Implementation and Effects Of One-to-One Computing Initiatives: A Research Synthesis

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Abstract

There are now a large number of initiatives designed to make laptops with wireless connectivity available to all students in schools. This paper synthesizes findings from research and evaluation studies that analyzed implementation and effects of one-to-one initiatives from a range of countries. Factors related to successful implementation reported in the research include extensive teacher professional development, access to technical support, and positive teacher attitudes toward student technology use. Outcome studies with rigorous designs are few, but those studies that did measure outcomes consistently reported positive effects on technology use, technology literacy, and writing skills. (Keywords: ubiquitous computing, research synthesis, laptops, wireless connectivity.)

INTRODUCTION

One-to-one computing initiatives that seek to provide laptop computers and Internet access to students for use at home and school are expanding rapidly across the globe. The decreasing costs, combined with the lighter weight of laptops and increasing availability of wireless connectivity, are all making such initiatives more feasible to implement on a broad scale. States such as Maine and Texas, for example, have invested in statewide initiatives to fund access to laptops for secondary school students. Large districts such as Henrico County in Virginia and Cobb County in Georgia are providing laptops and digital content to all middle and high school students. Hundreds of independent, parochial, and individual public schools are also implementing demonstration and large-scale projects that provide one-to-one, 24/7 access to computers and the Internet.

The educational technology research community's collective knowledge about one-to-one initiatives has not to date kept up with the rapid expansion of these initiatives or with their breadth. An earlier 2001 review of laptop initiatives that SRI International researchers conducted under contract with the U.S. Department of Education found just 19 studies that had analyzed outcomes (Penuel et al., 2001). Researchers concluded at that time that there was too little research-based evidence to determine whether such programs were effective, because the overall methodological quality of the studies was weak. Since that review, a number of new one-to-one computing initiatives have begun and have focused on providing wireless access to the Internet. In addition, a number of new studies have been published on the implementation and effects of these initiatives. In this paper, we describe results of a synthesis of research evidence with respect to the following questions:

- What new studies of one-to-one computing initiatives have been conducted, and what has been their focus?

- How are students and teachers using technology in initiatives?
- What new information is available from studies about the conditions necessary for effective implementation?
- Have there been any rigorously-designed outcome studies published on the effectiveness of initiatives? If so, what outcomes have been measured?
- What research is still needed on one-to-one initiatives?

In this paper, we provide a definition of one-to-one computing initiatives and a theoretical framework that elaborates on their potential for improving teaching and learning, as well as likely conditions for successful implementation. We then describe the methodology synthesizing findings from 30 separate studies of one-to-one initiatives. In the results section, we discuss the goals and scale of different initiatives included in the review, describe particular design features and factors that may influence teachers and overall implementation most strongly, and consider evidence of effects shown by the limited number of rigorously designed studies in the field and follow with an analysis of the untapped potential of most one-to-one studies to date. Finally, we consider in the conclusion section what is not yet known but needs to be explored in future studies of one-to-one initiatives.

ONE-TO-ONE INITIATIVES: A DEFINITION

There has been widespread interest and investment in initiatives designed to provide each student with a computer to support academic learning for close to ten years now in the United States. The earliest initiatives in the U.S. began appearing in the mid-1990s, and the most visible sponsored initiative at that time was Microsoft's Anytime, Anywhere Learning program (Rockman ET AL, 1998). As part of this program, scores of schools and districts implemented programs in which students could lease or buy laptop computers that they and their teachers were expected to use in school. In the past five years, Apple Computer, Inc. has become more actively involved in the area, and even though the estimated total cost of ownership of laptop computers remains high (Consortium on School Networking, 2004), whole districts and even states continue to invest in initiatives designed to give every student in particular grade levels a laptop computer.

In practice, the scope and detail of one-to-one initiatives are largely defined by the initiating institutions. Common to most initiatives is the idea that all students have individual access to computers, but program managers have different policies about, for instance, whether students can take computers home and about whether students lease or pay to own their computers. In addition, initiative leaders have adopted a variety of goals for initiatives that are often similar to initiatives in other localities (e.g., improving access to technology resources for all students), but policymakers and program leaders give different emphases to these goals and to the multiplicity of goals they use to convince school boards, foundations, state legislatures, and others to pay for laptop computers (Lemke & Martin, 2003a, 2003b, 2003c, 2003d).

A core set of characteristics shared by a wide number of initiatives, however, coupled with the continued if not growing interest among policymakers and educational leaders in one-to-one initiatives, makes it both possible and important to conduct a review of what is known about their implementation and effectiveness. For purposes of this review, we have chosen three core features common to a wide variety of initiatives as defining characteristics of one-to-one computing in the classroom: (1) providing students with use of portable laptop computers loaded with contemporary productivity software (e.g., word processing tools, spreadsheet tools, etc.), (2) enabling students to access the Internet through schools' wireless networks, and (3) a focus on using laptops to help complete academic tasks such as homework assignments, tests, and presentations.

These characteristics distinguish one-to-one initiatives that are the focus of this review from past efforts aimed at providing each student with his or her own computer. Earlier one-to-one efforts provided students with desktop computers for home use (Chang et al., 1998; Rockman et al., 1995) and with laptops with limited or no capability to access the Internet (e.g., Haynes, 1996; Myers, 1996). An earlier review of the literature (Penuel et al., 2001) included both these types of programs as one-to-one initiatives, but as we argue below in the next section, there is a clear need to analyze what we know about the implementation and effectiveness of laptop initiatives in which students have wireless access to the Internet from knowledge of other desktop and portable computers.

THEORETICAL FRAMEWORK: WHY WIRELESS ONE-TO-ONE COMPUTING MATTERS FOR LEARNING AND CONDITIONS FOR SUCCESSFUL IMPLEMENTATION

We drew on two kinds of research to guide our research review: theories of what kinds of learning outcomes are possible with wireless laptop computers and theories of implementation of technological innovations in the classroom. The first area of research helps explain why studying one-to-one initiatives can help us understand the potential of ubiquitous computing in schools and what advantages wirelessly connected computers may have over stand-alone computers. Latter research provides us with insight into both the likely conditions and supports necessary for implementing a technology innovation and the potential barriers to success.

The Potential of Wireless Laptop Computing for Student Learning

When they could afford to buy a large number of computers, many schools throughout the 1980s and early 1990s placed them in centrally located laboratories (Means & Olson, 1995). Computer use in labs has been found to be effective at least over the short term (Kulik & Kulik, 1991; Kulik, 1994), but researchers have long argued that for technology to make a powerful difference in student learning, students must be able to use computers more than once or twice a week in a lab at school (Kozma, 1991). Limited access has been cited as a reason why teachers make limited use of technology with students (Adelman et al., 2002; Cuban, 2001; Sheingold & Hadley, 1990). Teachers report that when computers are in labs, they use technology less often for instruction because of the difficulty of scheduling time in the lab and transporting students there (Adelman et al., 2002).

More widespread access to computers makes it possible for students and teachers in schools to transition from occasional, supplemental use of computers for instruction to more frequent, integral use of technology across a multitude of settings (Roschelle & Pea, 2002). Ubiquitous, 24/7 access to computers makes it possible for students to access a wider array of resources to support their learning, to communicate with peers and their teachers, to become fluent in their use of the technological tools of the 21st century workplace. When students are also able to take computers home, the enhanced access further facilitates students keeping their work organized and makes the computer a more "personal" device (Vahey & Crawford, 2002).

Beyond facilitating more frequent use of technology in class, many argue that providing students with better access to computers can provide students with more equitable access to resources and learning opportunities. Educational leaders have argued that providing students with a computer with Internet access gives everyone the ability to use up-to-date learning resources that before were available only to those who lived close to a library or benefited from school budgets that allowed for regular purchases of new textbooks (Penuel et al., 2001). Early evaluation studies of laptop programs reflected this emphasis on equity; in studies of the Beaufort (South Carolina) Learning with Laptops initiative, for example, researchers examined the extent to which providing laptops narrowed gaps between students of color and White students and between low-income and more advantaged students (see, e.g., Stevenson, 1998, 1999). Further, analyses conducted on some of the first tests of computer proficiency administered by states suggested that home access to computers helped to explain differences in student performance on those tests (North Carolina Department of Public Instruction, 1999). These studies together confirmed both the potential and significance of providing more ubiquitous access to computers to all students.

A number of researchers have also argued that providing students with ubiquitous access to wirelessly connected computers has the potential to transform learning environments and improve student learning outcomes (see Roschelle, Penuel, & Abrahamson, 2004, for a review). When computers are connected in the classroom, for example, the network can facilitate collaborative learning processes that are difficult to coordinate when teachers must be present to ensure that individuals stay on task and group members help each other learn (Zurita & Nussbaum, 2004). Further, graphical displays showing from individual contributions to solving problems (e.g., students creating points on a line for a particular equation) can help illuminate concepts that are otherwise difficult for students to understand and also motivate them to participate more actively in class (Hegedus & Kaput, 2004; Kaput & Hegedus, 2002; Stroup, 2002). Further, when all students have computers that are connected through a network, students can participate in simulations that allow them to experience complex systems such as patterns of traffic and population dynamics directly (Colella, 2000; Wilensky & Stroup, 2000).

Framework for Analyzing Conditions for Successful Implementation

Much of the excitement about the potential of providing students with wirelessly connected laptops is tempered by an appreciation for the complexities and difficulties of implementation of educational technologies. All too often, new technological innovations have proven unusable to a wide variety of teachers, whether because schools lack the capacity to implement them well, policies are not congruent with technology use, or the culture of the school is not supportive of technology adoption (Blumenfeld, Fishman, Krajcik, Marx, & Soloway, 2000). Critics of large investments in computers for schools often point out that technologies have been "oversold and underused," and that they have had minimal effects on learning environments (Cuban, 1986, 2001). Past research on implementation of educational technology must serve as a guide to helping interpret the effects (or lack of effects) of providing students with access to laptops, no matter how novel the technology is for classrooms, because the novelty itself poses special challenges for teachers and schools to fully realize the potential of these technologies.

One finding from past research that is likely to influence the implementation of one-to-one initiatives is that teachers' attitudes and beliefs about technology's role in the curriculum can influence how and when teachers integrate computers into their instruction (Becker & Anderson, 2000; Becker, Ravitz, & Wong, 1999; Ertmer, 1999). When teachers do not perceive that expected uses of technology are closely aligned with the curriculum, they use it less often (Sarama, Clements, & Henry, 1998). Other individual teacher characteristics that are associated with technology integration levels include teachers' pedagogical approach (Watson & Tinsley, 1995), their confidence or feelings of preparedness to use technology (National Center for Education Statistics [NCES], 2000; Yarnall, Shechtman, & Penuel, in press), and their subject-matter expertise (Roschelle, Pea, Hoadley, Gordin, & Means, 2000).

Teachers' beliefs are influenced by the nature and frequency of messages they hear in their environment (Coburn, 2004), and teacher professional development activities are a source of information about how and what to teach; these activities also prepare teachers to use technology effectively. The amount of professional development that teachers have received has been found to be related to teachers' feelings of preparedness to use technology with students (NCES, 2000). Teachers who reported spending nine hours or more in educational technology professional development activities were more likely than teachers who spent less time in such activities to report feeling well- or very well-prepared to use computers and the Internet for instruction.

In addition to amount of professional development, the form of professional development and its coherence with teachers' standards and curriculum shape the outcomes of professional development experiences. Kanaya, Light, and Culp (2005) found that when teachers perceive professional development activities to be aligned with the content schools expect them to teach and perceive the workshop to be relevant and useful to their teaching, they are more likely to integrate technology into their teaching. In addition, when teachers take on more active roles within professional development for their own learning and for their colleagues' learning, they are more likely to use technology with their students (Frank, Zhao, & Borman, 2004; Riel & Becker, 2000).

The technical infrastructure, including the availability of support for addressing problems as they arise, is also a significant factor in shaping teachers' technology use in the classroom. Difficulties with ensuring adequate resources for purchasing and maintaining hardware and software—including policies that make it difficult to make particular kinds of purchases—can reduce the likelihood that teachers will use technology with students (Blumenfeld et al., 2000). For classrooms using wireless networks, the reliability of the network is frequently an issue and a barrier to widespread use by teachers for instruction (Hill & Reeves, 2004; Tatar, Roschelle, Vahey, & Penuel, 2003). Further, even when access to computers and wireless connectivity is sufficient, perceptions among teachers that there is limited access to timely technical support from school-based or district staff can hinder their integration of technology into the curriculum (Molina, Sussex, & Penuel, 2005).

METHODOLOGY USED FOR THE RESEARCH SYNTHESIS

In this research synthesis, we sought to identify all high-quality research studies that analyzed implementation or reported outcomes of one-to-one initiatives from English-language journals and Web sites. We adopted a narrative, rather than meta-analytic approach to synthesizing findings, both because there were so few outcome studies and because the vast majority of studies reported on implementation processes that could better be summarized and synthesized using a narrative approach. In this section, we describe in detail our approach to identifying, selecting, and analyzing studies for the synthesis.

Scope of the Synthesis

The scope of this synthesis was limited to one-to-one initiatives that used laptop computers with wireless connectivity in K–12 education. We included in our synthesis articles that systematically investigated the implementation of laptop initiatives and/or studied outcomes of laptop initiatives using comparison group designs.

Process for Finding and Selecting Articles

We searched English-language peer-reviewed journals, dissertation abstracts, and the Web for studies that might be included in the synthesis using a common set of key words. Initially, our search included one-to-one initiatives that used handheld computers or graphing calculators. Researchers downloaded abstracts from all reports or articles found into EndNote, where they recorded essential bibliographic information and a common core of information about how the articles were found.

The initial search yielded 245 articles, of which there were 177 unique articles. Initially, secondary reports of research (those found in magazines such as *Technology and Learning*), meta-analyses, research syntheses, policy documents, curriculum guides, and conference reports were all eliminated from the pool of potential articles for inclusion in the study. After eliminating these, 123 articles remained in the database. Next, we eliminated articles that were outside the intended focus of the study as evidenced by the study abstracts. A total of 68 were eliminated at this point, resulting in 55 articles remaining. Finally, we eliminated articles about handhelds or graphing calculators, leaving 46 articles.

We obtained each of these articles, and researchers produced 2–3 page summaries of key aspects of each study: the goals and design of the one-to-one initiative, nature of the technology used, characteristics of schools in the study, data on implementation, and data on outcomes. A more thorough reading of articles and a subsequent decision to restrict the scope of the synthesis to one-to-one initiatives using laptops with wireless connectivity led us to include a total of 30 articles in the synthesis.

Criteria for Inclusion

We included articles in the synthesis that used systematic methods for investigating implementation or outcomes. We applied different criteria for studies we characterize as *implementation studies* and those we describe as *outcome studies*. *Outcome studies*, to be included, must have employed experimental designs with random assignment or quasi-experimental designs with pre- and posttest data on both treatment and control groups. To be included, *implementation studies* must have employed systematic methods of analysis of implementation data. Examples include statistical analysis of survey data, grounded theory, comparative case study analysis, or ethnographic analysis.

Process for Synthesizing Results

Two research team members worked independently to review the 2–3 page summaries, identify a set of recurring themes to highlight in the synthesis, and code individual articles using a spreadsheet to record results of our coding by study. We began with open-coding, beginning by looking at summaries of research reports for potential coding categories within the broad areas of professional development, technical support, teacher beliefs, and student uses of technology for implementation. Once we identified a set of common categories, two coders worked independently to identify whether from study summaries the category was evident within a particular study. We then reviewed and discussed discrepancies on coding to agree on a final code for each study.

FINDINGS FROM THE SYNTHESIS

Goals and Scale of One-to-One Initiatives

Beyond providing laptop and Internet access to students, the goals for the one-to-one initiatives included in the research synthesis tend to focus on one or more of four outcomes (Lemke & Martin, 2003a, 2003b, 2003c, 2003d; Zucker, 2004). For some initiatives, the primary focus is on improving academic achievement with the use of technology. For others, the goal is increasing equity of access to digital resources and reducing the digital divide. For still other initiatives, including the statewide initiative in Maine, the goal is increasing the economic competitiveness of the region by preparing its students more effectively for today's technology-saturated workplaces. Finally, some initiatives seek, by introducing ubiquitous access to computers, to effect a transformation in the quality of instruction. Many of the initiatives focused on transforming teaching seek specifically to make instruction more "student-centered," that is, more differentiated, problem- or project-based, and demanding of higher-order thinking skills.

The initiatives also vary widely in their scale. Some initiatives are providing laptop computers with wireless Internet access to tens of thousands of students across a district or an entire state. In still others, schools are experimenting classroom by classroom with introducing laptop computers into instruction. The challenges posed by scale are no doubt different from those posed by small pilot projects. In addition to coordinating professional development and technical support for larger numbers of teachers, large-scale initiatives must address the challenge of ensuring that programs address local teachers' needs and individual schools' goals for improving teaching and learning. Conversely, smaller-scale initiatives often face challenges in finding enough funding to support teachers and the technology; coordinating instruction with laptops when not all students in a school have laptops is an additional challenge.

Classroom Uses of Laptops in One-to-One Initiatives

A number of implementation studies have examined how students are using laptops in their classrooms and at home. Across a wide range of studies, students use laptops primarily for writing, taking notes, completing homework assignments, keeping organized, communicating with peers and their teachers, and researching topics on the Internet. (See Table 1.) For these tasks, they are using word processing software, Web browsers, e-mail clients, and chat programs. Use of software programs designed to teach basic skills appears to be less common, observed in only four of the programs studied by researchers whose work is included in the synthesis (Daitzman, 2003; Davis, Garas, Hopstock, Kellum, & Stephenson, 2005; Mitchell Institute, 2004; Warschauer, Grant, Real, & Rousseau, 2004; Zucker & McGhee, 2005).

The most common uses appear to reflect the fact that the observed students' teachers are in an "adaptation" stage of technology adoption (Sandholtz, Ringstaff, & Dwyer, 1997). In other words, they are adapting traditional teaching strategies to incorporate more adult productivity tools and having students work independently and in small groups, but they have not yet begun to implement widely more student-centered strategies for instruction such as project-based learning. Those students who do engage in more extended projects typically use design and multimedia tools, including presentation software and software for making and editing digital images and movies (Davies, 2004; Davis et al., 2005; Light, McDermott, & Honey, 2002; Mitchell Institute, 2004; Newhouse & Rennie, 2001; Stevenson, 2002; Warschauer et al., 2004; Windschitl & Sahl, 2002). Researchers presented several interesting examples of students' digital products, and some noted that these were particularly compelling to parents and adults in the school community (Light et al., 2002).

How Teacher Attitudes and Beliefs Shape Implementation

Although overall few studies on one-to-one computing initiatives have presented research-based evidence that determines the true effectiveness of the programs, there is evidence that particular program designs and factors affecting teacher attitudes and beliefs influence a program's implementation and success. (See Table 2.)

Table 1: Most Frequently Reported Student Uses of Computers From Studies

Student Use	Number of Studies Reporting
Word processing software	11
Internet browsers (primarily for research)	10
Presentation software	6
Basic skills practice	4
Spreadsheets	3
Multimedia authoring and design	3

Table 2: Most Frequently Cited Ways Teacher Beliefs Influence Implementation

Teacher Belief	Number of Studies Reporting
Perception of adequacy of access to appropriate subject matter content	3
Concern about unauthorized uses of laptops	3
Beliefs about role of computers as a learning tool for student	2
Beliefs about student capabilities for using computers	1

Case studies of teachers in laptop programs have shown that teachers' beliefs about students, the potential role of technology in learning, and the availability of high-quality digital content influence the degree to which they use laptops with students (Lane, 2003; Trimmel & Bachmann, 2004; Windschitl & Sahl, 2002). Teachers who believe that students are capable of completing complex assignments on their own or in collaboration with peers may be more likely to assign extended projects that require laptop use and allow students to choose the topics for their own research projects. Teachers who view technology as a tool with a wide variety of potential applications are more likely to use laptops often with students (Jaillet, 2004; Windschitl & Sahl, 2002). Third, those teachers who believe that there are adequate software and Internet-based resources available to help teach their particular content area may use laptops with students more often than teachers who believe that there are simply not enough high-quality materials available (Lane, 2003; Trimmel & Bachmann, 2004). Conversely, those teachers who are concerned that students will use their laptops for unauthorized purposes, such as playing games or searching the Internet for recreational purposes during class time, are likely to report implementing laptops less often with students in class (Jaillet, 2004; Trimmel & Bachmann, 2004; Zucker & McGhee, 2005).

Particular design features may influence teachers' beliefs in such a way as to make them likely to use laptops in conjunction with student-centered modes of instruction. Project Hiller, a within-school laptop program for high school students, required its teachers to engage in two extended projects with students and to mentor two to three student-driven projects in the school. In their projects, Project Hiller students took on significant and visible roles within the school, including helping teachers with planning lessons that used technology, developing multimedia materials for departmental projects, mentoring younger peers, and producing a newsletter. Many of the teachers reported that their expectations of what their students could do changed after seeing how skilled students were when using multimedia tools. Teachers reported that they then began assigning more complex and challenging work to students (Light et al., 2002).

The researchers who studied Project Hiller found that the number of teachers who reported doing long-term projects lasting more than a week (at least once a year or more) increased from 85% to 95% during the course of the project, as did the number of teachers who use journaling with their students, which rose from 58% to 68%. Analysis of observational data and interviews with Project Hiller teachers, students, and coordinators revealed an increase in the occurrence and quality of informal, project-based, and small group interactions between teachers and students participating in the program (Light et al., 2002).

The Roles of Professional Development and Technical Support in Fostering Implementation

Several of the implementation studies examined what teachers, students, and administrators believed were critical factors in supporting implementation of laptop programs. In addition, some researchers conducted observations in programs that led them to draw conclusions about what features of programs support or hinder implementation. These studies can provide valuable information to understanding implementation, even though research-based evidence that such factors lead to better student outcomes does not yet exist.

Formal professional development has been a critical component of many large-scale and smaller one-to-one programs, and the features of these activities reported to be important for implementation varied from program to program. (See Table 3.) Teacher workshops often focus on providing teachers with skills they need to use the technology themselves, but many reported that what was most critical was a focus on helping teachers integrate technology into their instruction (Davies, 2004; Dinnocenti, 2002; Fairman, 2004; Harris & Smith, 2004; Lane, 2003; Lowther, Ross, & Morrison, 2001). In Maine, content specialists have also been assigned to help teachers with finding digital resources and integrating technology into specific content areas (Silvernail & Harris, 2003). In addition, some programs have assigned staff (either internal to the school or external) to help teachers on an as-needed basis with technology integration (Davies, 2004; Dinnocenti, 2002; Fairman, 2004; Light et al., 2002). A third form of professional development, informal help from colleagues within the school, may be especially important to ensuring implementation success. A number of researchers reported that they observed teachers helping each other with technology problems or engaging in joint curriculum planning, and some have even reported that teachers prefer this form of professional development above others (Davis et al., 2005; Gaynor & Fraser, 2003; Lane, 2003; Silvernail & Harris, 2003; Windschitl & Sahl, 2002).

Some of the professional development that is targeted to help teachers become more "student-centered" in their teaching has been especially effective in transforming instruction in laptop classrooms. A good example of such a program is the iNtegrating Technology for inQuiry (NTeQ) model (Morrison,

Table 3: Supportive Features of Professional Development Reported In Studies

Student Use	Number of Studies Reporting
Focus on integrating technology into instruction	5
Informal help from colleagues	5
Ongoing access to coaches to help with integration	4
Focus on finding content-rich resources	1

Lowther, & DeMuelle, 1999), which helps teachers develop extended problems and projects that use real-world resources, student collaboration, and computer tools to reach solutions or create final products. The model calls for a full 10 days of professional development for teachers, plus follow-up during the year. Comparison group studies of teachers provided the NTeQ program and then either assigned to a laptop classroom or non-laptop classroom suggest that laptops can facilitate more use of project-based learning and cooperative grouping strategies (Lowther et al., 2001).

In addition to professional development, readily available technical support also appears to be important for laptop programs to succeed. Programs in which teachers report a high degree of reliability for laptops often have both within-building technical support staff devoted to helping with the program and ready access to outside vendors for major problems (Hill & Reeves, 2004). Ensuring that all students' laptops are working makes it less likely that teachers will have to develop two sets of assignments—one for students with laptops and another for students without laptops (Davis et al., 2005; Gaynor & Fraser, 2003; Zucker & McGhee, 2005). Being able to count on the reliability of the school's wireless network is also critical, as students are often using their laptops to access resources available on the Web (Hill & Reeves, 2004; Lane, 2003; Light et al., 2002).

Students have played an important role in providing the first line of technical support in several laptop programs. In Maine, for example, student "iTeams" exist in many schools to help troubleshoot routine problems with machines (Silvernail & Harris, 2003; Silvernail & Lane, 2004). In addition, teachers in Maine report that they often turn to students for help with technical problems when they arise in class (Fairman, 2004). In other, smaller-scale laptop programs, students play a similar role in providing technical support, both informally and formally as part of the program design (Dinnocenti, 2002; Light et al., 2002).

FINDINGS FROM OUTCOME STUDIES

Of the studies we identified and reviewed, just four groups of researchers analyzed results from quasi-experimental studies with pretest-posttest designs and comparison groups, and only seven others used comparison groups at all. We summarize findings from each study separately below in narrative form, as each study examined somewhat different outcomes and studied one-to-one programs that cannot be compared easily. The results are most promising in two areas that were identified in an earlier review (Penuel et al., 2001) as showing positive effects for laptops: computer literacy and writing.

Russell, Bebell, and Higgins (2004) compared the advantages for different student: computer ratios in classrooms. In a single public school, the school assigned different numbers of laptops to upper elementary grades classrooms to achieve either four-to-one, two-to-one, or one-to-one student-computer ratios. The researchers then observed classrooms and studied how students used computers in the classes and how teachers organized their instruction. The one-to-one classrooms provided several advantages over the two-to-one and four-to-one classrooms. In those classrooms, students used computers more across the curriculum and used them at home for academic purposes. In addition, their images of what is required for writing tasks nearly always included computers. In one-to-one classrooms, instruction was different as well; there was less large-group instruction than in two-to-one and four-to-one classrooms. Research-based evidence from six other comparison group studies that used posttest-only designs also report that students in laptop programs use computers more often and for a wider array of purposes than do students with less ubiquitous access to computers (Jaillet, 2004; Light et al., 2002; Lowther & Ross, 2003; Stevenson, 2002; Trimmel & Bachmann, 2004).

Schaumburg (2001) conducted a quasi-experimental study examining the effects of providing students with laptops on their technology literacy. She studied effects of a program that provided laptops to students in a high school in Germany. She found that the laptop students made greater gains than did comparison group students on a researcher-developed test of their knowledge of hardware and the laptop's operating system, common productivity tools, skill in using the Internet, and knowledge of basic computer security. Other comparison group studies with posttest-only designs reported greater levels of technology literacy among students in laptop programs, using judgments made by researchers on the basis of structured observations of their skill in using computers and the Internet (Lowther & Ross, 2003; Lowther et al., 2001).

We identified four separate studies that reported positive effects of laptop programs on students' writing skills (Gulek & Demirtas, 2005; Light et al., 2002; Lowther & Ross, 2003; Lowther et al., 2001). However, none of these studies used a pretest to determine whether students had actually improved their writing skills over the course of the study. Therefore, although several studies reported positive effects, the research-based evidence that laptop programs can improve writing is somewhat less strong than research-based evidence of effects on technology use and technology literacy.

DISCUSSION AND CONCLUSION

The research studies included in this synthesis provide a basic understanding of how students use laptops and wireless connectivity as part of one-to-one initiatives, and there is some preliminary evidence that providing students with more ubiquitous access to computers gives them more practice in using technology. In contrast to how students use technology in other initiatives that emphasize basic skills development or assessment, in one-to-one initiatives students most often use productivity and design tools in ways that are integrated into other classroom activities and assignments. Students gain practice with using these tools, and as outcome studies document, often improve their technology literacy and skill in using word processing tools to improve their writing skills.

What is less clear from these studies is what the potential is for one-to-one initiatives to improve student achievement in core subjects. Few projects reported using tutorial or practice software in mathematics and reading, subjects that are the central focus of most state accountability tests and systems. One study did examine effects on state achievement test scores (Gulek & Demirtas, 2005), but only results for writing suggest clear positive effects. The expectation that one-to-one initiatives will improve achievement scores bears further investigation, and it is likely that to expect achievement gains, one-to-one initiatives would need to be part of a larger, more comprehensive effort to improve instruction (Light et al., 2002). A number of researchers whose work is included as part of this study have argued that one-to-one initiatives that also provide professional development in how to improve instruction and provide curricular resources tied to content teachers must teach have the best chances of making significant improvements to teaching and learning (see, e.g., Morrison et al., 1999).

The research on implementation synthesized here is largely consistent with past research on educational technology reforms, though it does suggest that peers may pay a particularly important role in supporting implementation for teachers. As other studies have found, when teachers believe that technology can support student learning and offers resources that add value to the curriculum, they are more likely to use it. Similarly, professional development support and technical support are critical for one-to-one initiatives, just as they are for other technology initiatives. The finding that other teachers are particularly important in helping teachers learn how to integrate technology into the classroom, however, has only recently become the focus of systematic research in educational technology (Frank et al., 2004). It is consistent with emerging research on professional development, however, which has found that participating in professional development activities with peers can contribute to its overall effectiveness (Garet, Porter, Desimone, Birman, & Yoon, 2001).

What few studies to date have done is to test specifically the links between hypothesized outcomes for one-to-one initiatives and different implementation measures. In fact, a number of studies in the synthesis did not clearly specify the overall goals of the initiative they were studying. Some did not report on overall usage levels of the computers, and none specifically examined the relationship between usage and outcome measures. Finally, some researchers did not indicate when in the development of the program they conducted their study, making it difficult to know whether some of the implementation findings are primarily an artifact of a program's novelty in a school or district.

Including information about core aspects of the design and implementation of particular one-to-one initiatives in all studies would make research considerably more useful for policymakers and program developers. Policymakers need such information to establish priorities for external funding opportunities and give guidance to programs on the ways they ought to structure professional development opportunities for teachers and provide for technical support. Program developers need such information so that they can begin to identify "best practices" to replicate in their own program designs. Most educational technology innovations combine social, pedagogical, and technological elements, and program designers must constantly adapt and reconfigure these elements as programs evolve (Means & Penuel, 2005).

Different approaches to measuring outcomes are also needed in future evaluation research on one-to-one initiatives to advance research in this area. Several studies that focused more on implementation cited outcomes based on self-report survey data that researchers rarely measured in outcome studies. Half of the studies in this synthesis reported positive effects of laptop programs on student motivation or engagement, but just three attempted to measure it in some way other than by a single self-report item (Lowther & Ross, 2003; Russell et al., 2004; Trimmel & Bachmann, 2004). These researchers measured motivation either by observation or by using previously validated survey scales of achievement motivation. Many laptop programs in this study had as their aim broad goals such as the preparation of students for jobs in the 21st century or improving the economic competitiveness of the region (Jaillet, 2004; Silvernail & Lane, 2004), but these kinds of outcomes are difficult to measure in a one- or two-year evaluation. Similarly, researchers reported that students increased their organizational skills with laptop computers (Lowther et al., 2001; Zucker & McGhee, 2005), and that students gained access to a wider array of up-to-date educational resources as a result of their participation in laptop programs (Dinnocenti, 2002; Gaynor & Fraser, 2003; Lowther et al., 2001; Mitchell Institute, 2004). Both results seem plausible, but there are not many widely accepted measures of organizational skills or of the breadth and quality of materials students can access in school (whether through laptops or textbooks). Unfortunately, the researchers did not attempt to develop scales or measures as part of their evaluation research. Researchers conducting future evaluation studies investigating these potential effects of laptops will have to develop and establish the reliability and validity of a wide variety of outcome measures as part of their research.

The increasing popularity of laptop initiatives with a wide variety of stakeholders in education—policymakers, administrators, teachers, parents, and students—makes the need for sound research-based evidence of effectiveness especially critical at this time. States and district school boards must often choose between funding different compelling kinds of programs for students; data on effectiveness can help inform their decision-making progress. Although they are difficult to conduct, a significant number of experimental and quasi-experimental studies are needed if laptop programs are to provide stronger research-based evidence warranting investments in one-to-one initiatives.

In addition, there will always remain a significant role for research syntheses that periodically review extant research on one-to-one initiatives. Research syntheses can provide policymakers, educators, and researchers with a good idea about what the best evidence is from a range of studies. As scholars who are part of the National Research Council note,

> Rarely does one study produce an unequivocal and durable result; multiple methods, applied over time and tied to evidentiary standards,

are essential to establishing a base of scientific knowledge. Formal syntheses of research findings across studies are often necessary to discover, test, and explain the diversity of findings that characterize many fields. (National Research Council, 2002, p. 3)

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