of the evaluations were published during the 1960s, and one was published in the early 1970s. For nearly two decades after that, evaluators all but ignored CALL programs.

Today it is no longer possible to ignore computer-assisted language learning. The field has its own organizations: the Computer Assisted Language Instruction Consortium (CALICO) in America; EUROCALL, CALICO's European counterpart; and the Australian Association for Computer-Assisted Language Learning. The field has its own print journals: the CALICO Journal and ReCALL; and it has its own refereed on-line journals: ON-CALL and Language Learning and Technology. New books on the field come out every year. Higgins's *Computers and Language Learning* in 1995, Pennington's *The Power of CALL* in 1996, Bush and Terry's *Technology-Enhanced Language Learning* in 1997, Levy's *Computer-Assisted Language Learning* in 1997, and Swaffar's *Language Learning Online* in 1998 are recent examples.

The field still lacks a clear evaluation agenda, however. Studies that examine computer contributions to language learning are still few and far between. In 1996 Miech, Nave, and Mosteller wrote an excellent review of 22 studies published between 1989 and 1994 on CALL achievement effects in American colleges and universities. After a careful review of the studies, Miech and his colleagues concluded that the field had no agreed-upon research agenda. CALL research seemed to be a series of one-shot studies on different topics, and it was nearly impossible to draw firm conclusions on CALL effectiveness from the studies.

Earlier reviews

C. Kulik and Kulik (1986, 1991) described results of early studies of CALL by Andrews (1974), Morrison and Adams (1968), and Suppes and Morningstar (1969). The study by Andrews (1974) examined the use of computer-assisted instruction as a supplement to classroom instruction in French. He reported that students who received computer-assisted drill-and-practice performed at a slightly higher level on a French proficiency test than did students who received only conventional classroom instruction. Morrison and Adams (1968) carried out a field experiment in which students in one introductory German class received computer-assisted instruction in laboratories, whereas students in another section received traditional instruction. The researchers found that computer-assisted instruction had mixed effects. Speaking and listening effects were negative and moderate in size; reading and writing effects were positive but small in size. Finally, Suppes and Morningstar (1969) evaluated a program in which computer lessons substituted for classroom instruction in Russian. Overall, these researchers found strong positive effects from the program. Seventy-four percent of the computer-based students outscored the best student in the conventional class.

Most of the studies located by Miech and his colleagues were formative evaluations (Miech et al., 1996). These studies compared effects of different kinds of CALL programs (e.g., audio vs. visual feedback in CALL). Results of such comparisons can be useful to designers of CALL programs, but these studies do not compare effects of CALL programs to effects of conventional instruction. Therefore, they do not answer the bottom-line question: Do any of the CALL programs produce better results than conventional language programs do?

These formative studies led Miech and his colleagues to draw some tentative conclusions about the best way to design CALL programs. Two studies suggested that video segments presented with captions are more effective than video presented without captions. Two studies suggested that type of feedback on errors plays a central role in student learning. One of the studies found that students learned more from feedback when it was informational rather than judgmental; the other study found that written plus spoken feedback was more effective than feedback that was only spoken or only written. Finally, three studies demonstrated the feasibility of connecting students with other people inside and outside of the classroom to promote authentic communication in a target language.

Miech and his colleagues also located four summative studies in which achievement of CALL students was compared to achievement of students taught in a conventional program. The four studies led Miech and his colleagues to conclude that use of CALL can lead to substantial improvements in student language learning. The four studies included one study that Miech and his colleagues judged to be especially well designed (Avent, 1993). In Avent's study, students in CALL sections markedly outscored students in control groups on measures of foreign language achievement. Miech and his colleagues reported that two other studies found significant positive effects of CALL, but a third study found no significant effect of CALL on pronunciation training.

Empirical studies

Three of the effectiveness studies located by Miech and his colleagues contained results that met the inclusions standards established for this review (Avent, 1993; Stenson, Downing, Smith, & Smith, 1992; Wright, 1993). Four other studies, published during the 1990s, also met the inclusion criteria. The seven studies and their results are listed in Table 10.

Avent's study (1993) examined effects of computer-assisted instruction in a beginning course in German at the University of Georgia. Avent randomly assigned 272 students enrolled in the course to experimental and control groups. The experimental group worked in a computer laboratory on four units of vocabulary and grammar material, while the control group worked in a traditional language laboratory. The main evaluation instrument in Avent's study was the final examination. The experimental group outperformed the control group on both grammar and vocabulary items on this test; the respective effect sizes were 0.62 and 0.58. One limitation in Avent's study was the unequal time demands on students in the experimental and control groups. Students in the experimental group spent an average of nearly six hours in the computer laboratory, whereas students in the control group spent an average of only four hours in the language laboratory.

Despain (1997) evaluated performance of students who worked on Spanish listening comprehension exercises in a computer-based laboratory at North Carolina State University. Eighty students in a beginning Spanish class were randomly assigned to experimental and control conditions. Both groups received the same classroom instruction. Students in the experimental group also worked on listening comprehension exercises on computers, whereas students in the control group worked on these exercises at audio cassette stations in a language laboratory.

Table 10. Features and results of 7 postsecondary studies of computer-assisted language learning

Study	Study duration	Subject	Location	Sample size	Effect size
Avent, 1993	4 to 6 hours	German	University of Georgia	272	0.60
Despain, 1997	5 units	Spanish	North Carolina State	80	0.30
Liou, 1997	1 semester	English as foreign language	National Tsing Hua University, Taiwan	33	0.60
Liou, Wang, & Hung-Yeh, 1992	1 semester	English as foreign language	National Tsing Hua University, Taiwan	42	0.19
Stenson, Downing, Smith, & Smith, 1992	About 80 minutes	English as foreign language	University of Minnesota	36	0.08
Tozcu, 1998	8 weeks	English as foreign language	North Carolina language institutes	56	1.99
Wright, 1993	3 units	German	University of Arizona	107	0.63

Despain measured performance of the two groups on a pretest and on a series of listening comprehension tests. He found that the experimental group students marginally outscored the control group students on the listening comprehension tests (effect size = 0.30). The experimental group also outscored the control group on a scale of attitudes toward language learning (effect size = 0.44).

Liou (1997) examined effects of World Wide Web exercises on students in a third-year English composition course given at National Tsing Hua University in Taiwan. Fifteen students in one section of the course served as an experimental group, and 18 volunteers from other sections served as a control group. During the semester, students in the experimental group browsed Web sites, selected news articles to read, and made journal entries describing what they read. Students in the control group received regular composition instruction without reading WWW news articles and without keeping journals. Liou concluded that the Web exercises had a strong impact on students in the experimental group, who at semester's end outscored control group students in both overall reading skill (effect size = 0.60) and writing ability (effect size = 0.60).

Liou, Wang, and Hung-Yeh's study (1992) examined CALL effects on students studying English as a foreign language. Subjects in the study were 42 college freshmen at National Tsing Hua University in Taiwan. The students were assigned to two groups: an experimental group of 22 subjects and a control group of 20 subjects. For 10 weeks, students in the experimental group worked on drill-and-practice exercises in Chinese-English translation, received remedial instruction on-line, and made verbatim recordings of their responses to computer-presented questions. The students in the control group covered the same content in paper-and-pencil homework assignments. Results suggested that the combined effect of classroom instruction and CALL was helpful for writing instruction (effect size = 0.19).

Stenson et al. (1992) evaluated a program in which international teaching assistants working on their English speaking skills were able to see visual representations of their English language speech. Subjects in the study were 36 international teaching assistants at the University of Minnesota who were judged to be poor in spoken English and who enrolled in a quarter-long course to improve their spoken English and communication skills. Students in the experimental group (N = 18) used *Speech Viewer*, an IBM software program that provided visual representation of speech, during eight 50-minute one-on-one tutorials with their instructors. The typical student spent about 80 minutes using *SpeechViewer* during these sessions. Students in the control group (N = 18) did not use *SpeechViewer* at all during their tutorial sessions but instead received regular one-on-one tutorial instruction. Students took tests measuring their speaking skill at the beginning and end of the course. Stenson and her colleagues found no statistically or practically significant differences in pronunciation skills of the two groups at the end of the evaluation period (effect size = 0.08). Section instructors and teaching assistants expressed positive attitudes toward *Speech Viewer*, however. Stenson et al.'s report speculated that students might need to spend more time working with *Speech Viewer* for the program to produce significant learning results.

Tozcu (1998) studied the effects of computer-assisted vocabulary instruction on vocabulary knowledge, reading comprehension, and speed of word recognition. Subjects in the experiment were 56 students studying English as a foreign language in language institutes in North Carolina. Tozcu assigned these students randomly to experimental and control groups. Students in the experimental group (N = 28) studied frequently occurring words in the English language on the computer for three hours per week for eight weeks, whereas students in the control group (N = 28) completed three hours per week of reading and reading comprehension exercises during this period. At the end of the experiment, both groups showed increases in vocabulary and reading comprehension and decreases in reaction times for word recognition. However, experimental group gains were substantially and significantly larger than control group gains. Average effect size in the three areas was 1.99 (vocabulary effect size = 2.88; reading comprehension effect size = 2.02; reaction-time effect size = 1.07).

Wright's study (1993) evaluated the effects of a computerized workbook on language learning in a beginning German course. Students in one section of the course (N = 45) served as the experimental group and used a computerized workbook for vocabulary and grammar study. Students in the other section (N = 62) were assigned to the control section and used a standard workbook for vocabulary and grammar. Computerized and standard workbooks contained similar content and exercises, but the computerized workbooks also gave instant feedback and suggestions for finding correct answers. The average scores were higher for the CALL group on all three chapter exams used as the criterion test (average effect size = 0.63).

Conclusions

The number of evaluations of CALL programs during the last decade is disappointingly small. Only seven evaluations of CALL programs carried out during the past decade were located for this review, and these studies were extremely varied in focus. Each of the studies examined its own approach to improving language instruction with technology, and so the studies do not provide a sound basis for conclusions about overall CALL effects. The point that Miech and his colleagues made about the area of CALL—it lacks an agreed-upon research agenda—seems to be as valid today as when it was made five years ago (Miech et al., 1996).

That is the bad news about CALL evaluations. The good news is that studies of CALL, diverse though they may be, have yielded enough strong positive results to encourage CALL enthusiasts. This review examines results from seven CALL evaluations. In each of the evaluations, the CALL program had at least a small positive effect on instructional outcomes, and in five of the studies the effect was large enough to be considered educationally meaningful. The median effect of a CALL program in the seven studies was an increase in language test scores of 0.60 standard deviations. This is a moderate to large improvement in student performance, equivalent to a jump in scores from the 50th to the 73rd percentile. These results suggest that a number of approaches to CALL may have positive results on student learning. Although the various approaches still need in-depth examination, the future of CALL appears to be promising.

Conclusion

It is clear that computers can contribute substantially to the improvement of college teaching. Evaluation studies of the past decade usually found that college courses taught with computer help were more effective than similar courses taught without such help. These recent studies produced far more favorable results than did studies of the 1960s, 1970s, and 1980s. In 119 studies carried out between 1967 and 1986, the median effect of instructional technology was to raise scores on examinations by 0.30 standard deviations (C. Kulik & Kulik, 1986, 1991). In the 46 more recent studies reviewed in this report, the average effect of instructional technology was to raise student scores by 0.46 standard deviations. Both gains are large enough to be considered educationally meaningful, but a gain of 0.46 standard deviations on achievement tests is clearly a more important gain.

There were clues in the earlier reviews that computer applications were becoming increasingly effective as the years rolled on, but early reviewers did not chart the change in evaluation results over time (e.g., C. Kulik & Kulik, 1986, 1991). Now, the time trend is impossible to ignore. Analysis of results in the earlier reviews shows that the median effect size was –0.13 in 5 evaluation studies of instructional technology published during the 1960s, 0.22 in 85 studies published during the 1970s, and 0.35 in 35 studies published during the 1980s. This review found a median effect size of 0.46 in 46 studies published during the 1990s. In other words, computer-based teaching was as likely to shortchange college students as to help them in the early years of the computer revolution, but today's students are likely to gain substantial educational benefits when their teachers incorporate instructional technology into their courses.

The effectiveness of computer applications in college courses is not restricted to a single area. This review shows that computers have made significant contributions to a variety of instructional areas. Computer contributions were clear in mathematics courses, where computers are being used as algebra and calculus tools; in science courses, where older computer applications such as tutoring and simulation programs are being used along with such newer applications as computer animations; and in the field of language learning, where a diversity of computer approaches are now being tried.

Of all the results reviewed in this report, the most notable came from studies of computer and calculator use in algebra and calculus courses. Twelve studies focused on this topic. Six of the 12 studies took place in algebra courses. The remaining six studies took place in calculus courses. In each of the studies, experimental group students used computers or graphing calculators while doing coursework, whereas control group students completed their coursework without using such tools.

In the typical study, computer and calculator use raised student scores on tests of conceptual understanding a total of 0.88 standard deviations. This means that students who used computers and graphing calculators while studying algebra and calculus scored 0.88 standard deviation units higher on conceptual tests than did students in the control group. If control group students scored at the 50^{th} percentile on a conceptual test, scores of students using computers or calculators would be at the 80^{th} percentile or above. Evaluations of educational innovations rarely report average effect sizes this high.

Results on computational exams, on the other hand, were strongly influenced by the conditions under which the exams were taken. In studies in which experimental group students were permitted to use computers or calculators on final exams, they outscored control group students by a large amount on computational items. In studies in which neither the experimental group nor the control group was allowed to use computers and calculators on final exams, students in the experimental group performed computations about as well as students who learned in more traditional classes. Overall, these studies suggest that students who used calculators and computer tools when learning algebra and calculus did not suffer in their ability to solve computational problems with paper and pencil alone.

Finally, a review of study results did not yield any definite conclusions about the effects of computer and calculator use on student attitudes toward mathematics. In two studies, mathematics attitudes were clearly higher in the experimental groups, but in three other studies, mathematics attitudes were not significantly different in the experimental and control groups. No definite conclusion about computer and calculator effects on attitudes can be drawn from such conflicting results.

Studies of computer effects on science learning examined both older and newer instructional approaches. The two older approaches still being evaluated during the 1990s were computer tutoring and computer simulations. The newer approach that was extensively evaluated during the 1990s was computer animation. Reviewed in this report were 7 studies of tutoring, 11 studies of simulations, and 9 studies of animations.

The seven studies of tutorial instruction examined two kinds of instructional outcomes: student achievement and student attitudes. Effects of computer tutorials on student achievement were mixed. Four of the six studies of student learning reported significant positive effects of tutoring, and two studies reported trivial effects. The median effect size in the studies was 0.33. Tutorial effects on attitudes were likewise mixed. One study reported strong positive effects of computer tutoring on student attitudes; one study reported a strong negative effect; and one study reported a nonsignificant positive effect.

Eleven studies of computer simulations in science also presented a somewhat mixed picture of effectiveness. In 7 of the 11 studies, effects were large enough to be considered statistically significant and educationally meaningful, but in 2 other studies computer results were nonsignificant and in the remaining 2 studies results were significant and negative. Median effect size in the 11 studies from the past decade was 0.39. While the most likely outcome of using simulations in teaching was an increase in student test performance, using simulations could also have a negative effect or no effect at all on student test scores. The studies suggest that computer simulations can be valuable tools for teachers, but teachers must use some care in deciding on how to use simulations and which simulations to use.

Computer animation is the most recent addition to the science teacher's toolkit, but this instructional innovation has already compiled a record of strong contributions to science instruction. In each of nine studies of computer animations, the group that viewed the animations outscored the control group, but the effects differed in size from small to large. In seven of the nine studies, the improvement was large enough to be considered educationally meaningful. The remaining two studies reported positive effects of animations, but the effects were not large enough to be considered practically important. The median effect of computer animations in the nine studies was to increase student scores on science tests by 0.48 standard deviations. As a group, therefore, these studies suggest that animations can help students substantially in their attempts to understand scientific phenomena.

Computer searches yielded a total of only seven controlled quantitative evaluations of computer-assisted language learning (CALL), and these studies were extremely varied in focus.

Each of the studies examined its own approach to improving language instruction with technology, and so the studies do not provide a sound basis for conclusions about CALL effects. Several years ago, Miech and his colleagues observed that the area of CALL lacks an agreed-upon research agenda (Miech et al., 1996). Their point seems to be as valid today as it was when they first made it.

Diverse though evaluations of CALL may be, they have yielded enough strong positive results to encourage CALL enthusiasts. In each of seven evaluations, CALL had at least a small positive effect on instructional outcomes, and in five of the seven studies, CALL effects were large enough to be considered educationally meaningful. The median effect of a CALL program in the seven studies was an increase in language test scores of 0.60 standard deviations. This is a moderate to large improvement in student performance, equivalent to a jump in scores from the 50^{th} to the 73^{rd} percentile. These results suggest that a number of approaches to CALL may have positive results on student learning. Although the various approaches still need in-depth examination, the future of CALL appears to be promising.

Overall, computer-based teaching approaches have come a long way during the last four decades. Originally almost a hindrance to learning, computer-based instruction is now an important ingredient in many successful college courses. The growing effectiveness of instructional technology in college programs should not come as a great surprise. Computers have improved dramatically during the last three decades. They are faster, friendlier, and vastly more sophisticated in their operations than they were 35 years ago. In addition, many educators have become sophisticated designers of instructional software, and most college students have become proficient users of computing technology. Recent evaluation studies suggest that instructional technology can thrive in this climate and that computers—which have transformed society in so many ways—are also making college teaching more effective.

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